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# *Interactive comment on* "On the characteristics of sea ice divergence/convergence in the Southern Beaufort Sea" *by* J. V. Lukovich et al.

**J. V. Lukovich et al.**

Jennifer.Lukovich@umanitoba.ca

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Dr. Christian Haas Editor, The Cryosphere November 20th, 2014

Dear Professor Haas:

Thank you for your suggestions and supplementary material. Please find below responses to reviewers' comments on the manuscript "On the characteristics of sea ice divergence/convergence in the Southern Beaufort Sea", by J.V. Lukovich, D.G. Babb, R.J. Galley, R.L. Raddatz, and D.G. Barber, manuscript number tc-2014-117, in italicized text. Responses to referee's comments will also be provided separately in response to the individual referee suggestions and recommendations.

General comments The authors would like to thank the editor and three reviewers for



helpful comments and suggestions. Effort has been made to improve the quality of the figures, emphasize the focus of the study on differences in sea ice convergence and divergence near the pack ice edge and interior, emphasize the applicability of the triplet approach to an understanding of sea ice deformation, and to improve clarity in the manuscript. Please find below specific responses to the Reviewer's comments and suggestions.

Responses to Referees

Interactive comment on "On the characteristics of sea ice divergence/convergence in the Southern Beaufort Sea" by J. V. Lukovich et al.

Anonymous Referee #1

Received and published: 20 August 2014

In September 2009, 11 buoys (beacons) were deployed on the sea ice of the southern Beaufort Sea. The authors group these beacons into 5 triangles (triplets, labeled A-E) and analyze the motion and area of each triplet during Sept-Oct-Nov 2009.

Thank you for your helpful and insightful comments and suggestions. Please find below responses to your questions.

First I would like to comment on the quality of the figures. I printed a hard-copy of the pdf, and most of the accompanying figures are too small to read the axis labels and/or too small to see what's going on. This seems to be partly the fault of the journal and partly the fault of the creators of the figures. In my opinion, figures should be fully legible and intelligible when printed. I can read the main body of the text perfectly well in the hard-copy printout, but not the figures. The authors should use font sizes for the axis labels and legends that are the same size as the main text, and the journal should not shrink figures in order to squeeze multiple panels onto a single page if doing so C1582 makes the figures illegible.

The authors have made significant effort in the revised manuscript to improve the qual-

ity of the manuscript figures to ensure that they are legible.

I have three main comments about the paper.

The authors use the change in area of the triangles to measure divergence, as in equation (1): (1/A)dA/dt = divergence. This is theoretically valid, but in practice the use of only 3 points leads to large error estimates and extreme sensitivity. Thorndike (Kinematics of Sea Ice, Chapter 7 in The Geophysics of Sea Ice, NATO ASI Series, vol 146, 1986) finds that the ratio of estimation error variance to signal variance is about 0.7 when using 3 points to estimate divergence (see Fig 23b and the discussion at the top of page 536). Furthermore, a simple analysis of the area of a triangle, A = (1/2)base*height, shows that for a constant base b and variable height h, divergence = (1/A)dA/dt = (1/h)dh/dt so when h is small, the divergence is extremely sensitive to small changes in a single vertex of the triangle (the one that's not part of the constant base). Figure 2 shows that in fact there are many highly elongated triangles in this data set. The problem is this: in estimating the divergence of a region using a discrete set of boundary points, the implicit assumption is that the points adequately resolve the material boundary of the region. In other words, as the shape evolves over time, there should not be a flux of ice into or out of the region. But a region of sea ice defined by a highly elongated triangle will almost certainly violate this implicit assumption in a big way. The sides of the triangle will almost certainly not be material boundaries. If one could track (say) 10 points along one side of the triangle, one would often find that after one time step, the 10 points no longer fell along that side of the triangle. In other words, 3 points do not accurately resolve a large material element of sea ice, especially when that element is highly elongated. As Thorndike (1986) showed, 6 points provide much better accuracy. It's too bad the authors did not group the beacons into sets of 6. The bottom line is: I question the quality of the divergence measurements from this data set.

Sea ice deformation in Thorndike (1986) is described by large scale average strain rates ($\partial$u_i)/($\partial$x_j ) used derive strain rate invariants including sea ice divergence and



convergence (p. 521, Thorndike, 1986). A similar approach is incorporated in the study of sea ice deformation in East Antarctica (Heil et al., 2011). In the present study sea ice divergence and convergence are described by the fractional rate of change in the triplet area, computed using Heron's formula as described below. Reference to the review by Thorndike (1986) is included in the revised manuscript in the context of estimation error, the strain component and triplet area approach.

The numerically stabilized version of Heron's formula, A= $\sqrt{}$(s(s-a)(s-b)(s-c) ), where a, b, and c denote the length of the sides for each triplet, and s= 1/2 (a+b+c), is used to compute the triangle area and is implemented in the present analysis in order to avoid the sensitivity that the present Reviewer notes to small changes in a single vertex resulting in small h and an elongated triangle. This is now emphasized in the Methods section of the revised manuscript.

Increasing area for triplet B during the late stages of evolution in the present study suggests that sea ice is mixed into and out of the triangular configuration. As is noted by LaCasce (2008), however, even if material boundaries are not resolved by the triangles, the aspect ratio can be used to provide insight into the nature of dispersion and mechanisms involved/responsible for such behavior. A continued increase in the aspect ratio following rapid elongation and collapse in area suggest sustained shear dispersion. In contrast, a decline in the aspect ratio indicative of an approach to a more equilateral configuration could provide a signature of an inverse cascade or transport of energy from small to large scales of motion. In the present study, an increase in and non-conservation of triplet B area in the later stages of evolution suggests that sea ice is mixed into and out of the triangular configuration near the pack ice edge. Elongation of triplet C at the southern periphery of the Beaufort Gyre provides a signature of shear associated with anticyclonic circulation. Non-conservation of area and its implications for an assessment of dispersion are also addressed in the revised manuscript in response to this and similar concerns expressed by the present and third referee.

