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Abstract

The present study is a part of the project "Iceberg on GPU" funded by Statoil, where the overall aim of the project is to take the first step to develop a new model system for iceberg trajectory forecast that is based on massive ensembles for ocean currents, iceberg geometry and different forcing factors. The aim of this report is to see if we can improve the forecast of iceberg trajectories by adjusting/assimilate the geometrical shape of the iceberg. In most cases when forecasting iceberg trajectories, the observed iceberg geometry is not available (for instance, we do not know the depth of the iceberg below the water surface, type of iceberg or the size). The iceberg model implemented at met.no and applied in this study, is the Canadian Hydraulics Centre (CHC) iceberg model (Kubat et al. (2005), Kubat et al. (2007)). The results using different iceberg geometry and forcing, are compared against observations on iceberg drift, obtained during the Ice Data Acquisition Program (IDAP) (Spring (1994)). We find that the modeled iceberg velocity is very sensitive to the different iceberg characteristics and the scaling of the wave drag and water drag. For the cases studied in this report, we find that by increasing the size of the iceberg, depth of the keel, decrease the wave drag and increase the water drag we achieves a more realistic velocity, and a smaller deviation between modeled and observed trajectories.

Keywords

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1 Introduction

The Barents Sea is part of the Arctic Ocean, located north of Norway and Russia. The Barents Sea is a region with large oil and gas reservoirs, and is therefore of great interest to oil companies. However, the exploration for petroleum in the Barents Sea is more challenging than in most other environment due to the hazard climate; furthermore, each year several icebergs are observed in this area. In order to ensure safe offshore operations it is important to take precautions against drifting icebergs. In some cases an iceberg is towered away if there is any risk of collision with offshore installations. These operations are expensive, and to minimize the cost it's important to be able to forecast the motion of the icebergs in the decision making processes. To support operations that are sensitive to icebergs, the Canadian Hydraulics Center (CHC) iceberg model (Kubat et al. (2005), Kubat et al. (2007)) was incorporated into the operational system at met.no in 2009 (Broström et al. (2009b)).

The drift of the icebergs depend on wind, waves, ocean currents and ice movements. The uncertainty in the drift trajectory of icebergs will depend on the quality of these conditions and how well they are forecasted. One of the main uncertainties in present iceberg modeling is the ocean current field. Traditional ocean model systems are able to reproduce the statistics of the currents, but they often fail to predict observed currents for a specific time and place. Another uncertaintie for iceberg drift trajectory forecasts, is the geometrical shape of the iceberg (i.e., type of iceberg, and the horizontal and vertical shape) and how it respond to forcing. The results presented in this report is part of the project "Iceberg on GPU" funded by Statoil, where the overall aim is to take the first step to develop a new model system for iceberg trajectory forecast that is based on massive ensembles for ocean currents, and iceberg geometry and different forcing factors. The primary objectives is to (i) design and implement a prototype of a simplified ocean model system for the upper ocean currents on a heterogeneous computing platform (presented in another report by SINTEF), and (ii) study the sensitivity of the iceberg model system at met.no due to different types of iceberg shapes and sizes, where the main question is: "can we improve the forecast of iceberg trajectories by adjusting/assimilate the geometrical shape of the iceberg?". The results are compared against observations on iceberg drift, obtained during the Ice Data Acquisition Program (IDAP) (Spring (1994)), and presented in this report.

The report is organized as follows. In section 2 and 3 the background and iceberg model is described. Section 4 gives an introduction of the data and methods applied. In section 5 we go through the results and in section 6 we have the summary and conclusions.

2 Background

The icebergs in the Barents Sea mainly come from the Franz Josef Land, Svalbard, and Novaja Semlja (Spring (1994), Dowdeswell (2008)). Fig.1 shows the Barents Sea area and the most important glaciers for iceberg production. The cold currents moving westward from Franz Josef Land and southwestward from eastern Svalbard are the most important current systems for bringing icebergs to the western part of the Barents Sea during spring, as shown in Fig.1. Most data of icebergs are from spring and summer, with a minimum in October.

