The Cryosphere Discuss., 2, S350–S364, 2008
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The Cryosphere Discussions

Interactive comment on "Antarctic summer sea ice concentration and extent: comparison of ODEN 2006 ship observations, satellite passive microwave and NIC sea ice charts" *by* B. Ozsoy-Cicek et al.

B. Ozsoy-Cicek et al.

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General Issues

1. (Reviewer Comment) The NIC ice edge is determined from the best available data, which may include various forms of high resolution satellite data, as well as passive microwave data. In regions, or on days, when no better data are available the NIC charts may only use the passive microwave data, in which case the NIC and AMSR ice edges will be the same. How often this happens I'm not sure, but a more critical look at what goes into compiling the NIC ice edge should be examined before too many conclusions are drawn about "differences" between the NIC and AMSR-E ice

edges. The NIC ought to be able to provide some statistics on what goes into their ice edge products. The last sentence of section 2 claims the NIC "is also an independent sensor". This is not always true and it is not a "sensor"it is a product.

2. (Reviewer Comment) Given (1) above, and the fact the there is no consistent definition of the NIC ice edge, it is drawing a long bow to extrapolate the result from one cruise to the entire circumpolar sea ice zone. How can the authors be sure that the same data sets were used to compile the NIC ice edge in all regions of Antarctica, and that the difference observed in the study region applies to all areas of Antarctica? This could only be done by looking at the information used to compile the NIC charts, and this hasn't been done.

Authors' Response to Reviewer Comments 1&2

NIC originally produced its ice charts using all available satellite imagery, in-situ reports and meteorological/oceanographic guidance data. The sources of these data were (1) shore station reports, (2) ship reports, (3) aerial reconnaissance, (4) buoy reports, (5) meteorological guidance products, (6) ice prediction model output, (7) climatology and sea ice information obtained from international partners such as foreign ice services, and (8) satellite imagery (Godin 1981). The last group, satellite imagery, however, dominated (prior to 1981 and since). Satellites provide between 90 and 98% of the data. In the 1970s, analysts often had to also make educated guesses based on climatology or persistence. As data sources grew to include active as well as passive sensor data, analysts could chart ice in increasing detail. From 1972 through 1979, only total concentration and ice extent was recorded, (not, for example, partial concentrations of different ice types which were added in later years). Analysts depended then more heavily on visible, infrared, and particularly, single channel passive microwave imagery (e.g. ESMR (Electrically Scanning Microwave Radiometer) launched in 1972), all only available in analog form in near realtime at that time (photographic "strips" of microwave data, and prints of e.g. AVHRR (Advanced Very High

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Resolution Radiometer) visible and IR images) which were overlaid with transparent grids for approximate geolocation of ice edges, coastlines and other features. Passive microwave data from SMMR (Scanning Multichannel Microwave Radiometer) and SSM/I (Special Sensor Microwave/Imager) were added in 1980 and 1989 respectively. In 1991, NIC began to use OLS (Operational Linescan System) visible and IR imagery, with roughly half km resolution, versus the 1 km resolution of already available AVHRR. NIC began to use ERS-1 SAR (European Remote Sensing satellite at 240 m resolution) in 1995 and RADARSAT-1 (at 200 m, 100 m, and 25 m resolutions) in 1996, while continuing to add to the capabilities of its computer system for image analysis and beginning to move toward a GIS (Geographic Information Systems) production. QuikSCAT (Quick Scatterometer) was added in 2004. More recently, beginning in 2005, MODIS (Moderate Resolution Imaging Spectroradiometer) and ENVISAT (Environmental Satellite) Advanced SAR (ASAR) Global Monitoring Mode (GMM) data have been available to analysts. In January 2006, the NIC installed SIPAS (Satellite Image Processing and Analysis System), an almost completely ESRI-GIS-based analysis and production system, which allows the analyst to both analyze imagery digitally and produce spatial data (ice chart) files in a common environment (NSIDC, http://nsidc.org/data/docs/noaa/g02172_nic_charts_climo_grid/index.html)

Based on a large number of charts produced, the average percentages of various types of imagery used in producing the charts is found at (www.natice.noaa.gov) and listed in the table below.

Supplemental Information: SSM/I (1.87%), AVHRR (16.73%), ENVISAT (5.43%), QuikSCAT (36.67%), MODIS (12.84%), OLS (13.72%), Remaining (12.74% from e.g. climatology, drifting buoys, ship reports, etc)

Note that AMSR-E is not listed as used but the roughly equivalent passive microwave product SSM/I was used with however, a component of <2% in contribution to the average production of an ice chart.