Furthermore, in light of comments provided by the present and third Reviewer re-

garding highly elongated triplets, analysis of triplet E has also been excluded in the revised manuscript in order to focus the discussion and study on sea ice divergence/convergence within the central pack, and in particular on differences in sea ice deformation near the pack ice edge and interior.

The "Results and discussion" section is mainly a detailed description of the figures. Page 4292 describes Figure 2. Pages 4293-4 describe Figures 3 and 4. Page 4295 C1583 describes Figure 5. And so on, through most of the section. It is frankly rather tedious.

The authors agree that detailed descriptions for each of the figures in the initial manuscript detract from the paper objectives, namely i) evolution in ice beacon triplet area in the fall of 2009 and ii) ice and atmospheric contributions to the observed behavior in sea ice convergence/divergence. Effort has been made in the revised manuscript to consolidate the descriptions in order to highlight differences in sea ice divergence/convergence near the pack ice edge and interior based on the position of the beacon triplet relative to the ice edge.

The actual main results seem to be that the ice behaves differently near the ice edge, near the coast, and in the interior of the pack; the wind affects the ice motion in different ways; and there are episodes of large divergence.

The authors emphasize in the revised manuscript differences in sea ice divergence and convergence at the pack ice edge and interior based on the position of the triplet relative to the ice edge, intervals of enhanced divergence/convergence in September, 2009 for all triplets and in October, 2009 for only triplet B, and the influence of winds on deformation associated with ice-ice and ice-coast interactions, in an attempt to better convey the main results that the present reviewer has noted.

Specific Comments

Page 4284, lines 10-11. What does it mean for "spatial scaling" to have "high values"?



This sentence has been revised to clarify its meaning, and now reads

'Documented also in recent studies is spatial scaling dependent on season and region, with comparatively high deformation rates and increasingly negative exponents during summer, at the periphery of the ice pack, or in first year ice (FYI) associated with loss of connectivity and coherence in the ice cover (Stern and Lindsay, 2009; Weiss, 2013).'

Thank you for pointing this out.

Page 4287, lines 23-24. "increase in triplet area characteristic of non-divergent flow". But if the area is increasing, doesn't that imply divergence? See equation (1).

Although area is conserved in non-divergent flow, an increase in area may be a result of surface divergence or random displacements induced by such influences as surface winds, as is noted by LaCasce and Ohlmann (2003). This is now stated in the revised manuscript in the following sentence:

'Non-conservation in area may be attributed to either divergent surface flow or, as has been demonstrated in previous drifter studies, random perturbations superimposed on the mean flow (LaCasce and Ohlmann, 2003).'

An increase in triplet area observed in studies by Molinari and Kirwan (1975) and LaCasce and Ohlmann (2003) is attributed to random displacements associated with wind forcing superimposed on the normal motion rather than surface divergence. Due to an absence of convergence that would cause the triplet areas to decrease, ruling out divergent flow, the authors attributed an increase in area to the superposition of random walks associated with wind forcing on the surface flow. This sentence has been clarified in the revised manuscript

'Both studies depict a monotonic increase in triplet area characteristic of displacements in response to wind forcing rather than divergent surface flow, the latter of which would be captured by both positive and negative divergence resulting in decreases in the triplet area (LaCasce and Ohlmann, 2003).'

Page 4289, lines 9-10. Wow, E is an extremely elongated triangle, with shortest leg 11 km and longest leg 400 km!

The authors have removed Triplet E from the analysis in light of the present and third Reviewer's comments, and to focus the assessment on sea ice convergence and divergence near the pack ice edge and interior.

What is the temporal resolution of the beacon data? In other words, when you plot a time series like Figure 3, are you plotting one value per day? 10 values per day?

The temporal resolution of the beacon data is two hours, and daily averages are computed for the analysis and time series. This is now noted in the Methods section.

Page 4290, line 4. The formula for delta-A is not dimensionally correct, so an algebra error must have occurred somewhere. Since a,b,c have dimensions of length (L), the expression inside the square root has dimension LËĘ6 and so the overall expression has dimension LËĘ3/LËĘ2 = L, not LËĘ2.

Thank you for pointing this out. The positional error $\delta$x was inadvertently excluded from the equation in the original version of the manuscript. This has been corrected. The error bars are now also included in Figure 3.

Page 4293, line 17. Not sure what is meant by "signature of regional small-scale constraints". See also page 4299 line 2.

This phrase was initially intended to address regional variability in triplet area evolution, and has been changed in the revised manuscript to "with differences providing a signature of regional variability" to reflect this. Similarly, the phrase "highlight spatial variability in the influence of small-scale constraints" has been changed to "highlight regional spatial variability".

Page 4294, line 14. In Fig 4b, I don't see much of a positive slope for triplet E.

As previously noted, analysis of triplet E has been excluded from the study.



Page 4297, line 21. There is no scale bar in Fig 7a so it's impossible to tell that the floe sizes are 2 to 10 km. Or does that information come from another source?

The floe sizes were obtained from the CIS ice charts and egg code, as is now noted in the revised manuscript.

Page 4298, line 9. Spell out what SIC stands for.

SIC has been expanded in the revised manuscript.

