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The Cryosphere Discussions

Interactive comment on "Recent wind driven high sea ice export in the Fram Strait contributes to Arctic sea ice decline" *by* L. H. Smedsrud et al.

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General comment from Referee #2:

Ice export is one of two main processes that govern the overall sea ice balance in the Arctic Ocean. The recent strong decline in Arctic sea ice area and sea ice volume pose the question whether an increase in export could have contributed. The main conduit for sea ice export is Fram Strait. Consequently, the authors combine Envisat ASAR estimates of sea ice velocity in Fram Strait with SSMI and AMSR sea ice concentration data to estimate recent sea ice area export through Fram Strait.

A statistical relationship between the geostrophic meridional wind component and sea ice drift as well as sea ice area export is put forward. For the period of available satellite

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data there is a good linear fit between sea ice area export and the geostrophic wind. This relationship is used to reconstruct sea ice area export for the period of available atmospheric reanalysis data. According to this reconstruction, sea ice area export through Fram Strait has increased by 25% compared to the 1960s.

The manuscript is a contribution to the question of overall sea ice mass balance in the Arctic and the possible causes for the recent dramatic decline. This topic is highly relevant and fitting for TCD. There are a few recommendations that I can suggest and which might improve the manuscript.

It should be realized that with the data considered here, only the ice area export from the Arctic can be estimated. The title of the manuscript is thus clearly too ambitious and must be changed. Neither is the ice export (implying volume or mass export of sea ice) from the Arctic considered nor can the data really be used to establish a contribution to the sea ice volume balance in the Arctic Ocean. At all places where “sea ice export” is used in the text, it should be replaced by “sea ice area export”.

Answer:

We are aware that we would need to combine our data with estimates of sea ice thickness to present results on sea ice volume and mass transport. This may be possible for a similar period after 2004, and we will work towards this goal with other partners once this improved time series of area export has been established. The title has been changed as suggested, and some more text in the introduction stating more clearly that we do not address the mass and volume ice export. We have also added "area" in the text where this makes it clearer. Note that a change in area export is a major change in boundary conditions for any model of the Arctic sea ice, and may well serve as one of the most prominent forces of change to the volume balance, along with heat transport to the Arctic by the ocean and atmosphere.

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Detailed comments from Referee #2 :

Page 1312, line 2: Arctic sea ice area decline does hardly continue at a steady rate. The rate of sea ice area change is itself changing considerably inter annually and on longer time scales.

Answer: Valid point, sentence deleted, but the trends are quite linear, both for multi-year and total ice cover.

Page 1312, line 7: The name of the “underlying current” should be mentioned. The statement that it drives 33% of the ice export is a little bit too concise to be understandable. Does it refer to the trend, the variability, or is this referring to the long-term mean sea ice area export?

Answer: East Greenland current added now, and 33% changed to “around a third” - it is the mean overall value.

Page 1313, line 7: Statement unclear: Are year 2000 conditions and vanishing summer sea ice in 2080 extreme cases for the end of the century according to the climate projections? The term “prediction” should be avoided in this context.

Answer: Agreed - “prediction” deleted here, "indicates" is better.

Page 1313, line 16: There is a tendency in the literature on Arctic sea ice to only mention positive feedbacks. One wonders how Arctic sea ice can exist in the first place. It should be noted that open water favours new sea ice production, a negative feedback associated with declining sea ice cover.

Answer: Indeed very true. Our previous paper in GRL had this as a main point, and we are happy to cite it here too. New text: “There are also negative feedback mechanisms operating, the most important likely being the more efficient growth of new sea ice with more open water during winter. This could lead to a substantial recovery of the Arctic sea ice given that the large scale forcing (heat transport and ice area export) returns to previos levels (Smedsrud et al 2008).

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Page 1313, line 23: Trends in sea ice area export have not previously been found in Fram Strait. Have there been attempts to estimate these trends? Please provide references.

Answer: The same references as for the mean values have been added now, and more text on the difference towards volume/mass export.

Page 1313, line 26: The statement on increasing sea ice drift in Fram Strait since 1979 needs a reference.

Answer: Added now (Rampal et al 2009), and rewritten for clarity.

Page 1314, line 4: It is not true that a conclusion regarding the effect of changes in sea ice area export on the thinning of Arctic sea ice will be given in section 5. I only find one statement there that such a relationship is likely. Anyway, without knowledge of the ice volume export changes in Fram Strait, we cannot arrive at conclusions about the sea ice mass balance in the Arctic.

Answer: Point taken. It has very likely had an effect, but we have not estimated the effect here. That should be done. Sentence rewritten to: "Section 5 gives our conclusions on influence of the recent high ice area export on the September minimum ice cover of the last few years, and the general thinning of Arctic sea ice."

Page 1317, line 13: It remains unclear how eq.(1) could be used to estimate the mean speed of the East Greenland Current in Fram Strait, as eq.(1) is for ice drift.

Answer: A few lines have been added to explain this now: "Assuming that the internal stresses in the sea ice can be ignored Eq.(1) also provides an estimate of the underlying current.

Page 1317, line 23: "our pressure dependency" and "our constant term" are awkward expressions and should be replaced.

Answer: Changed to: "Our value representing the constant contribution from the East

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Greenland current (24562 km/month, Eq. 1) is 12% lower than Kwok (2009), and the term stating the dependancy on the across strait pressure difference is is 19% larger (8737 “delta” P, Eq. 1).