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We processed and checked the complete one year (2006) of AMSR-E data and daily ice edge provided by NIC to see if those are providing the same edge more generally than we were assuming. The result shows that these two products are coincident at a similar edge for only around 30% of the area around Antarctica over the entire year. This appears to be mostly because of the AMSR-E ability to catch the true ice edge better during winter time, as confirmed by ship comparisons previously for similar microwave imagery (Worby and Comiso 2003). Generally, therefore, these factors, we feel justify the extension of the study area to circumpolar extent for summer and the claim that the NIC product is mostly independent of passive microwave: 1) the low (<2%) percentage claimed use of microwave by the NIC in preparing ice charts used; 2) our study of the year-round low coincidence between the ice chart ice edge and that from AMSR-E; 3) the previous poorer comparison of ship data with summer ice edge from various locations, i.e. "more circumpolar" consistent with the measurement of the ship track reported here.

Additionally from personal communication with a NIC analyst (National Ice Center Liaison): "We prefer to use the Scatterometer/ QuikSCAT images over passive microwave data. The imagery gaps occur every day with varying locations. As for the south, it is not as detailed as the north. We use a combination of QuikSCAT and ENVISAT images (High Resolution Active Radar) due to lack of usable images (from QuikSCAT alone)". Later in the paper (Fig 6) we also comment that the Scatterometer qualitatively appears to better represent the ice edge on the NIC charts particularly relative to the AMSR-E, which confirms again both the implicit preferences that the NIC analysts use in their determinations and the inference that the Scatterometer also better compares to the ship observations as the NIC charts do.

The paper in final form will include a revision that addresses these questions, as suggested by the reviewer.

3. (Reviewer Comment) The authors make a series of confusing claims against the de

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la Mare whaling result. Firstly, they seem to confuse ice area with ice extent. In the abstract they claim that the underestimate of 14% in ice area from AMSR data "alone accounts for more than half of the purported sea ice loss between the pre 1960s and the satellite era", however the whaling data was only used to examine ice extent, not area. Secondly, the authors claim that "the NIC sea ice edge agrees well with the ship observations, while the AMSR-E shows the ice edge further south" which would lend support to the whaling result, which used the NIC charts, not just the passive microwave data. This is something that de la Mare has been very quick to point out in this debate, so I would strongly advise the authors to think about their claims in relation to the de la Mare result and to re-read his paper (and his follow up which is in press).

Authors' response to Reviewer Comment 3

Although we are not confusing ice area with ice extent, we would agree with the reviewer that the terminology is inaccurate. The "area difference" we are discussing is the difference between the extent estimated by the NIC ice charts and the same "extent" given by the northern-most positions from the AMSR-E data. Appropriate corrections will be made in the revised submission.

We have reread de la Mare's paper as suggested (de la Mare 1997). From de la Mare, his analysis when comparing whaling derived ice edge with the "...the JIC (NIC at that time) ice edge used applies to 15% coverage" (1987 was latest year analysed with whale catch records). The clear implication of that statement is the almost exclusive use of passive microwave (the 15% contour) as the major determinant of the ice edge in the charts for that period. As the discussion above confirms, this interpretation is consistent with the prior imagery and analysis used by NIC up until 1991 when other higher-resolution imagery was added (only then) to aid analysis and continued to be added up until the present. Therefore, there has been substantial evolution in the NIC charts, from this apparently nearly 100% reliance on passive microwave prior to 1991

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and only a 2% passive microwave usage in our recent study period as indicated . So, as referred to in the response to Comments 12, the NIC charts we are comparing to passive microwave in the recent period are derived from very different data sources with high reliance on scatterometer, and several other high resolution sensors in more or less equal contribution. Our conclusion therefore is that the whaling data and its purported agreement with the JIC ice charts is actually an agreement with predominantly passive microwave data. The newer analyses for NIC charts which we are comparing here, in general use < 2% passive microwave data, suggesting the recent NIC charts are actually nearly independent of passive microwave data, justifying the comparisons we make. The implications of our results therefore are maintained, that the "whaling correlation" may be far south of the ice edge location ("first sighting" discussed below) that is supported by our direct ship observations and the co-location with the present mapping.