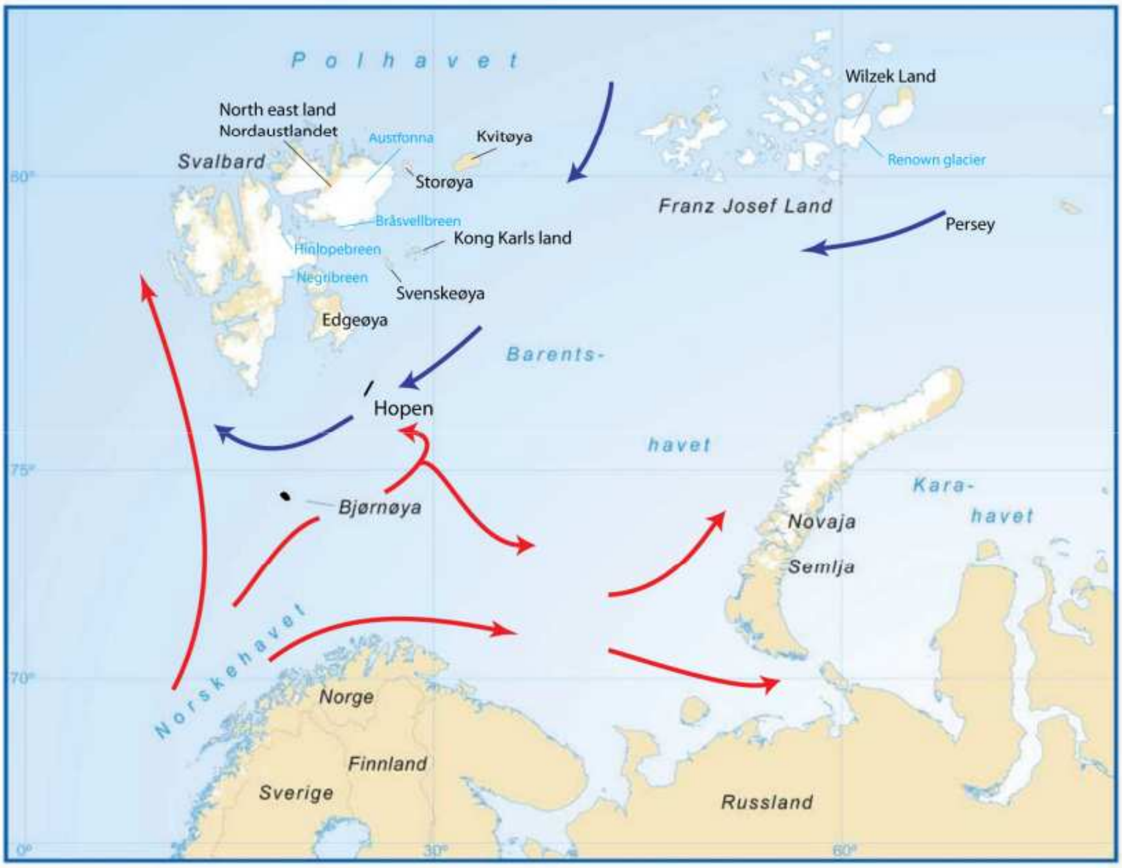

Figure 1: Map of the Barents Sea area, showing the glaciers important for iceberg production. Source: Brostøm et al. 2009

The Barents Sea is a shallow area with a maximum depth of 500m. In some very shallow areas characterized by strong tides like north of Bjørnøya and around Hopen, several icebergs are grounded. Observations shows that icebergs can be stuck in this area for months (Spring (1994)).

The two basic types of iceberg that forms in the Barents Sea, are tabular and non-tabular. **Tabular (T)** icebergs have steep sides and a flat top, much like a plateau, with a length-to-height ratio of more than 5:1. Another tabular iceberg, is the **tilted tabular (TT)**. As the name implies, a tilted tabular iceberg have a top flat surface, but it is not parallel to the ocean or sea ice surface. The tilted tabular iceberg are probably tabular icebergs that have grounded for some time and become tilted due to inhomogeneous melting. Non-tabular icebergs have different shapes, and include:

Weathered (W): An iceberg which is irregular in shape, due to an advanced stage of ablation.

Pinnacle (P) : This iceberg has a pyramid shaped keel with one or more spires.

Blocky (B) : An iceberg with steep, vertical sides and a flat top. It differs from tabular icebergs in that its shape is more like a block than a flat sheet.