Page 4298, lines 24-25. The authors define "loop reversal events" as "the spiraling motion of a triplet beacon", and "meander reversal events" as "advection exceeds rotational motion". First, I don't understand how these "reversal events" are calculated, and second, why not use the beacon triplet positions to calculate the vorticity of the triangle, if the goal is to describe rotation?

Loop and meander reversal events are not calculated in the present study, but are instead identified as and refer to coherent features in the centroid paths. The phrases "loop reversal events" and "meander reversal events" have been changed to "loop and meander reversals" to highlight that these are features in the centroid trajectories used to identify coherence in sea ice deformation. The following statement has also been included in the revised manuscript to clarify reference to loop and meander reversals:

'Loop and meander reversals are used qualitatively in the present study to examine spatial coherence in triplet paths indicating intervals when the ice cover moves as an aggregate entity.'

Page 4298, lines 27-28. "loop reversal events are observed throughout the array ... (Fig 9)." I can't make out anything in Fig 9. Where should I see a loop reversal event?

Loop reversals are now identified in the panel showing sea ice concentrations and centroid paths on 14 September in Fig 9. Reference is also made to this panel in the revised manuscript.

Figure 4b. Wow, the aspect ratios of the triangles are sometimes 100 or more.

Large aspect ratios depict triplet elongation and filamentation. Specific reference is now made to the values associated with local maxima observed in triplets B, C, and D in the description of Figure 4.

Figure 6. The units on the Y-axis are given as 1/sec but this cannot be correct. Probably it should be 10ËĘ-6 /sec.

Thank you for pointing this out. The divergence units have been corrected.

Figure 8 caption, "within a 0.21 degree ... radius" – does this mean 0.21 degrees of latitude? Can you give the radius in km instead?

This value refers to 0.21 degrees in the zonal and meridional directions, and is now expressed in terms of km, with a value of $\sim$ 25 km.

Figure 9. I can't figure out what I'm supposed to be seeing.

Significant effort has been made to improve the quality of this figure, depict the evolution in triplets superimposed on sea ice concentrations, and highlight their shape relative to the ice edge. The text has also been modified to capture features illustrated in this figure.

Figure 10. The wind vectors appear to be plotted on top of one another. I cannot distinguish the wind for one triplet from the wind for another.

Figure 10 has been modified to illustrate differences in winds surrounding triplet centroids.

Technical Corrections

In the Abstract, after the first occurrence of the word "beacon" on line 7, insert "(buoy)" to clarify the meaning of beacon.

This has been included in the abstract. Thank you.



Page 4284, line 25. Insert "is" after "the ice cover".

This has been changed.

Page 4287, section heading "Triplet analysis and (oceanic and sea ice) applications". I suggest either removing the parentheses or removing the entire parenthetical phrase.

The parenthetical phrase has been removed.

Page 4288, line 27. Antarctic should be Antarctica.

This has been corrected.

Page 4289, line 4. "Sea ice drift data were determined from...". Probably better to say "were obtained from".

The word “determined” has been replaced with “obtained”.

Page 4290, line 21. Put the word "forcing" immediately after the word "atmospheric".

The ordering in wording has been changed.

Page 4292, line 26. "the time rate of change of which monitors ice convergence". Better to say "measures ice convergence". People and gadgets can monitor things, but time rates of change do not monitor things.

This phrase has been removed in consolidation of descriptions for Figures 2 and 3 in the revised manuscript.

Page 4293, line 19. Same comment about monitored vs. measured. Page 4296, line Same comment.

“Monitored” has been replaced with “measured” in both instances.

Page 4298, lines 25-26. I don't see Griffa et al (2008) or Lukovich et al (2014) in the References. Please check all references.

Both references are now included in the References in the revised manuscript.

Page 4300, line 3. Delete "in" after the word "highlight".

This has been changed.

Page 4311, Table 1. Correct the 3 typos in the caption.

These typos are corrected in the revised manuscript.

Page 4313, Table 3. In the column labeled "Intervals" I see the notation "09/10-09/24" and "10/09-10/26". Are these meant to be dates in the format MM/DD? The dates in the final column are in the format YY/MM/DD so "09/10" looks like it could be 2009 October or it could be September 10 with the year 2009 implied.

The dates are changed in the “Intervals” column to the YY/MM/DD format to ensure consistency with the format used in the final column of Table 3. Thank you for this suggestion.

Conclusion and Recommendation

This paper is basically a long description of the motions of 11 buoys in the southern Beaufort Sea in Sept-Oct-Nov 2009. There is nothing technically wrong with it, once a few minor details are corrected and the figure quality is improved.

I leave it to the editor to decide whether such a paper belongs in The Cryosphere.

Interactive comment on The Cryosphere Discuss., 8, 4281, 2014. Anonymous Referee #2 The paper offers a new data set describing the convergence and divergence of sea ice in the Beaufort Sea in September 2009. This data set follows previously measured sea ice convergence/divergence data sets and supports current understanding within this field. In summary, I agree with referee 1 that sections 3.1 and 3.2 should be shortened and that generally the figures are too small and difficult to read. Overall the paper is written clearly and well referenced. Thank you for your comments. Effort has been made to shorten sections 3.1 and 3.2, and to improve the quality of the figures. Please see also responses to reviewers 1 and 3 for additional description of changes



to the revised manuscript.

