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ICE DRIFT SPEED IN THE FRAM STRAIT – A COMPARISON OF MEASURED AND CALCULATED ICE DRIFT SPEED

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ABSTRACT

The draft and velocity of the sea ice at three locations in the Fram Strait were observed in the period September 2012 to September 2013. The ice draft was recorded with using upward looking sonar (ULS) while both the current and the ice drift speed were recorded with an Acoustic Doppler Current Profiler (ADCP).

The present study compares recorded ice drift and approximated ice drift from a free ice drift model. The free ice drift model is required in order to estimate ice drift for ULS ice draft recordings in the Fram Strait from the period 2006-2011 that lack ADCP ice drift data. The consequence of lacking ADCP ice drift data is that the ULS data cannot be fully utilized for estimating several ice parameters that require information on drift velocity, e.g. ice ridge keel widths.

The free drift model only includes current and wind. The current at 40 m water depth was measured by the ADCP while wind speed from the NORA10 dataset was used. The free drift model is primarily valid for ice concentrations below 80% when there is no internal friction between ice floes.

Estimated drift and the observed drift are compared for two locations in the Fram Strait. The results suggest that the mean drift speed from the estimate is 10-17% greater than the mean observed drift speed. This translates to an error of 7-12% in the mean keel width. This difference may originate from the high ice concentration (>80% for 96% of the time) which means that internal friction between ice floes cannot be ignored like in a free drift model. A wind surface factor of 2.5% (equal to Ekeberg et al., 2014) was used. Using the method of least squares to derive a wind surface factor, results in a factor of 1.8% and 2% for the two locations, respectively. This improves the drift speed estimate and decreases the deviation in the mean drift speed from 10–17% to 2.8-3.5%. By applying these surface wind factors the mean keel width changes from being overestimated to being slightly underestimated.

INTRODUCTION

Upward looking sonars (ULS) are excellent tools for long term observations of the ice conditions in an area. By analysing ice draft obtained with a ULS, ice ridges and other ice features can be identified and quantified statistically in terms of frequency, geometry and shape. However, upward looking sonar only measures the ice draft directly above it at fixed time intervals. This means that the observed ice drafts are temporally referenced. To extract spatial data such as keel width and keel area, the ice drift speed must be known. In the Fram Strait, ULS data prior to 2011 did not include ice drift speed recordings and the ice drift had to be approximated by a free ice drift model (Ekeberg et al., 2014). To estimate the free ice drift the measured current and an estimated wind speed obtained from the ERA-Interim hindcast archive (Dee et al. 2011) was applied. ULS data from the deployment season 2012-2013 did include measurements of the ice drift speed. The present study attempts to quantify how well the free drift model matches ice drift in the Fram Strait.

METHOD AND DATA

Ice draft was observed with upward looking sonars (Ice Profiling Sonar, IPS) at two locations in the Fram Strait (see Figure 1 and Table 1). The moorings were deployed in 200 m water depth with a target ULS operating depth of 60 m. The ULSs were complemented by an ADCP (Acoustic Doppler Current Profiler) which recorded the current and ice velocity. The sampling rate of the ULS varied from 1/3 Hz to 1 Hz and the sonar footprint was about 2m. The ADCP recorded ice drift speed and current every 20 minutes. The ice drift speed was estimated using eq. 1 (see Leppäranta, 2011).

$$V_{ice,est} = |\beta \cdot \cos(\theta) \cdot \mathbf{V}_{wind} + \mathbf{V}_{current}| \qquad (1)$$

where β is the wind factor and θ is the deviation angle between the wind-driven ice drift and the wind direction. A representative surface wind factor (β) is 2.5% in the Arctic (Leppäranta, 2011) while θ typically is 30° in the Arctic.The observed current ($V_{current}$) at 40 m depth was used while Leppäranta (2011) suggests using geostrophic current. The wind speed is an estimate obtained from the hindcast archive Nora10 (Reistad et al. 2011). Nora10 is a refined version of the ERA-Interim data (a 0.1° resolution as opposed to 1.125°). The latter was used e.g. by Ekeberg et al. (2014).