Without the higher resolution imagery used in ice charts at present, we cannot make the same comparison with the ice charts and passive microwave for the earlier (up to 1987) data, other than to infer that de la Mare's interpretation with the ice charts is more akin to a passive microwave correlation than to a present-day ice chart determination of the ice edge. All we can say is that there are currently significant large differences between the present NIC Charts, (confirmed by ship observations of the summer ice edge), and passive microwave determinations of the ice edge at present. The issue of how ship observations compare to passive microwave determinations of ice edge, showing the higher seasonal uncertainty in the Oct-April period, has also been addressed previously in Worby and Comiso 2004. How, therefore can whale catch data as a proxy for ice edge location correlate with both data sets at the same time as de la Mare claims (Fig 3 in his paper)? The answer is that he uses two different definitions of the ice edge observed for the two data sets, the Discovery Ship observations (1930-39) (close pack ice assigned (arbitrarily?) as the "80% contour") and the JIC ice charts (1972-87) (the "15% contour") (de la Mare 1997). Those contours are mapping approximations and their relationship to the northern-most position of sea ice ("THE"

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ice edge) or even to each other is a function of wind and air temperature (season), and ocean currents and temperature. The distance to this ice edge to either one of these artificial contours can vary from 0.1km to 3x102 km in our experience, so assigning fixed values to these distances (de la Mare 1997) across a broad range of seasons (Oct to April) for the purposes of addressing sea ice extent variability between eras, has "credibility issues" in our opinion. We also note that the Discovery was a WIND-DRIVEN WOODEN SAILING VESSEL (it had insufficient supplies of coal to cover long distances powered by steam). There is no icebreaking capacity for a vessel of this type under wind, since under wind power, it would have no capability to "back and ram", a common procedure for icebreaking if stopped by thicker or more concentrated ice. Under the circumstances of low relative power, poor hull design for icebreaking, and wood construction, could other than a few cm of ice be broken even under steam power (modern small steel vessels, with probably ten times the power and correct hull design are rated at only 25-30 cm of ice broken continuously)?. Even "lead-following" in fairly open conditions (<50% concentration) is impossible unless under continuous steam power. So assigning the Discovery as capable to approach the 80% ice concentration contour (where floes are in contact, with only narrow and discontinuous leads) or traverse even an ice band of a mile wide in the outermost ice edge is a far stretch of the imagination. Since de la Mare 1997, specifically mentions the "80% contour", we assume it must have some bearing on how his analysis is conducted. In our view, until that "confusion" is resolved, we are sceptical of any conclusions he draws on the relationships between satellite ice edges, ship observed ice edges and "whale catch ice edges" with both. Irrespective of how well the analysis is conducted, our contention is that if the physical assumption of what "ice edge" the data purports to show is in question, conclusions as to the variability of that ice edge (80%?) compared to yet another ice edge (15%) in a different era have to be tenuous at best. As Ackley et al 2003 showed, under the assumption that the Discovery data is the northern-most ice edge, it still falls within the variability in ice cover given by the passive microwave data (the 15% contour) for the modern era.

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Since whale hunting stopped in 1987, before the modern mapping methods we are discussing in this paper were in existence, the direct issue of whether whale catch as a proxy compares well with those derived ice edges (the present NIC charts) cannot be resolved. An important issue we can address more directly is the accuracy of the passive microwave data record for the sea ice extent climatology in the Southern Hemisphere for the past 30 years. Our study shows that this climatology has significant deviations from reality, as shown by the validation here of better mapping, available currently in the NIC ice charts and potentially the Scatterometer data alone (highly relied on in the NIC chart production). Since sea ice extent is a principal comparison with numerical models for validation, these deviations between passive microwave determinations and the higher resolution determinations in the ice charts need to be taken into account. It suggests that the climatology of Antarctic sea ice should be carefully examined for the recent period using ice charts and scatterometer data to see if the passive microwave record so commonly used to validate other studies has the constant more southern bias and therefore less reliability over the long term. In the revision we will therefore focus primarily on the data comparisons reported here, and deemphasize the implications for the whaling records which have already been addressed in other forums, e.g. Ackley et al 2003, and instead focus on the possible pitfalls for using the passive microwave record alone for determining ice extents for use in validation efforts for climatic and modelling purposes.

4. (Reviewer Comment) There is an assumption throughout the paper that the ship observations are always the correct data. This needs some justification, because critics will argue that the observations are subjective.