Anonymous Referee #3 Summary This manuscript presents an analysis of the drift of 11 buoys deployed on sea ice in the Southern Beaufort Sea shortly before the annual extent minimum in 2009. The authors group these 11 buoys into 5 triplets, with two 4-buoy pairs. By analyzing the changes in the shape and area of the triangles formed by these triplets, the authors identify periods of convergence and divergence during which the response of the buoy triplet respond differently depending on their proximity to the ice edge and the coast. Unfortunately, the manuscript is written in such a way to defy further summarization. As well as incoherent punctuation and ambiguous use of terminology, the authors repeatedly fail to clarify confusing references to the positions at different times of specific triplets, which makes it difficult to follow the intended line of reasoning. It would help if the figures were legible but poor design and an absence of error bars increase the challenge for the reader. I also have serious concerns about the suitability of the authors analytical approach for such highlight elongated triplets, which I apparently share with at least one other reviewer. On face value, this manuscript has the potential to make significant and interesting contributions to our understanding of ice transport and deformation in the Beaufort Sea, but in its current state it has serious problems that will take significant effort to rectify. Thank you for your helpful comments and suggestions. The authors have made a concerted effort to address issues related to punctuation and ambiguity in terminology in the revised manuscript. Distinction has also been made between the initial identification of triplets based on their position relative to the coastline, and positions of triplet centroids relative to the dynamic reference frame of the ice edge to highlight differences in sea ice divergence and convergence near the pack ice edge and interior. As is noted in response to the first reviewer’s comments, the quality of the figures has been improved to ensure that they are legible and illustrate key features in centroid evolution, and error bars included for triplet areas in Figure 3. The suitability of triplet area to measure sea ice divergence and convergence is addressed through description of the stabilized Heron’s formula to avoid singularities for elongated triplets; triplet E has also been excluded from the

analysis to focus on sea ice deformation near the pack ice edge and interior. Please find below responses to specific comments. General Comments Use of highly elongated triangles for calculating changes in area Reading the discussion on this paper so far, it appears I share the same concern as the other reviewer regarding the use of such highly elongated triplets for calculating divergence. In particular, triplets with such configuration are prone to "turning inside out" and violating the implicit assumption that ice does not pass between the vertices of the triangle formed by the triplet. Indeed, the authors note themselves on p. 4292 lines 12-13 that the beacons in triplet C became "interchanged", demonstrating that such behavior is commonplace. The highly elongated triangle associated with triplet E has been removed from the revised manuscript in order to focus the study on sea ice divergence and convergence in the pack ice and in particular on differences in sea ice deformation near the pack ice edge and interior. Although fluid can be mixed in and out of the triangle, elongation of triplets illustrates filamentation associated with shear, such as if found at the periphery of the Beaufort Gyre. By contrast, a subsequent increase illustrates the emergence of conditions that increase spatial variability and increases in the inter-beacon distances. Please see also responses to the first comment provided by the first referee. Reference to the position of triplets with respect to "distance from the continental coastline and pack ice edge" At the risk of sounding obtuse, this is a highly confusing reference frame to use. First, the ice edge evolves through the study period while the coastline is remains fixed and, second, due to the shape of ice edge, some triplets can be further from the coastline, yet closer to the ice edge than others. Why do the authors try to use both reference frames? To make matters worse, in some cases the text contains references to the westernmost or southernmost ice edges. The authors could help the reader by clarifying which triplets they are referring to, but they consistently fail to do so. Moreover, despite the repeated references to variations in the convergence/divergence with distance from these edges, the reader is not presented with any table or graph providing the actual distances. The authors agree that reference to the position of the beacon triplets relative to both the ice edge and coastline confounds interpretation of sea ice



divergence and convergence in the context of a fixed and moving reference frame. In light of the present referee's comments, the authors have sought to distinguish between the role of the continental coastline as a fixed reference used to initially identify the beacon triplets and categorize them according to distance from the continental coastline, and the role of the ice edge as an evolving reference for the measurement of differences in sea ice deformation near the pack ice edge and interior. Additional text has also been included in the Methods section to distinguish between reference to the continental coastline and ice edge, as follows: "It should be noted that triplets are initially identified relative to the fixed reference of the coastline. However their evolution and in particular sea ice divergence and convergence are investigated relative to the dynamic frame of the pack ice edge to investigate differences in dispersion at the pack ice edge and interior." Use of punctuation I recommend the authors review some basic rules of punctuation usage, such as when and how to use semi-colons and parentheses and how to construct sentences without requiring ambiguous uses of commas. For guidance on parentheses in particular, I encourage the authors to read the following EOS article: Robock, A. (2010), Parentheses are (Are Not) for References and Clarification (Saving space), Eos Trans. AGU, 91(45), 419-419, doi:10.1029/2010E0450004. Thank you for the suggested reference. Effort has been made to improve punctuation in the revised manuscript following the recommendations outlined in Robock (2010, and to limit the use of parentheses in the description of results and their assessment. Use of elongated and stretched The authors use elongated and stretched interchangeably throughout the manuscript. Elongated is the more appropriate term and I recommend the authors use it in favor of stretched in all cases. The authors have replaced the term stretched with elongated throughout the manuscript where appropriate. Specific comments P4282 Line 4: replace "true" with "important". This has been changed. Lines 7 – 9: The use of the word "defined" here is very confusing. Please clarify what is defining what, or use a different word. This word "defined" has been replaced with "initially identified" to clarify triplet categorization based on their distance from the coastline. Lines 9 – 11: Between "illustrate" and "demonstrate" there's some redundant text that could be