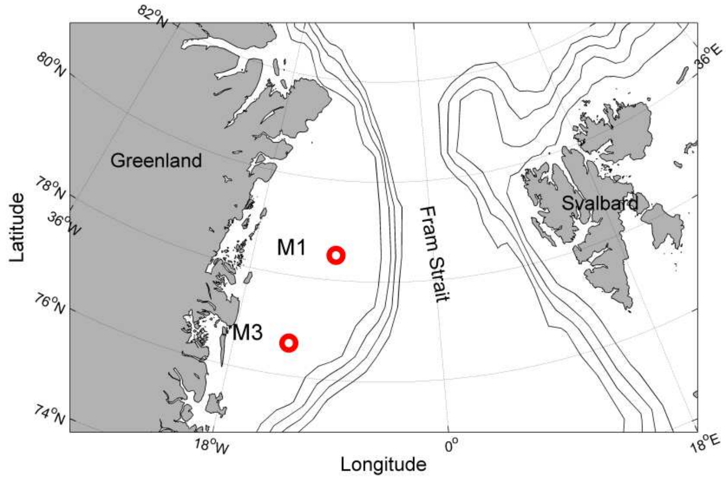

Figure 1. Location of the moorings used in the present study.

Table 1. Coordinates, operating depth and data coverage at each ULS location.

Mooring no.	Location	Operating period (Month-Year)	Operating depth of ULS (m)	Data coverage (%)
1	78°33'N, 9°46'W	09-2012 to 08-2013	58	85%
3	76°39'N, 13°17'W	09-2012 to 08-2013	67	81%

RESULTS

The free drift model predicts slightly greater mean and maximum drift speed at both locations (Table 2). The correlation between the estimated and the observed ice drift varies from 0.84 (mooring 3) to 0.88 (mooring 1).

Table 2. Observed and estimated ice drift speed normalized to the mean observed drift speed at each location.

Mooring No.	1			3		
	Mean	Std.dev.	Max	Mean	Std.dev.	Max
Observed drift speed (-)	1	0.61	3.9	1	0.61	4.0
Estimated drift speed (-)	1.17	0.67	4.1	1.1	0.63	4.1

A comparison of the drift speeds (excluding directions) reveals that there is a close match between the estimated drift speed and the observed drift speed (Figures 2 and 3). The figures also include the magnitude of the current and the wind and indicate that the greatest contribution originates from the wind speed (red line in Figures 2 and 3). The current component adds the faster fluctuations to the estimated drift speed.

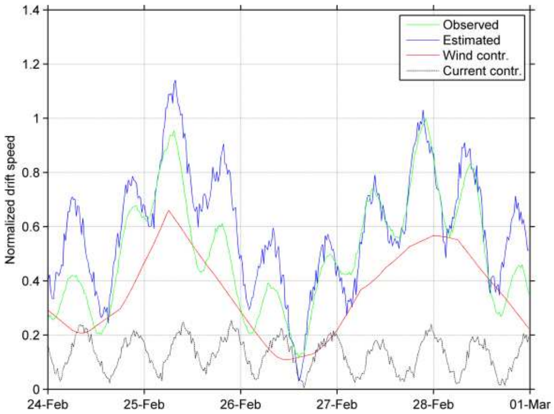

Figure 2. An example of the close match between the modelled drift speed and the observed drift speed.

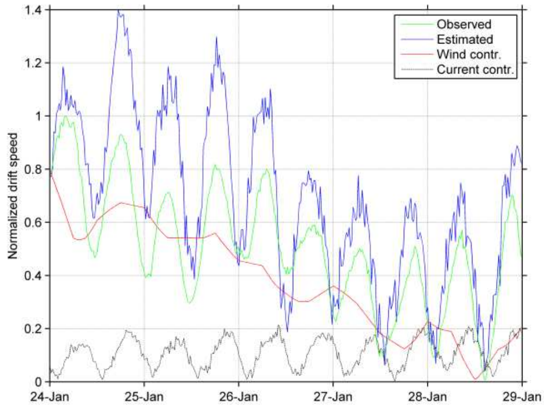

Figure 3. An example of the overestimated drift speed by the model. The fluctuations are replicated by the model.