The IDAP study for the years 1988 to 1992, shows that the iceberg shapes in the Barents Sea differ from year to year. However for the entire data set, tabular and tilted tabular shaped icebergs are the predominant shapes, while pinnacle-shaped icebergs are the second most common shape, followed by blocky and the the weathered icebergs. The iceberg height data from the IDAP study, shows a minimum iceberg height of 4.5m, maximum height of 40m and an average height of 15m. The iceberg length data shows a minimum value of 26m, a maximum value of 319m and an average value of 91m. For pinnacle, blocky and weathered icebergs, it seems true that larger icebergs are higher (and probably deeper) than smaller icebergs. For tabular icebergs there is no clear relation between characteristic size of the iceberg and the iceberg height (Broström et al. (2009b)).

3 Iceberg Model

The Canadian Hydraulics Centre (CHC) iceberg model (Kubat et al. (2005), Kubat et al. (2007)), was implemented in the the Norwegian Meteorological Institute (met.no) operational system in 2009. A validation of the system is presented in (Broström et al. (2009b)). Further documentation of the iceberg model code is described in (Sayed (2008)). The iceberg model was originally designed for pinnacle iceberg at Grand Banks, while tabular iceberg geometry have been added to the model as an option. Therefore, the iceberg classes studied in this report are tabular and pinnacle. The form of pinnacle icebergs are based on a self-similar form, such that a large horizontal size also implies a higher iceberg (and probably a deeper iceberg). The sail and keel are therefore given as a predescribed function of iceberg length. The sail area, A_a for pinnacle icebergs, is given as

$$A_A = a_0 L + b_0, \tag{1}$$

where L is the iceberg length, and $a_0 = 28.194$ m, $b_0 = -1420.2m^2$ are empirical constants (Barker et al. (2004), Kubat et al. (2005)). For iceberg length smaller than 50 m, the sail area is set to zero. The area beneath the water surface (the keel), A_w, is in a similar way given as

$$A_w(k) = a_k L + b_k, \tag{2}$$

where a_k and b_k are empirical constant given at every 10m interval in the deep (Barker et al. (2004), Kubat et al. (2005)). For tabular iceberg there is no clear relation between size of the iceberg and iceberg height. In the original model code, the keel and sail are set to 70m and 7m respectively for all iceberg lengths.

Icebergs are mainly transported by ocean currents, but wave stresses is also an important factor. The size of the wave stress depends on the shape and the size of the iceberg and how it is oriented with the wind. For a big blocky iceberg, we will typically expect a larger wave drag than on a pinnacle iceberg with a smaller surface. For water drag, the force on the iceberg depends on the size of the keel. In this study we only have observations of iceberg tracks, and not the shape or size of the iceberg. Since the geometrical shape of the iceberg is often unknown, some changes has been implemented in the model code:

- A scaling factor for both wave drag and water drag has been implemented in the model and can be read from a input file together with the iceberg length, iceberg type, keel depth and sail height.

The drift of the icebergs depend on wind, waves, ocean currents and ice movements. For the present study we are most interested in the period August 1987 to August 1988, and the data we use to force the model are described below, taken from Broström et al. (2009b).

- The atmospheric hindcast run that we force the iceberg model with, was based on the ERA40 model data and was downscaled at met.no using HIRLAM-5 model (Undén et al. (2002)).

- The wave model is based on the WAM model (Komen et al. (1994)), which predicts the wave energy in different directions for various frequency intervals. The wave model is forced with the met.no reanalysis described above.

- To create hydrography and currents for the year of 1988, Broström et al. (2009b) used a coupled numerical ocean-ice model, i.e., the MIPOM MI-IM code (Engedahl (1995), Røed et al. (2004)). The coupled ocean-ice model covers the Barents Sea region and part of the Nordic Seas, with a 4km horizontal resolution. The atmospheric forcing fields for the ocean model were taken from the ECMWF ERA-40 reanalysis. Tidal forcing included eight harmonic constituents (M2, S2, N2, K2, Q1, O1 and K1) gathered from barotropic tidal models (Flather (1981), Gjevik et al. (1990)). In addition, sea surface temperature (from ERA-40) and merged ice concentration fields (a combination of data from the ice service of the Norwegian Meteorological Institute and the ERA40 data-set) were assimilated by a nudging scheme (Albretsen et al. (2006)).