Authors' response to Reviewer Comment 4

Ice edge is defined by "first sighting of ice" in the ice observations protocol. The other ship observations used here are on concentration estimates within the ice limits or ice

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extent boundary. We would argue that for ice extent or ice edge determination that the visual observations made from the ship are highly accurate since an observer is actually asked to make a simple, unequivocal (therefore correct) binary decision on the question: Is this the ice edge? (Yes if ice observed, No if it is not). Ice concentration estimates are more subjective. Knuth and Ackley 2006 however, describe an experiment where digital aerial imaging was compared between an observer's point interpretations at 12km intervals and an objective digital analysis of the continuously imaged strip. The correlation was 99 %, SD: +/- 3.3 %) between the observer's point analyses and the continuous imaging with error of +/-3% which provides some confirmation of the validity of point ship observations as "correct" data. The error assigned in the ice concentration estimates for ship observation is +/-10% to safely take account of the subjective judgment required, visibility, limited field of view and possible observer biases (www.aspect.aq).

Specific Reviewer's Comments

Reviewer Comment: Last sentence of Section 2.1. Values of ice concentration from the ship observations are given to 1 decimal place, yet the observations are only accurate to +/- 10%.

Authors' Response: Number will be changed to 44 (SD: +/- 26.72 %), more accurately given as 40% but we feel 44% arises from a large number of values averaged so is more appropriate to use, and the +/- gives the SD of the range (which is large and also larger than observational accuracy of one observation).

Reviewer Comment: Section 3, discussion of Figure 3. It is a very brave person who would look at the scatter in this data and claim it shows a linear trend. While I'm sure Microsoft Excel will happily draw a line through any data set, it is worth standing back and asking whether it makes sense. Clearly in this case it does not and I don't

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believe the authors can claim there is any relationship between these two data sets. Why should there be given that an AMSR pixel represents 625 sq km and the ship observations represent about 5 sq km? Much of the other discussion of Figure 3 is perfectly valid and highlights some interesting features in the data

Authors' Response: Spatial resolution of the AMSR-E sea ice product is 12.5 km. Therefore an AMSR-E pixel represents 156.25 sq km, but still a large value compared to the ship observation of 5km2. (Looking at it another way, by distance instead of area however, since the observation separation is 12km, under an assumption of some spatial homogeneity (which may not apply in lower ice concentrations) a single observation may represent a pixel value (12.5x12.5km) with some consistency?). However, this comparison, one observation to one pixel, usually gives better correlation when done with the winter data (Worby and Comiso 2004; Knuth and Ackley 2006) even though the AMSR-E is averaging the concentration of sea ice for each pixel (larger area than the observation). So we wish to make the point with this figure that the melting season data gives a particularly poor correlation under the same assumption that does give a better correlation for winter data. We do not have any confidence to say that the relation is linear. However, the physics of the microwave algorithms does predict that a linear relationship would exist between these, ship observations and satellite data, so we wish to report this prediction is poorly satisfied, as a linear trend between the satellite data and ship observations has a low R2 value. As Knuth and Ackley 2006, also found, this low correlation for summer ice concentration makes the general use of passive microwave data (SSMI there) particularly unreliable. Yet the passive microwave data set continues to be used for a variety of correlative studies and may be particularly problematic when used to validate models. Knuth and Ackley also reported that the Aspect point sampling compared well for ice concentration with continuous image analysis over an aerial photo track at distances over 50km, i.e. a good linear correlation does exist between concentration derived from observations and from remote but visible imagery when objectively analysed, further emphasizing the difficulty is not remote evaluation but with using the passive microwave to deter-

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mine ice concentration in these summer conditions since it compared poorly.

Reviewer Comment: Figure 4 is introduced before the discussion of Figure 3 is completed and this is confusing for the reader. This should be revised.

Authors' Response: We are introducing figure 3 and then figure 4 before completing the figure 3 discussion. We wished to make the point is to indicate how the correlation increases with averaging (figure 4) comparing to figure 3. Also part of the text went under the table 1 by mistake. We will correct it in the revised version and also try to clarify the confusing points in this discussion.

Reviewer Comment: Figure 4 is an interesting result. It would be valuable to say why you averaged the AMSR-E data, which is already coarse resolution

Authors' Response: We wished to see if averaging gave some better picture of the data, and cleaned up some of the noise in a point to point comparison (fig. 3). We note that averaging both observations and the AMSR-E data is required since several pixels are crossed once we use more than one or two observations. The choice of using 10 pixels is arbitrary, and we varied the number of observations averaged to coincide with the 10 pixels selected.

Reviewer Comment: Section 3.2 heading and text. The authors describe "sea ice edge" and "sea ice extent" as if they are two different things, which they are not. This continues into the next section as well.