removed here. This sentence has been clarified so that it now reads as “Results from this analysis illustrate differences in the evolution of ice beacon triplets at the periphery and interior of the ice pack in the SBS.” P4283 Line 25: Replace “thickness” with “thickening”. This has been corrected. P4284: Lines 21 – 26: These lines would be much better written as three separate sentence rather than forced into a awkward semi-colon separated list. Also, the authors should explain the meaning and significance of terms such as elliptic or hyperbolic. These lines have been rewritten as three separate sentences, and the significance of elliptic and hyperbolic included. This section now reads as follows “Previous studies have highlighted the role of forcing (namely wind stress) and coastline geometry in establishing lead patterns/fractures in the ice cover captured by sea ice deformation (Pritchard, 1988; Overland et al., 1995; Hutchings et al., 2005, 2011). Overland et al. (1995) demonstrated that in the Beaufort Sea for spatial scales exceeding 100 km the sea ice cover moves as an aggregate. For scales between 1 km and 100 km the ice cover moves as an aggregate or discrete entity based on whether an elliptic (homogeneous) or hyperbolic (discrete) regime is established relative to the coastline, providing a characterization of ice-coast interactions. More specifically, an elliptic regime is characterized by diffusive behavior and spatial homogeneity in the ice pack, in contrast to a hyperbolic regime that is characterized by propagation of discontinuities and directionality in the ice pack (Overland et al., 1995). Furthermore, for spatial scales on the order of 1 km the ice cover is characterized by floe, or ice-ice, interactions.” Line 22: replace “less than 100 km” with “between 1 km and 100 km”. This has been changed. Please see also previous comment.

P4286 Lines 10 – 24: The last paragraphs of the introduction read like they were taken straight out of a grant proposal. It does not behoove the authors to appear to be trying to sell something to the reader. The authors have removed some of the text from the last section of the Introduction to address this concern. The last paragraph of the Introduction is now written as “Recent studies of sea ice motion in the marginal ice zone (MIZ) in the southern Beaufort Sea (SBS) analyzed ice beacon trajectories during the fall/winter of 2007/2008 as part of the International Polar Year Circumpolar Flaw Lead



study based on absolute, or single-particle dispersion statistics to provide a regional account of sea ice dynamics (Lukovich et al., 2011). Results from this investigation highlighted the existence of two scaling law regimes, namely in the zonal direction characteristic of westward advection and in the meridional direction characteristic of a hyperbolic (strain-dominated) regime and quasigeostrophic turbulence (Lukovich et al., 2011). Coherent ice drift features associated with mesoscale ice dynamics, namely loop and meander reversal events in the SBS were also investigated through analysis of relative (two-particle) Lagrangian dispersion statistics (Lukovich et al., 2014). In the present study we examine smaller-scale features and deformation characteristics of sea ice motion in the SBS based on a three-particle analysis that monitors evolution in a triangular array of ice beacons during the fall of 2009. In particular, a triplet analysis is used to provide insight into sea ice convergence and divergence at the pack ice edge and interior that is essential to an accurate representation of sea ice dynamics in modeling studies and to our understanding of the role of sea ice dynamics in ocean-sea-ice-atmosphere interactions. In consideration of these objectives, we therefore examine the following research questions: What is the evolution in area of ice beacon triplets during the fall of 2009? (Sea ice convergence and divergence) Is sea ice deformation in fall 2009 governed by ice and/or atmospheric forcing? How is this evolution influenced by triplet proximity to the pack ice edge? (Sea ice and atmospheric forcing)”

P4287 Lines 16 – 17: Changes in aspect ratio do not necessarily imply changes in area. In fact in the previous sentence the authors just explained this.

The authors agree. The aspect ratio does however reflect changes in shape, and “area” has been changed to “shape” to reflect this.

Lines 23 – 25: How can an increase in area be related to non-divergent flow? An increase in area can be related to non-divergent flow through displacements superimposed on the mean flow in response to external factors such as surface winds. In response to the comments of both the present and first referee, text has been included in the revised manuscript that reflects this:

“Non-conservation in area may be attributed to either divergent surface flow or, as has been demonstrated in previous drifter studies, random perturbations superimposed on the mean flow (LaCasce and Ohlmann, 2003; LaCasce, 2008).

The sentence on lines 23 – 25 of the original manuscript has also been revised and now reads:

“Both studies depict a monotonic increase in triplet area characteristic of displacements in response to wind forcing rather than divergent surface flow, the latter of which would be captured by both positive and negative divergence resulting in decreases in the triplet area (LaCasce and Ohlmann, 2003).

P4291 Lines 16-19: There is some serious punctuation abuse in this sentence. Between the parentheses, parenthetical commas, and commas in series, it is difficult to read this sentence in one sitting. Consider re-writing without parentheses and using as many separate sentences as necessary.

This sentence has been revised and separated into two. The rewritten text is as follows:

‘Values of $\sim$1.7 are found for beacons 9, 10, and 11 that comprise triplet D. This is in contrast to values of $\sim$1.3 for beacons at lower latitudes, indicating more erratic ice drift at higher latitudes in the SBS in the fall of 2009.’

P4295 Lines 19-22: This is not appropriate use of punctuation. Rewrite without colons and semi-colon. E.g:

Comparison of centroid velocities highlights intervals when sea ice in the SBS is governed either by non-local mechanisms, in which case it moves as a consolidated aggregate, or local mechanisms when it moves as a fractured ice cover governed by local interactions.

Thank you for the suggested revisions. This sentence has been changed.

Line 24: Why are these not listed in chronological order?



The dates are now listed in chronological order.

P4304 Line 20: What is the parenthesized “(closest to)” supposed to refer to?

This sentence has been revised as follows:

“It is further shown that triplet area evolution is depicted by decreasing coherence with increasing latitude, evident in triplet base length scales of $\sim$70 km, 30 km, and 20 km for triplets B, C, and D respectively from mid-September to October.”

Figure 1a: This figure present highly important information for the reader, yet the key details are rendered too small to be of much use.

As previously noted, the authors have made a concerted effort to improve the quality of the figures and their legibility.

