Reply to: Interactive comment on "Cyclone impact on sea ice in the central Arctic Ocean: a statistical study" by A. Kriegsmann and B. Brümmer, T. Vihma (Referee), Received and published: 8 June 2013

First, we thank the referee for the constructive and helpful comments. *Referee comments in Italics,* our answers in Roman.

In free-drift conditions (no ocean current and no internal resistance of the ice field) the deviation angle between the wind and ice drift vectors depends on the ice thickness. This is not mentioned anywhere, but it might explain some of the variations the authors found in the deviation angle. See also line 15 in Conclusions: the deviation angle does not depend on the cyclone intensity, because it is controlled by the ice thickness.
Now we mention, when discussing Figure 4 (top), the dependence of the deviation angle on the ice thickness. We added in the discussion of Figure 4 (top): 'The deviation angle varies only to a minor degree with the intensity of the cyclone, because cyclone intensity appears not to be systematically related to ice thickness, ice resistance, or ocean current.' Furthermore, we added in Section 4.3 on the regional differences, that the mean deviation angle within the cyclone radius varies with the region, that is with thickness and compactness: values around 28° are found in Sib and values around 35° in Can.

The authors do not pay enough attention on the effect of the ocean current on the wind factor (when the factor is simply calculated as a ratio of the ice drift speed and wind speed). The Transpolar Drift Stream (TDS) probably has a strong effect on the wind factor (Vihma et al., 2012). In particular, during the study period the wind was often aligned with TDS, which favours a large wind factor. In Conclusions (page 1157, lines 7-8) the authors state that the main reason for regional differences in the wind factor is differences in ice thickness. I think that the main reasons are related to the ocean current and ice concentration, the latter being important for the internal ice resistance.
In general, the TDS certainly plays an important role for the wind factor. But, in case of cyclones the wind stress is on the one side of the cyclone with, and on the other side of the cyclone against the TDS, because of their circular wind field. So accelerating and decelerating effects of the TDS are nearly in balance.
Furthermore, in Kriegsmann (2011) model experiments with an idealized cyclone passing through the Arctic were performed. Experiments with an ocean current, that reacts on the wind and ice compared to experiments where the ocean current is kept to zero suggest that the influence of the ocean current on the reduction of SIC is small. So, one might expect that the ocean currents influence on the ice drift under the impact of cyclone is small.
Ice concentration as further reason is added on page 1157, line 8.

The authors' reasoning on the linear dependence of the wind factor on wind speed is incorrect (page 1149, lines 6-12). In stationary free-drift conditions for very thin ice, the air-ice stress balances the ice-water stress and the wind factor simply depends on the square root of the ratio of air-ice and ice-water drag coefficients multiplied by densities (e.g. Vihma and Launiainen, 1993). With thicker ice (coriolis force involved), ocean current, and internal resistance of the ice field, the situation becomes more complicated, but certainly there is not any linear dependence of the wind factor on wind speed.
We thank the referee for hinting at this mistake. We have dropped this part of the discussion in the paper.

The manuscript is entitled "Cyclone impact on sea ice in the central Arctic Ocean: a statistical study", but the authors only address the dynamic impact of cyclones. Cyclones also have a strong thermodynamic impact on sea ice, as cyclones are responsible for a major part of advection of warm and moist air masses from lower latitudes to the Arctic. The authors should make it clear that cyclone impacts on sea ice are not restricted to the dynamic impacts addressed in this study.
We have added a remark in the Introduction, concerning the importance of cyclones with respect to temperature and moisture advection to the Arctic.

Both in the Abstract and Conclusions the authors state that the manuscript is the first statistical study on cyclone impacts on sea ice in the Arctic Ocean. This may be true, but it would be relevant to mention that an extensive statistical study on cyclone impacts on sea ice in the Antarctic has been carried out by Uotila et al. (2011).
We have decided not to refer to Uotila et al. (2011) at this place because in that paper the section about

ice concentration change due to cyclone impact is rather short and the ice concentration change is opposite to our results and the results of many other papers. The reasons for this differences are not clear to us and are not explained in that paper. We refer to Uotila et al. (2011) further down with regard to another aspect.

I am not sure if it is good to merge together results of cyclones of all scales, as the authors do when showing the figures with normalized cyclone radius. Uotila et al. (2011) showed that the interaction between cyclones and sea ice is different for small and large cyclones.
We have added a remark on Page 1150, Line 20. 'Our results indicate that the non-normalized cyclone radius may also be important for the cyclone impact as is reported in Uotila et al. (2011).'