A validation of the ocean model used to force the icebergs is presented in Broström et al. (2009a) and Broström et al. (2009b). Due to the large uncertainties in the bottom topography on the fine scale and the actual size of the iceberg, grounding in the model is uncertain, and we have removed grounding of icebergs in the model.

4 Data and Methods

4.1 The IDAP study

Observation on iceberg drift used in this study was obtained during the Ice Data Acquisition Program (IDAP) (Spring (1994)). The IDAP activities, started in 1988 and continued through 1992 to obtain information on the sea ice and icebergs present in the Barents Sea. To monitor iceberg drift and to develop velocity statistics, ARGOS buoys were deployed on icebergs. Fig.2 shows the drift of some of the iceberg during 1988 and 1989, named Argos buoy 3105, 3106, 3108 and 8895. Iceberg 3105, traveled in a loop from 20 March to 19 May 1988, with a short grounding in the period March 20 to April 17 1988. Since iceberg 3105 has the best data coverage, most of the examples in this work will be based on the 3105 iceberg.
The available observations from the IDAP study gives information on the iceberg tracks for

every hour. However, information about the icebergs length, sail- and keel height for the different tracks are unknown.

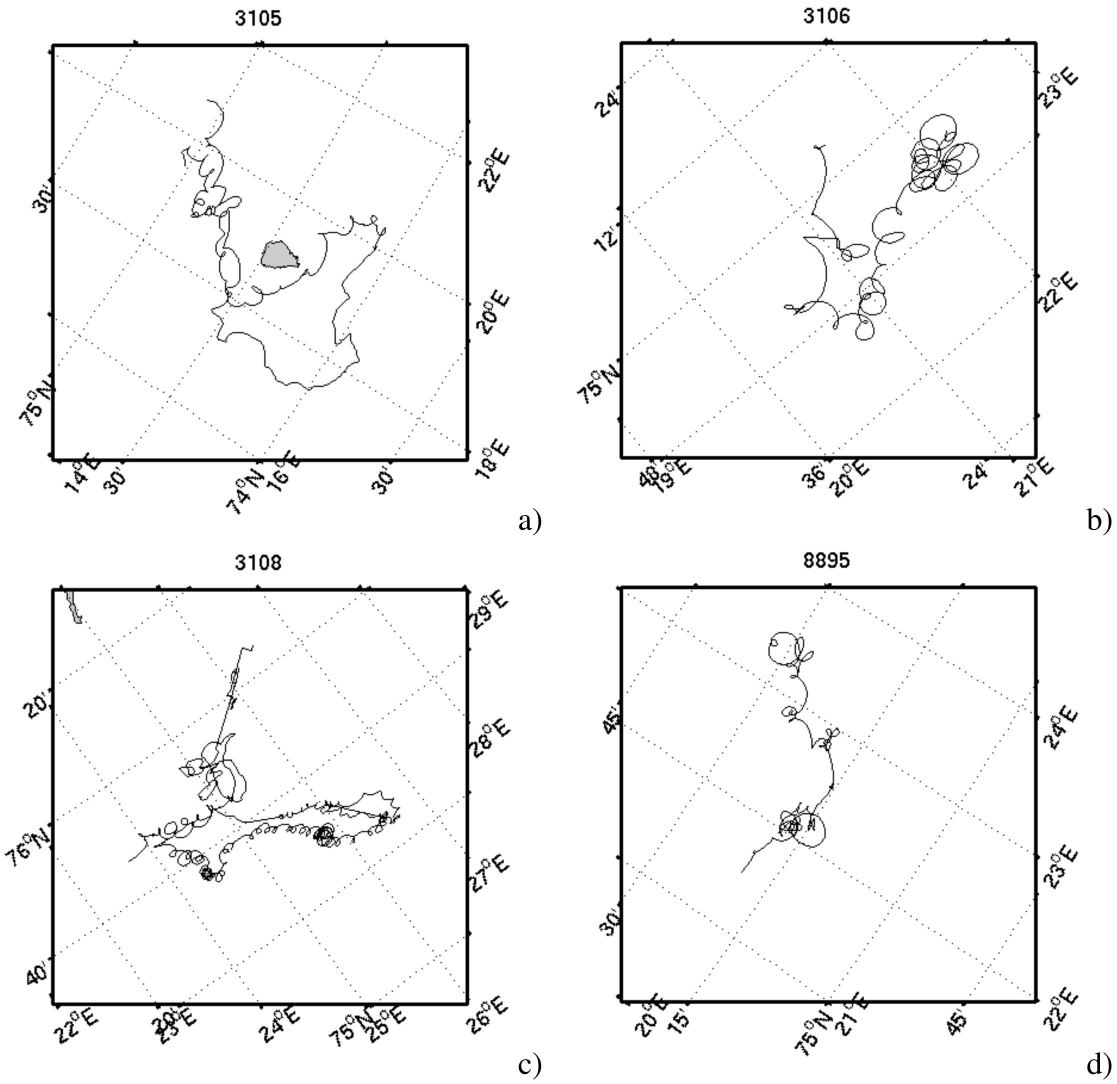

Figure 2: ARGOS buoy tracks for iceberg 3105, 3106, 3108 and 8895. The island shown in panel a) is Bear Island.

4.2 Iceberg simulations

In this study, the aim is to see how sensitive the met.no iceberg model is to different changes in the geometrical shape of the icebergs and forcing, and the main question is: can we improve the iceberg forecast by adjusting/assimilate the icebergs characteristics? The iceberg trajectories from the model are released at observed positions taken from the IDAP database. Each study contains three experiments released at midnight one day apart. For each release, a three day hindcast is simulated. The different changes applied in this study are:

- Simulations with different iceberg lengths.
- For tabular icebergs, different sail and keel heights are used in the simulations.
- Different scaling factors are applied for the wave drag and water drag.

To determine the deviation between the different simulations and observations, the distance between the modeled tracks and the observed tracks are defined as:

$$\Delta L(t) = \sqrt{[(lon_m(t) - lon_{obs}(t))^2 \cos^2(lat_{obs}(t))] + [(lat_m(t) - lat_{obs}(t))^2]} \cdot G \quad (3)$$

where t is the time after the release of the iceberg, (lon_m,lat_m) and (lon_{obs},lat_{obs}) are the modeled and observed longitude and latitude positions of the icebergs, respectively.
$G = \frac{4 \cdot 10^4}{2\pi} [\frac{km}{degree}]$ is a geometrical factor for converting results in spherical coordinates to km.

5 Results

In Fig.3, Fig.5, Fig.7 and Fig.9, trajectories of modeled and observed icebergs are shown. In this study, 58 cases has been simulated for each experiment suite based on iceberg 3105, 3106, 3108 and 8895 from the IDAP study as shown in Fig.2. Each model run is a three day hindcast (72h). Each figure show three experiments released at midnight one day apart (+24h), and the observed tracks are shown for five days. The release position is taken from the IDAP study, and the examples shown below are from 12 cases based on iceberg 3105. Since grounding is removed from the iceberg model, we only study periods where the observed icebergs are not grounded.

5.1 Experiments with different iceberg type and geometry

Fig.3 shows iceberg trajectories with different shapes and iceberg lengths for the period April 18 to May 9 1988. The different shapes are pinnacle and tabular, and the iceberg lengths used in these experiments are 50m, 100m and 150m. Fig.3a to Fig.3d show results for pinnacle shaped icebergs and Fig.3e to Fig.3f show results for tabular shaped icebergs. Pinnacle shaped icebergs display more spreading between the tracks of different iceberg lengths than tabular shaped icebergs. This is due to the description of pinnacle and tabular icebergs in the iceberg model. For a pinnacle iceberg, sail and keel is given as a function of the iceberg length, which means that a large iceberg gives a higher sail and deeper keel. On the other hand, for a tabular iceberg the sail and keel is set to 7m and 70m respectively for all iceberg lengths. Therefore, if we increase or decrease the length of the iceberg, it will not effect the height or depth. Adjusting the length of a tabular iceberg will only change the mass. However, this seems to have minor effects on the drift of the icebergs as seen in Fig.3e and Fig.3f.
In Fig.3a and Fig.3c, all iceberg tracks have a good direction compared to the observed tracks.