To make better use of space and avoid the problem of having some beacons form parts of multiple triplets, I recommend the following changes: Plot the trajectories for the triplet centroids rather than the individual beacons. Instead of using different symbols to indicate the triplet configurations on specific dates, connect appropriate beacon locations with colored (perhaps dashed) lines corresponding to the appropriate triplet. Less text should be needed in the legend, so the authors should now be able to use a larger fontsize.

Figure 1a is now included as Figure 1b, and following suggestion 1) now illustrates the beacon centroids. The triangular configurations are also indicated for specified dates in colors associated with the appropriate triplet, and larger font size included in the legend for the triplet labels. Please see the attached supplementary material providing the revised figures.

Figure 1b: I recommend the authors choose a different color scale for the ice concentration to avoid clashing with the colors used for the beacon drift paths.

Thank you for this suggestion. Sea ice concentrations are now presented in greyscale

in Figures 1a and 9.

Figure 3: Error bars would be helpful for understanding the significance of the variability in this figure.

Error bars are now included in this figure for all triplets.

Figure 4: This figure wastes a lot of white space and reproduced at such low resolution that zooming in to see the details does not help greatly.

The resolution for this figure has been improved and the range for the y-coordinates for both panels reduced so as to eliminate white space.

Figure 6: Same comment as for Figure 4.

This figure now depicts the full time series and an enlarged version of the first interval for enhanced divergence/convergence. The resolution has also been increased.

Figure 8: The text is too small in this figure.

The font size has been increased for this figure.

Figure 9: Same comment as for Figure 1b.

As previously noted, greyscale contours have been used for sea ice concentration maps in the revised figure.

Please find attached as well the files in pdf for the revised manuscript, figures, and responses to comments.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/8/C2426/2014/tcd-8-C2426-2014-supplement.pdf