Authors' Response: This is a good point. We described that way because the AMSR-E provides the sea ice concentration and the total sea ice extent. On the other hand NIC is only providing the border of the sea ice edge as a line but it is also the sea ice extent. Corrections will be made according to these comments and changes will be

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applied to the text in the revised submission.

Reviewer Comment: Section 3.2 second paragraph. The description of the parallel lines drawn on the charts is extremely confusing. I have re-read it several times and I'm still not sure what has been done. The text claims "parallel lines are drawn along the ice edge". But in fact I think the lines must be drawn perpendicular to the ice edge. This section needs to be re-written so that it is a concise, accurate description of the data analysis.

Authors' Response: It will be re-written. Actually nearly perpendicular lines were drawn along the ice edge to measure the distance between NIC and AMSR-E. Since the ice edge for both the NIC ice edge and the AMSR-E edge are "random (and un-correlated) wavy lines", it is difficult to choose between representations that measures the distance in a consistent way between the two ice edges. We therefore chose to use parallel lines in a constant orientation on the image between the two rather than say, a due south orientation at all locations. Both methods are equally arbitrary, since it is easy to find locations where they would give either greater or less distance than the other method, suggesting these differences would average out to a similar value when taken over many measurements and give similar max and min values also. By using a large number of parallel lines however of equal small separation, a total area between the two can be easily calculated by summing the trapezoidal areas formed by the two parallel lines and the separation distance (constant at 50km) along the respective ice edges of those parallel lines. This method is also easier to implement on the GIS platform used for the analysis than a constant direction vector.

Reviewer Comment: Section 3.3, 10th line incorrectly claims that "summer is the time when the sea ice breaks into individual floes". In fact this is a process that occurs all through the year in response to ice dynamics.

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Authors' Response: We will change this to: Summer is the time when the sea ice floes can be more distinctly identified since no new ice forms in the cracks and leads when floes separate, giving a distinct open water rather than a less easily identified ice boundary between them.

Reviewer Comment: I'm not at all sure of the value of Figure 6, which shows plots of scatterometer data in the lower panels and AMSR data in the upper panels. The figure only receives a passing (1 line) mention which suggests "general agreement" between scatterometer data and NIC data, which are not the data sets plotted.

Authors' Response: With the current highest usage of scatterometer data to produce ice charts (36.7% from above discussion) for the recent NIC ice charts, we wished to compare using scatterometer data alone to the passive microwave. At present, however, the scatterometer data is only available in analog (jpeg) form in an easily accessible way (Polarview website) to us. We therefore cannot digitally analyse them and can only make the general agreement statement between the scatterometer and the NIC ice charts, which is expected because of the high reliance. We will add, either here or in concluding remarks, of the need to analyse scatterometer data alone in a quantitative comparison with digital data. This will require either the modification or testing of current scatterometer algorithms for Arctic sea ice tailored to Antarctic sea ice conditions. This effort will be undertaken shortly.

Reviewer Comment: The table captions should say what +ve and -ve values mean. For example "A positive value indicates that the NIC ice edge is north of the AMSR-E ice edge". This would make the data much easier to understand.

Authors' Response: Change will be made as commented.

Reviewer Comment: Dates throughout should be in the international format (unless the

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journal specifies otherwise) which should be day/month/year.

Authors' Response: Change will be made as commented.

Reviewer Comment: There are quite a few grammatical errors but in light of the larger problems these can wait.

Authors' Response: We will undertake these with closer copy editing in the revised version.

Editor Comment: This is an interesting paper. Any paper that attempts to combine such different sources of sea-ice concentration/area/extent data (and there are not too many of these) is a potentially valuable contribution. But as mentioned in the review by Dr. Worby, there are a number of confusing/contentious points of scientific substance that need addressing. Therefore I would like to strongly suggest that the authors carefully consider and respond to Worby's review, as the present reviewer agrees with many of his comments. The authors need to be more precise/specific about the mix of data going into producing the NIC ice charts, as this will considerably influence comparisons with the other sea-ice data types attempted in the study.

Specific Abstract, l.1: "slight increase" - quantify/specify.

p.4, bottom line: "...the sea ice of the area has shown significant changes in the satellite era." - please add brief details/reference.

p.5: What is the "SSM/I automated contour"? "data" should be pluralised throughout the MS.

Authors' Response: Thank you very much Dr. Hanna for your comments. We will consider your comments and make changes accordingly on the manuscript.

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http://nsidc.org/data/docs/noaa/g02172_nic_charts_climo_grid/index.html

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