However in Fig.3c and Fig.3d, the main direction of the tracks are not so well described. Nevertheless, by increasing the length from 50m to 150m, the modeled icebergs moves more to the right of the main direction in nearly all experiments, which better describes the observed tracks. However, we can not change the main direction of the iceberg by changing the characteristics. We can achieve some minor corrections of up to 10 - 20 %. To get a more accurate iceberg track, the forecast of wind, wave, currents and iceberg movements have to be adjusted if the main problem is inaccuracies in any of these forces (where the most likely source of error, is inaccuracies in the ocean currents).

In all experiments, we observe that the modeled icebergs have a higher velocity than observed, especially the smallest iceberg with a length of 50m. By increasing the size of the iceberg, the speed decreases and we get a more realistic velocity. Fig.4 show deviation plots for all releases performed in Fig.3a to Fig.3d for pinnacle icebergs. In nearly all cases the iceberg with a length of 150m (green curve) has the smallest deviation from observation for all hindcast hours, while the 50m long iceberg has the highest deviation. This is mainly due to the decrease in the drift velocity when the iceberg size is increased, giving a more realistic speed.

In Fig.5 we have changed the keel depth and sail height for tabular icebergs based on experiment 3105 from April 18 to May 9 1988. Each iceberg has an iceberg length of 100m, with keel and sail height of 60m and 12m, 100m and 20m respectively together with the default value 70m and 7m. By changing the keel and sail for tabular we get more spread between the different experiments, compared to the cases where we only changed the length of the iceberg. Furthermore, the iceberg with the deepest keel (100m) achieves the most realistic velocity and moves more to the right of the main direction of the modeled iceberg (which is more in agreement with the observations). This is the same results as we achieved by increasing the size of a pinnacle iceberg.

For simplicity, we have chosen to focus on only 12 cases based on iceberg 3105, even though we have simulated 58 cases for each experiment with different iceberg lengths, keel and sail height based on iceberg 3105, 3106, 3108 and 8895 as shown in Fig.2. To establish a better understanding of the model performance for different iceberg characteristics, we have to consider all simulations. In Fig.11a and Fig.11b the mean model-observation deviation from all experiments with different lengths and keel/sail height are plotted. Overall, the deepest/highest icebergs (green curves) describes the observed tracks somewhat better than the small icebergs, which indicates that we can adjust/assimilate the iceberg geometry from observations to produce a better forecast. Table1 show the number of cases (N) where the longest (150m) and the deepest (100m) iceberg have the smallest deviation from the observed tracks after hindcast hour +24, +48 and +72, for a total of 58 cases. The percentage is calculated as follows $\frac{N \cdot 100\%}{58}$, and is evaluated separately for each experiment suite. The table show that a pinnacle iceberg with a length of 150m achvies the smallest model-observation deviation in 90% of the cases with different iceberg length after a 24 hour hindcast, and in 84% of the cases after a 72h hindcast. For a tabular iceberg with a keel depth of 100m and a sail height of 20m, the table show that these simulation has the smallest model-observation deviation in 96% of all runs with different keel and sail height after a 24h hindcast, and in 88% of the cases after a 72h hindcast. The main reason for this, is that the velocity of the iceberg becomes more realistic when we increases the keel depth.