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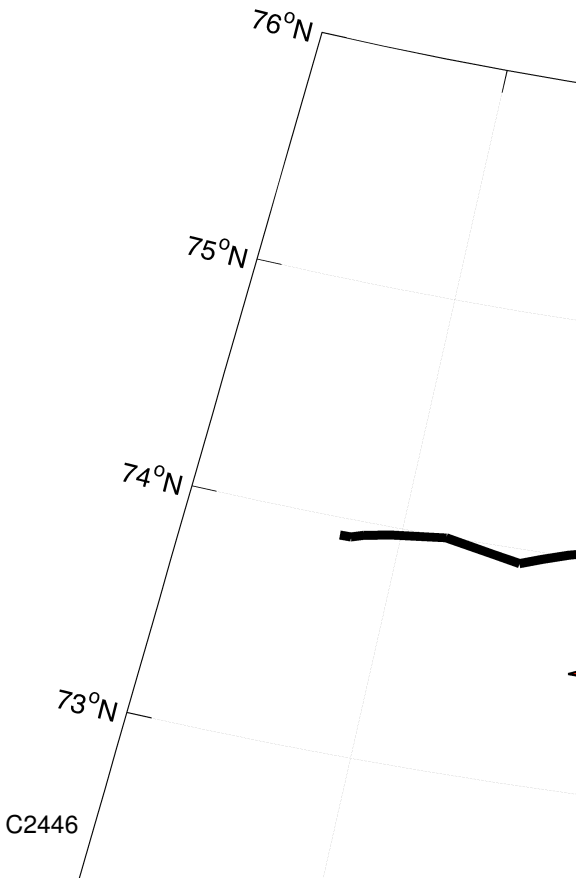
Interactive comment on The Cryosphere Discuss., 8, 4281, 2014.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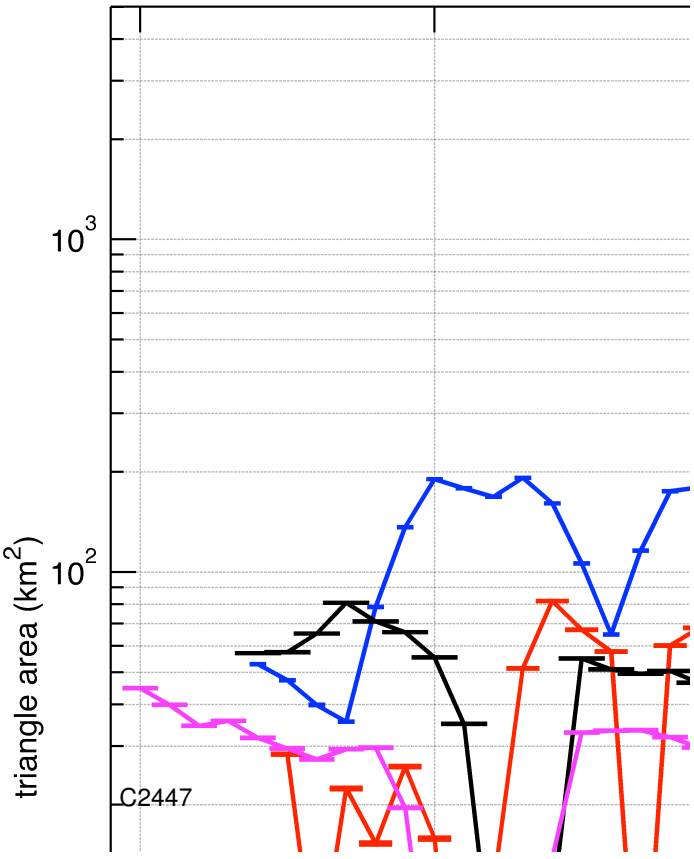
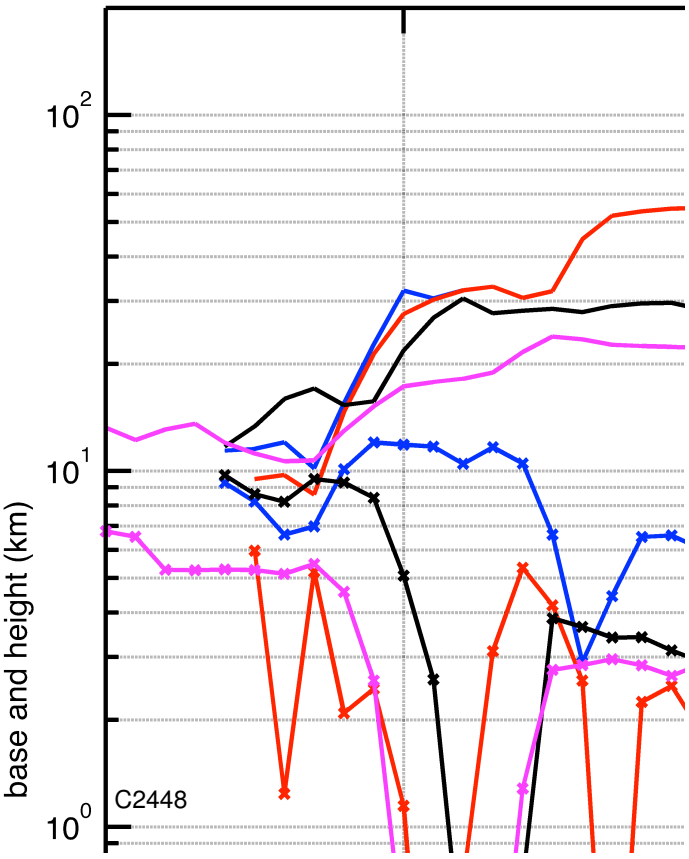
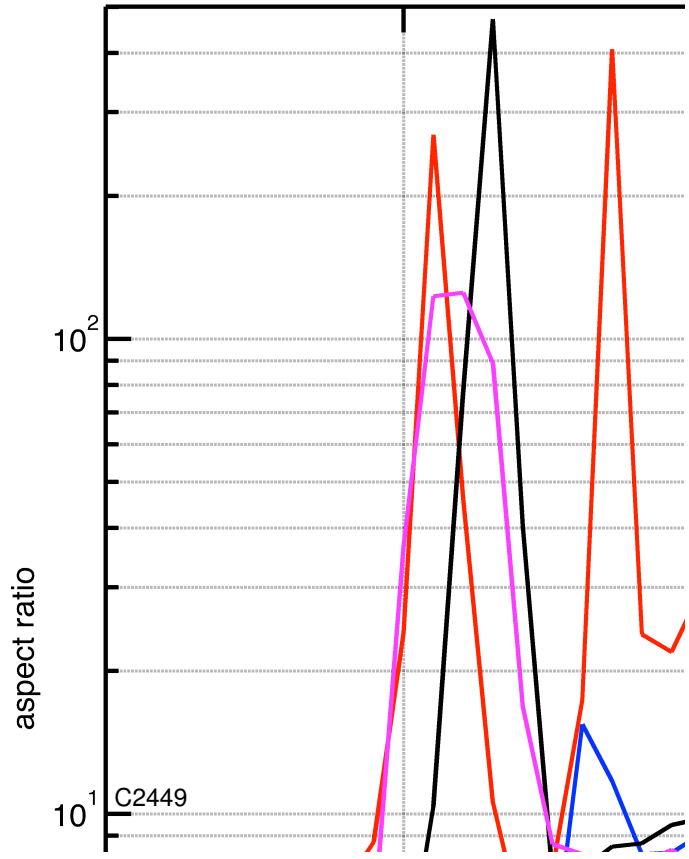
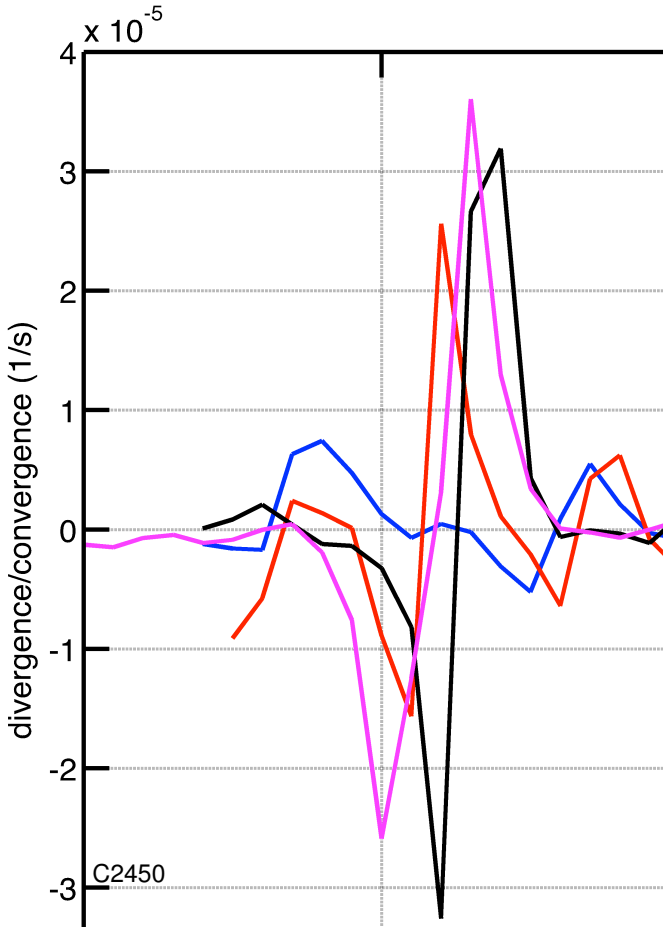
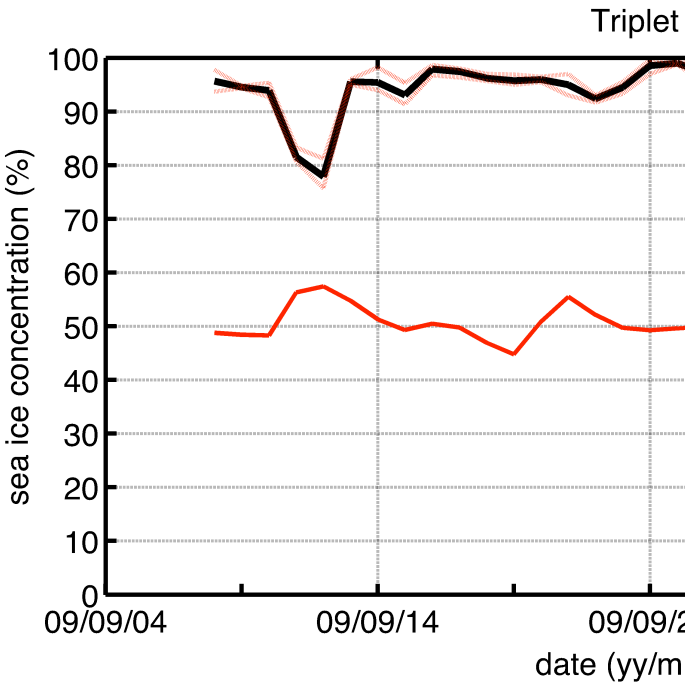
73°N
C2446