Page 1318, line 10: “AMSR derived drift vectors” – I believe that you only consider the meridional velocity component (or rather the drift component perpendicular to the line connecting the two points between which the atmospheric pressure gradient is taken).

Answer: Yes. In both cases southward ice drift should be concise. Added now.

Page 1319, line 13: Discussing the ice area export using changes in annual mean sea ice drift and concentration is misleading. Since both the drift and the concentration vary seasonally and with higher frequency, the correlation of fluctuations cannot be neglected in the total annual mean transport.

Answer: Valid point. We have used the observed ice concentrations for the period since 2004. Before that year we do not have any high resolution SAR images, and so we cannot really know for sure what has been going on. Rewritten for clarity now. This was also discussed on page 1321, line 20.

Page 1321, line 11: Trends might be statistically significant and robust according to formal statistical criteria. However, it would still be interesting to see the impact of single extreme export years on the trend estimate. This could easily be done by recalculating the trends with certain anomalies (e.g. 1995 or 2000) taken out. From Fig.7, I suspect that the result would actually be quite different.

Answer: There are large year to year fluctuations, indeed. We did calculate a large number of trends, and presented the once we found to be most important. The trends looking back from today were all similar, which we found surprising, but important. On the contrary, starting in 1995 and ending in 2004 does, as you may expect, produce a negative trend. A trend for 2000 - 2010 is twice as large as the one we have stated. Based on your suggestion we also tested removing the 1995 and 2000 maximums, as

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well as the minimum of 2003. This lowered the trend to 4.8 +-2.7 % per decade. Only removing the two maxima lowers the trend to 4.3% +-2.8 % per decade. But we expect the peaks to be real, and by only removing positive maxima we would systematically bias the data. No changes to the text.

Page 1322, section 4.3: A time series plot showing all three estimates (AMSR, SAR, and NCEP) for sea ice area export would be helpful.

Answer: We did initially attempt to produce such a figure. The problem with the AMSR data is that it is not continuous throughout the year, and that there are large gaps in the data coverage both spatially and temporally. The best comparison we could do is shown in Figure 5 and 6, which does result in an explanation of the overall lower values from the AMSR data.

Page 1324, line 8: Where does the information about the intensification of cyclones over the Nordic Seas come from? Please provide a reference.

Answer: This is our own work. This is described on page 1320, line 10-25. We did not add any figures though, as the pressure changes are directly proportional to the ice speed and area export of Figure 7. A figure has been uploaded here to illustrate the correlation of 0.75. We could add this figure to the paper if it adds further understanding.

Page 1324, line 13: Statement (GCMs -> additional forcing necessary) is unclear.

Answer: The paragraph has been re-written, and the classical Stroeve (2007) citation has been added to make the point clear.

Fig.2: How are the values binned? It would be good to have an explanation in the caption without need to refer to the main text.

Answer: Changed to: “Red circles show values binned for each m/s of wind.”

Fig.3: What exactly is meant by “changes in seasonal monthly ice export”? Changes

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compared to what baseline?

Answer: Changed to: “Increase due to the linear trend of each seasons ice export from 1957 to 2010 are plotted at the bottom.”

Fig.5: What is the cause for the conspicuous vanishing SAR-based velocities where AMSR ice drift is non-zero?

Answer: We believe this is due to the following as stated on Page 1318, line 13. 2) AMSR has many non-zero drifts in the fast ice (at zero SAR speed)

Fig.7: Values from Kwok (2009) are given as red dash-dotted line?

Answer: Yes, added.

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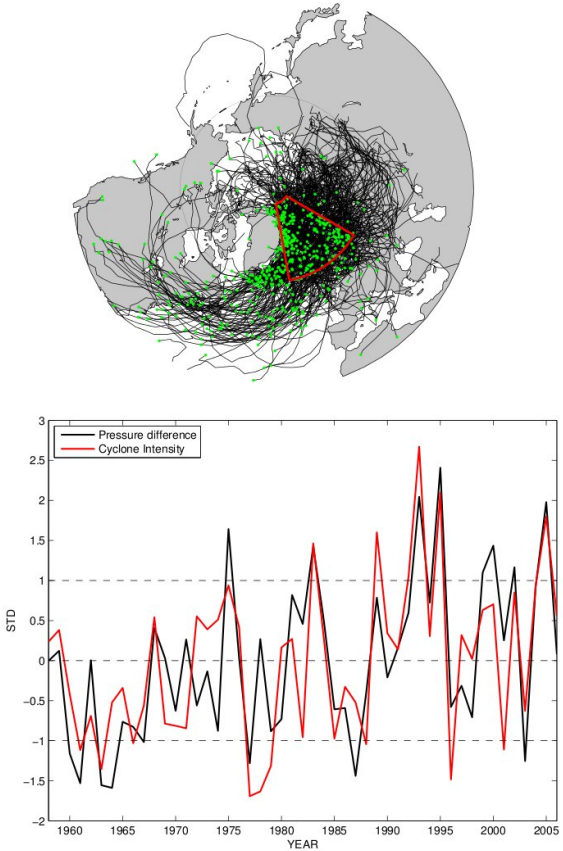

Fig. 1. Cyclones tracked by the algorithm moving through the red box area (60–85N and 20W–30E in Dec, Jan and Feb. Green dots show start location. Lower: Delta P (Eq1) and Cyclone intensity.

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