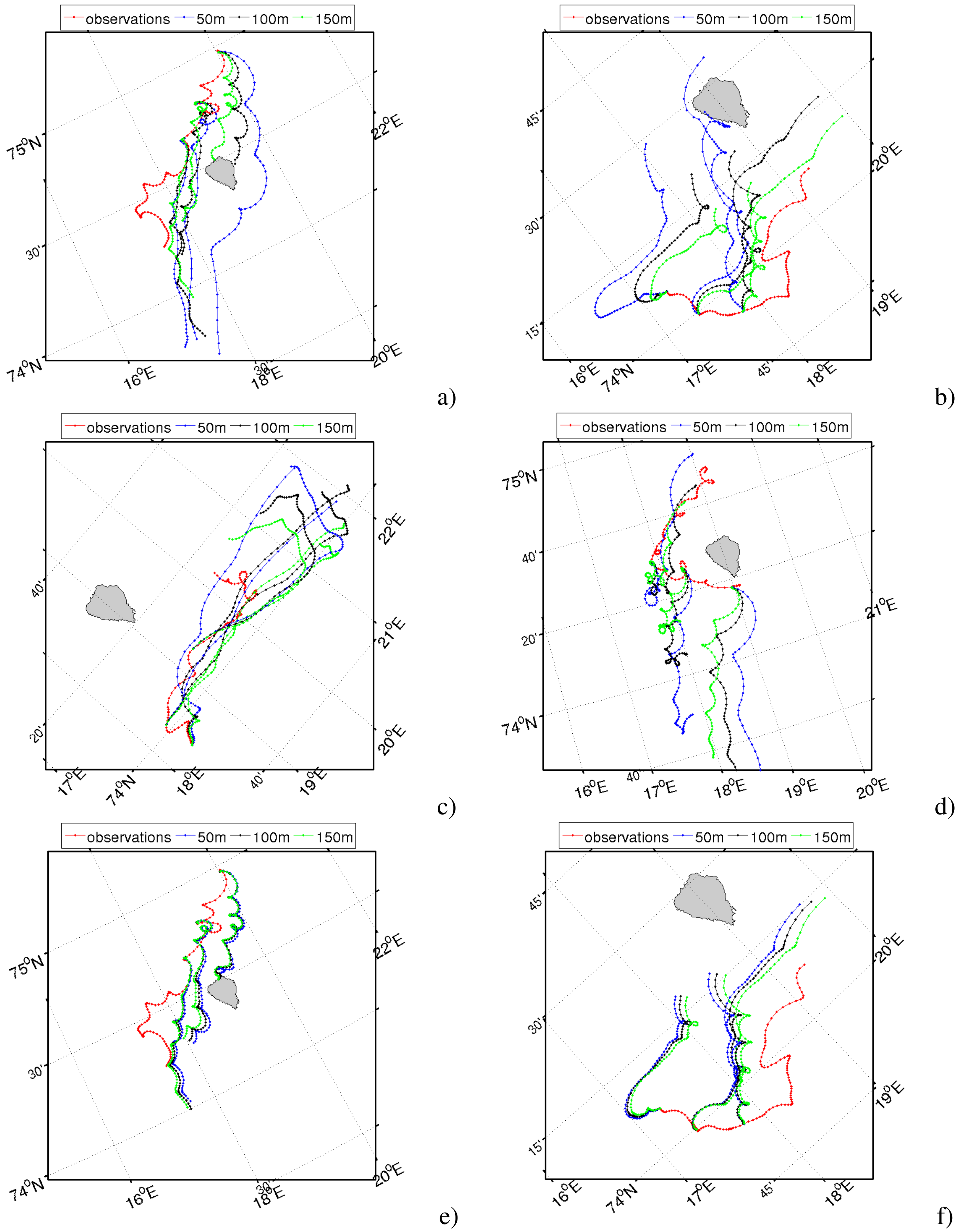

Figure 3: Iceberg trajectories of icebergs with different length for the period April 18 to April 23 1988. The red trajectories are observed data while the other tracks are from model runs. Each run is starting at midnight and runs for 72h. The different iceberg lengths are: blue: 50m, black: 100m, green: 150m. Panels a) to d), show results for pinnacle shaped icebergs, panels e) to f) show results for tabular icebergs.