Equation 2 is used to calculate the relative contribution from wind. The average wind contribution is 53%.

$$V_{wind,contr} = |\vec{V}_{wind}| / (|\vec{V}_{current}| + |\vec{V}_{wind}|) \qquad (2)$$

The contribution from the wind increases with estimated drift speed (Figure 4) and is above 50% for normalized drift speed greater than 30-40%.

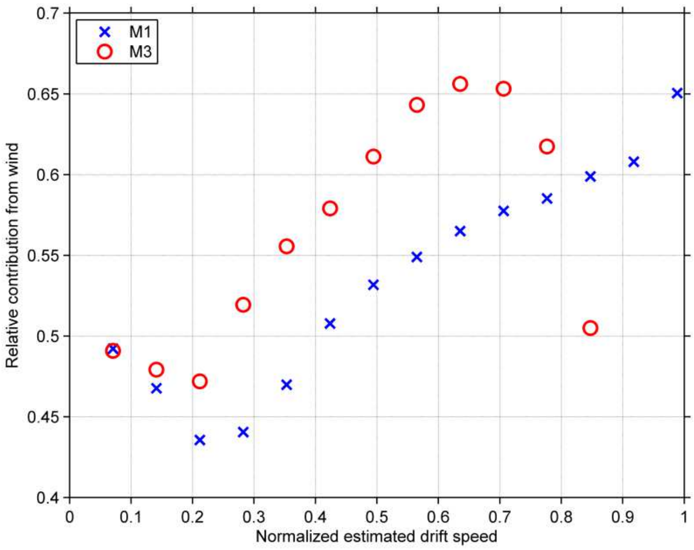

Figure 4. Relative contribution from wind speed plotted against estimated drift speed normalized to maximum observed drift speed.

Residuals

The deviation between the observed drift speed and the estimated drift speed (the residual) is calculated with eq. 3.

$$r = v_{ice,obs} - v_{ice,\mathrm{est}} \tag{3}$$

The estimated drift deviated less than ±0.1m/s in 85-90% of the cases (Table 3).

Table 3. The fraction of estimates the residuals is within the specified range. Square bracket "]" indicates that the value is included in the interval.

Residual (m/s)	(-0.2, -0.1]	(-0.1, 0]	(0, 0.1]	(0.1, 0.2]
M1	13%	61%	24%	1.6%
M3	6.6%	57%	33%	2.5%

Figure 5 shows the relative mean error plotted against normalized estimated drift speed where the normalization is done by dividing by the greatest observed drift speed. The relative mean error is found by dividing the mean error on the drift speed. This means that a relative mean error in the range ±0.2 suggests that the estimated drift speed on average is within ±20% of the observed drift speed. For the lowest drift speed the high relative error suggests that the observed drift speed is significantly lower than the estimated drift speed. This means that the width of any feature derived by the model estimate, on average, would be half the width or less than the reality (relative error >0.5). The ice drifted slower than 10% in 15-17% of the time (Figure 5). Figure 6 shows the relative mean error against the observed drift speed. At low observed drift speed the relative mean error is lower than -1 which suggests that the estimated drift speed on average is twice the observed drift speed. The observed drift speed is low for about 8% of the time at both locations.

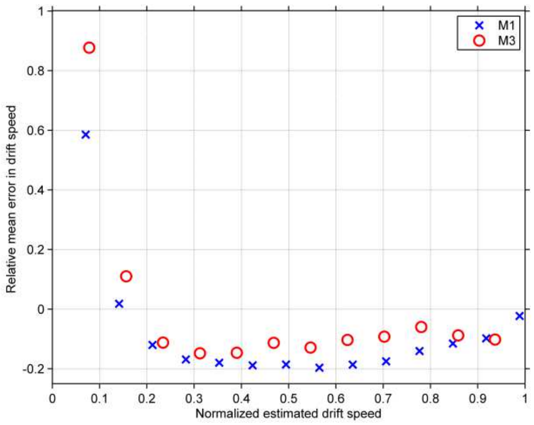

Figure 5. Relative mean error in drift speed vs normalised estimated drift speed.