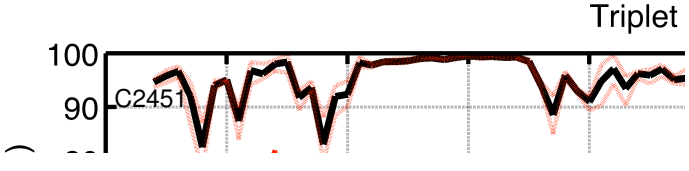

10^3
10^2
triangle area (km^2)
C2447

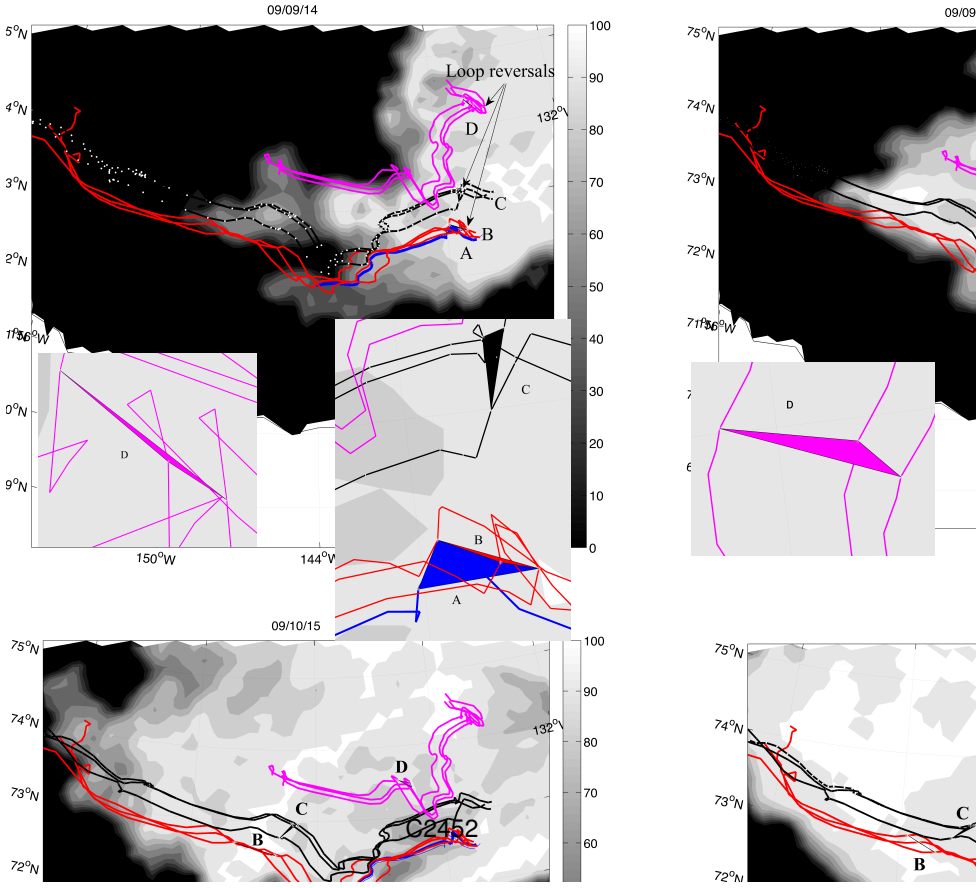

base and height (km)
$10^2$
$10^1$
$10^0$
C2448


aspect ratio
$10^2$
$10^1$
C2449


x 10^-5
4
3
2
1
0
-1
-2
-3
divergence/convergence (1/s)
C2450


Triplet
100
90
80
70
60
50
40
30
20
10
0
sea ice concentration (%)
09/09/04
09/09/14
09/09/2
date (yy/m


Triplet
100
90
C2451


09/09/14
Loop reversals
D
C
B
A
5°N
4°N
3°N
2°N
1°N
0°N
9°N
150°W
144°W
132°W
100
90
80
70
60
50
40
30
20
10
0
09/10/15
C2452
09/09
75°N
74°N
73°N
72°N