To better understand how representative the results are, the study period of 2006- 2008 should be described with respect to large-scale circulation (AO, NAO, Arctic Dipole), cyclone activity, and sea ice conditions.
We have added a new paragraph at the end of section 3: 'The study period 2006–2008 contains the time (September 2007) when the so-far second lowest summer ice extent minimum occured. In terms of general circulation, North Atlantic Oscillation and Arctic Oscillation, this period was not particularly outstanding. (`http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Plot/index.html`). The cyclone frequency in the area north of 75°N during this period was on an almost constant level, in an otherwise increasing trend since 1958 (Haller, 2011). So, our results may be regarded to represent typical recent Arctic conditions.'

High-resolution fields of sea ice drift, based on satellite remote sensing, are available for recent years (see e.g. http://arctic-roos.org/observations). I am not sure if such products would have allowed as comprehensive study as the authors made, but this could be briefly discussed in the manuscript.
We added a comment on Page 1147: 'Satellite derived fields of daily mean ice-drift vectors with a horizontal resolution of 25 km or more appear to be not yet adequate for a study of cyclone impact which requires simultaneous fields of atmosphere and ice with high time and spatial resolution as applied in this paper.'

Minor comments *Page 1144, lines 10-13: the results of Screen et al. (2011) appear somewhat contradictory to the results presented in the previous paragraphs. Some more explanation would help a reader.*
The results of Screen et al. (2011) show that the fact that cyclones are related with clouds and, thus, less shortwave downwelling radiation appear to have also a significant effect.

Page 1145, line 13: make clear that you use ECMWF operational analyses instead of reanalysis. The choice is good.
We added operational.

Page 1145, line 15-16: in addition to precipitation, also the ECMWF wind stress is based on forecasts.
added

Page 1145, line 20: replace "next" by "nearest", I guess.
Done

Page 1146, line 2: two-dimensional field of sea level pressure
Done

Page 1150, lines 9-20: The text should be clarified. In two sentences the authors refer to a cyclone that approaches the place of detection. How can we speak about a cyclone approaching some place, if the cyclone is not yet detected?
If a cyclone and it's radius are detected we determine the time development in this fixed region from two days before to five days after the detection time.

When writing about the highest cyclone activity in summer in the study region, it would be good to mention that further south, around 70N, the highest cyclone activity occurs in winter (e.g. Sorteberg and Walsh, 2008), just to provide a more comprehensive picture of Arctic cyclones.
We added Sorteberg and Walsh (2008).

Page 1155, lines 3-4: I don't get this impression from Figure 13 (top panel).
We clarified this in the text.

Page 1156, line 9, and throught the manuscript: I suggest replacing "angle difference" by "deviation angle".
Done everwhere.

End of Conclusions: I fully agree on the importance of the individual storm in August 2012, but I am not convinced about the general importance of summer storms, as they are so rare (although summer cyclones are common). See e.g. Vihma et al. (2008; their Figure 2f) for the diurnal mean summer wind speeds observed at the Russian drifting stations, SHEBA, and Tara.
We think that the impact of summer storms is still an open question. Nevertheless, even if rare, their consequences are irreversible. A strong summer storm also occured in mid-August 2007 (see peak in Figure 2f in Vihma et al., 2008) which cause a step-like change of ice conditions lasting for several weeks (Haller et al., 2013)

References

M. Haller. *Arktische Zyklonen und Meereisdrift während der DAMOCLES-Bojenexperimente 2007–2010*. PhD thesis, Meteorologisches Institut, Universität Hamburg, 2011. 212 pp.

Arne Kriegsmann. *Einfluss von Zyklonen auf das Meereis in der zentralen Arktis: Modellstudien und Beobachtungen*. PhD thesis, Universität Hamburg, Von-Melle-Park 3, 20146 Hamburg, 2011. URL http://ediss.sub.uni-hamburg.de/volltexte/2011/5257.

Asgeir Sorteberg and John Walsh. Seasonal cyclone variability at 70N and its impact on moisture transport into the Arctic. *Tellus A*, 60(3), 2008. ISSN 1600-0870. URL http://www.tellusa.net/index.php/tellusa/article/view/15372.

P. Uotila, T. Vihma, A. B. Pezza, I. Simmonds, K. Keay, and A. H. Lynch. Relationships between antarctic cyclones and surface conditions as derived from high-resolution numerical weather prediction data. *Journal of Geophysical Research: Atmospheres*, 116(D7):n/a–n/a, 2011. ISSN 2156-2202. doi: 10.1029/2010JD015358. URL http://dx.doi.org/10.1029/2010JD015358.

Haller, M., Bruemmer, B., and Mueller, G.: Results from the DAMOCLES ice-buoy campaigns in the transpolar drift stream 2007–2009, submitted.