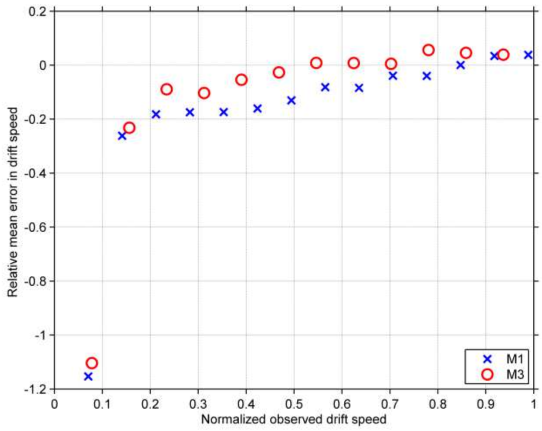

Figure 6. Relative mean error in drift speed vs normalised observed drift speed.

Drift direction

Figures 7 and 8 show that the drift direction is south-southwest most of the time and that the model replicates this very well. The results are similar for both locations. The model produces a slightly greater variation in direction compared to the observations. The wind is primarily in the south-southwest direction (Figure 9). In contrast to the drift speed, the wind direction is also clearly north-easterly for a portion of the time. The current is directed towards south-west (Figure 10).

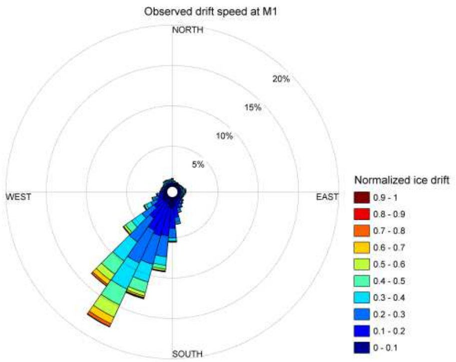

Figure 7.Wind rose of the observed drift speed at M1. All values are normalized to the maximum drift speed.

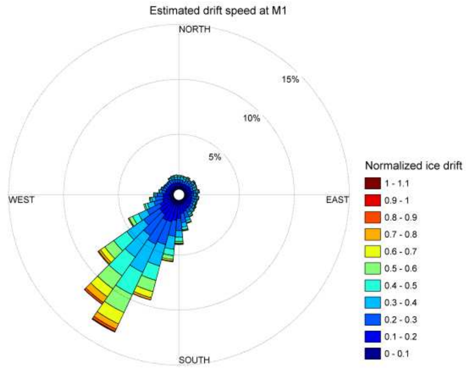

Figure 8. Wind rose of the estimated drift speed at M1. All values are normalized to the maximum observed drift speed.

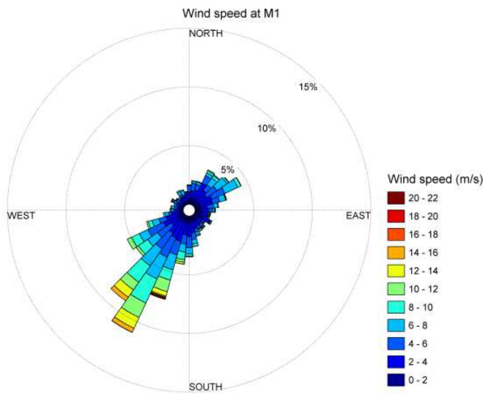

Figure 9. Wind rose of the wind speed from the NORA10 hindcast archive at M1.

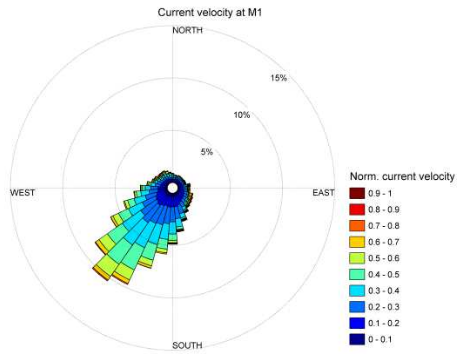

Figure 10. Normalized current velocity from 40 m depth at M1.

Ice concentration

The ice concentration is calculated as the number of records with ice draft thicker than 5cm (the accuracy of the IPS instruments, Melling et al., 1995) divided by the number of observations. The ice concentration is calculated over a fixed time interval (6, 30 and 60 minutes) and is greater than 80% in 96-98% of the time (Table *4*). This means that there are few observations at low ice concentration when the free drift estimate is applicable. At M1 the drift estimate at ice concentrations below 95% is significantly better. At M3 the mean residuals are within ±0.03 for all concentrations.

Table 4. Mean and standard deviation of the residuals per ice concentration.

	Ice conc.	Mean residual	Std. residual	Fraction
M1	0 - 0.8	0.003	0.1	0.09
	0.8 - 0.9	0.003	0.1	0.02
	0.9 - 0.95	-0.003	0.09	0.01
	0.95 - 1	-0.04	0.06	0.88
M3	0 - 0.8	0.02	0.07	0.05
	0.8 - 0.9	0.03	0.07	0.02
	0.9 - 0.95	0.02	0.07	0.01
	0.95 - 1	-0.02	0.06	0.92

Keel width statistics

One application of the drift speed estimate is to transform the ice draft data from temporally referenced data to spatially referenced data. Such transformation allows the derivation of keel width statistics. Ice ridges are identified using the Rayleigh criterion with a threshold value of 2.5m and a minimum draft of 5m (see e.g. Ekeberg et al. 2014). The mean keel width derived from the estimated drift speed is 7-12% greater compared to the observed mean keel width and the standard deviation is also slightly greater (Table 3).

Table 5. Keel width statistics normalized by dividing on the mean observed keel width.

Location	Based on observed drift velocity		Based on drift speed from model	
	Mean	Std	Mean	Std
M1	1	0.9	1.12	1.2
M3	1	0.9	1.07	1.1

To understand the error in the keel width it is useful to show the keel width ratio against the normalized observed drift speed (Figure 11). The keel width ratio is calculated by dividing the keel width based on the estimated drift speed ($w_{k,est}$) by the keel width based on the observed keel width ($w_{k,obs}$). Figure 11 illustrates that there is a significant error associated with low drift speed and the mean ratio becomes greater than 1.5 at observed drift speed lower than 10 % of the maximum observed.

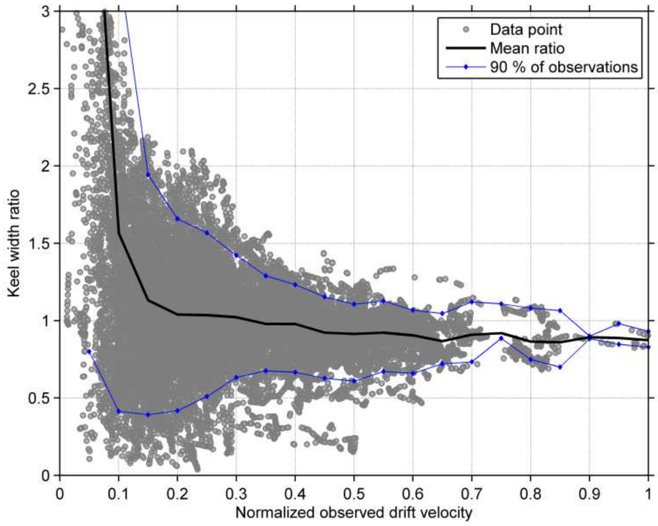

Figure 11. Keel width ratio at M3 plotted against the normalized drift velocity. The mean keel width ratio (black solid line) and the 5% and 95% empirical quantiles (blue lines with diamonds) are shown.

DISCUSSION

The free drift model performs well considering that the model and the surface wind factor is primarily valid for free floating, thin ice at low ice compaction. Leppäranta (2011) suggests that limit ice concentration is around 80%. For greater ice concentrations the contribution from the internal friction of ice should be included (Leppäranta, 2011).

The concentration is very high most of the time and the effect from low/high ice concentration is associated with lower confidence at low ice concentration. Table 4 indicates that the mean residuals are negative and a magnitude greater for ice concentration greater than 95%. A negative mean residual suggests that the drift model on average predicts to great drift speed. This is natural because the contribution from internal friction of ice decreases the inertial energy of the ice and thus reduces drift speed.

In the study area a great portion of the ice is ridged ice, thick first year ice and old ice. The investigations of keel widths, which represent periods with thick deformed ice, shows that the model performs well even in periods with deformed ice. The exception is in periods with low drift velocities where the drift model predicts too great drift speeds which also results in too great keel widths.

The surface wind factor of 2.5% suggested by Lepparänta (2011) is an empirically derived parameter and this study suggests that 2.5% could be an overestimate in this area. By using the method of least squares the best fit parameter at location M1 and M3 was 1.8% and 2% respectively. This surface wind factor gave a deviation in mean keel width of -2% and -5% and deviation of mean drift speed of +2.8% and +3.5%. Considering that the deviation in the mean drift speed is greater at M1 than M3 it is natural that the best fit wind factor is lower at this location compared to M3.

The difference of only 10 % for the predicted mean keel width (Table *5*) is considered a good result. The results of Ekeberg et al. (2014) are from the same area with the same surface wind factor as the current study. An error of about +10 % in the mean keel width is therefore expected. A lower wind surface factor may have increased the accuracy of the mean keel width. However, considering that the deviation in best fit surface wind factor is 0.2% between M1 and M3, the difference between the locations in this paper and the location studied by Ekeberg et al. (2014) (79°N, 6°30'W) might be of the same order of magnitude.

The current study considers an application where the relative error is important. Figure 5 and Figure *6* show clearly that the relative error is the greatest at low drift speeds (both observed and estimated). This does not mean that the drift model performs poorly at low drift speeds since a small error could lead to a great relative error. One way of increasing the precision of results as presented in e.g. Ekeberg et al. (2014) could be to discard all ridges with an estimated drift speed less than approximately 10% of maximum drift speed. Applying this approach to the current study, the error in mean keel width becomes +10% and +5% for location M1 and M3 respectively. This is an improvement compared to +12% and +7%.

The drift direction is a parameter which was left out of the comparison in the current study. However, the wind roses in Figures 7 and 8 suggest that the model and the observations are well aligned. As can be seen from the ice drift and wind directional distributions in Figures 7 to 10 there is both a dominating ice drift direction towards SSW and a dominating wind direction from NNE. Dominating current drift is also towards SSW. This is most likely favourable for the ability to estimate ice drift velocity since all driving forces are acting in the same direction. In regions with higher variability both in current directionality as well as wind directionality the interactions between wind, water and ice may be more complicated and thus reduce the ability to calculate ice drift.

The current drift speed model uses the NORA10 wind speed product while Ekeberg et al. (2014) use the ERA-Interim product from ECMWF. The NORA10 product is derived by downscaling the ECMWF reanalysis fields. In general, the NORA10 hindcast archive shows better agreement with wind measurements than the ERA-Interim fields, especially close to shore, where better resolution of topography is important. However, close to the boundaries (points M1 and M3 are located on the western edge of the NORA10 domain), the influence from the underlying ERA product is higher (Reistad et al, 2011), such that the difference between the two datasets is likely to be less pronounced here.

CONCLUSION

A free drift model, equal to that applied by Ekeberg et al. (2014), is used to estimate the sea ice drift at two locations in the Fram Strait. The drift estimate is then compared to the observed drift velocity in the same period. The comparison suggests that the mean drift speed from the estimate is 10-20% greater than the mean observed drift speed. This translates to an error of 7-12% in the mean keel width.

This difference may originate from the high ice concentration which means that internal friction between ice floes cannot be ignored like in a free drift model. An empirically derived wind surface factor of 1.8% and 2% is used for locations M1 and M3, respectively. This improves the drift speed estimate and decreases the deviation in the mean drift speed from 10-17% to 2.8-3.5% as compared to a wind surface factor of 2.5%, e.g. used in Ekeberg et al. (2014). By applying the new surface wind factors, the mean keel width changes from being overestimated to be slightly underestimated.

The observed direction of the sea ice drift is well replicated by the estimated drift. This is favoured by the fact that all driving forces are acting in the same direction. In regions with higher variability both in current directionality as well as wind directionality, the interactions between wind, water and ice could be more complex and as a result reduce the ability to calculate ice drift .

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