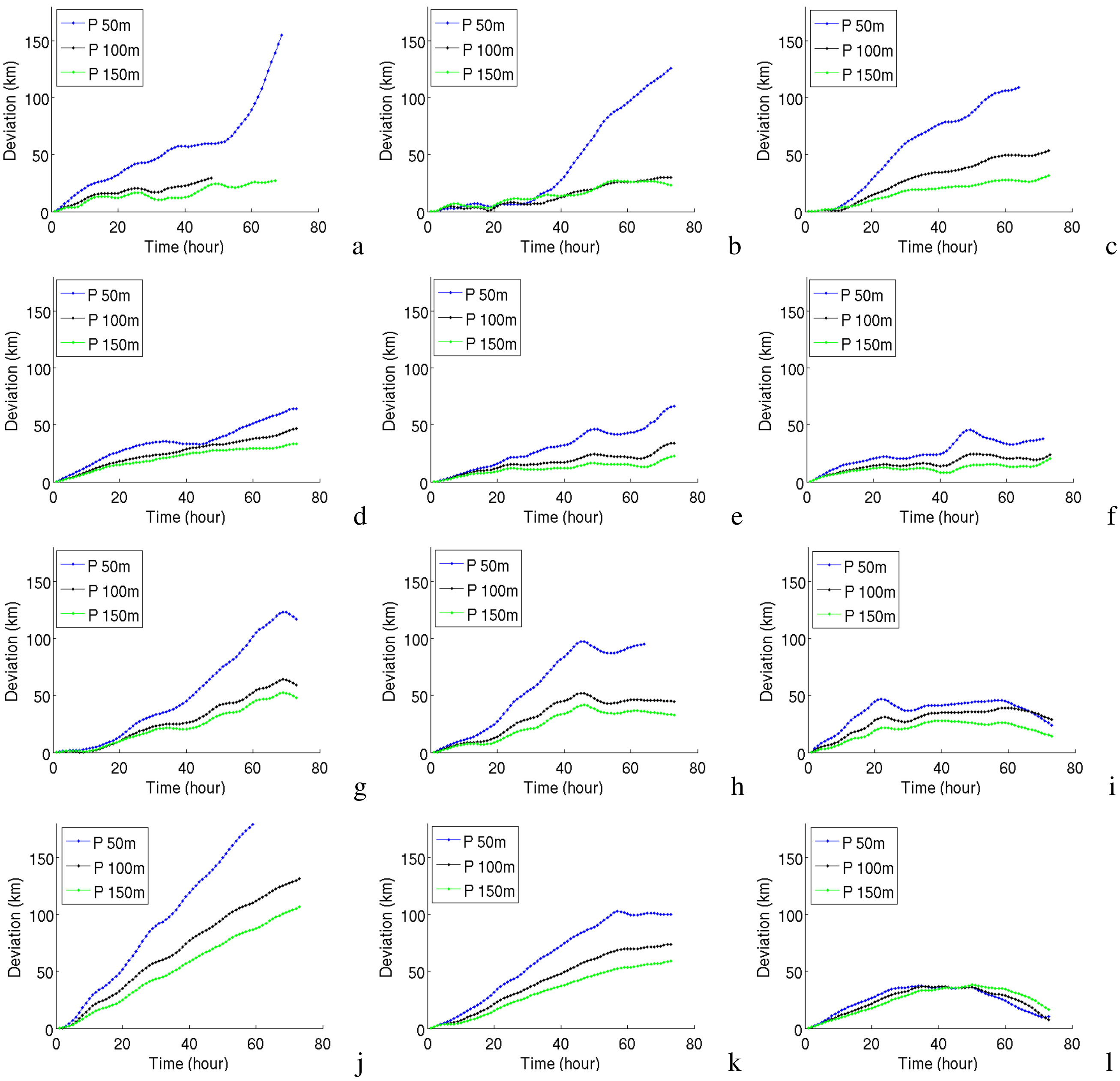

Figure 4: Plots of the deviation between modeled and observed positions for a three day hindcast for a pinnacle iceberg with length 50m(blue), 100m(black) and 150m(green). Panel a): release date: April,18 00UTC, b): release date: April,19 00UTC and c): release date: April,20 00 UTC, d): release date: April,24 00UTC, e): release date: April,25 00UTC and f): release date: April,26 00 UTC, g): release date: April,27 00UTC, h): release date: April,28 00UTC and i): release date: April,29 00 UTC, j): release date: May,4 00UTC, k): release date: May,5 00UTC and l): release date: May,6 00 UTC. It is interesting to note that the largest iceberg (green) is the ”best” iceberg in almost all simulations.

5.2 Experiments with different wave and water drag

In any risk analysis its important to know how quickly the iceberg will move (i.e. how quick can they reach the plattform). We observe that the velocity of the modeled iceberg is too high in nearly all 58 cases preformed in this study. The difference in magnitude between the observed and modeled velocity changes from case to case.
Since the icebergs in the model moves too far, we have simulated experiments with weaker wave drag and stronger water drag. Fig.7 shows 12 different experiments with weaker wave drag for iceberg 3105 for the period April 18 to May 9 1988. For most of the cases based

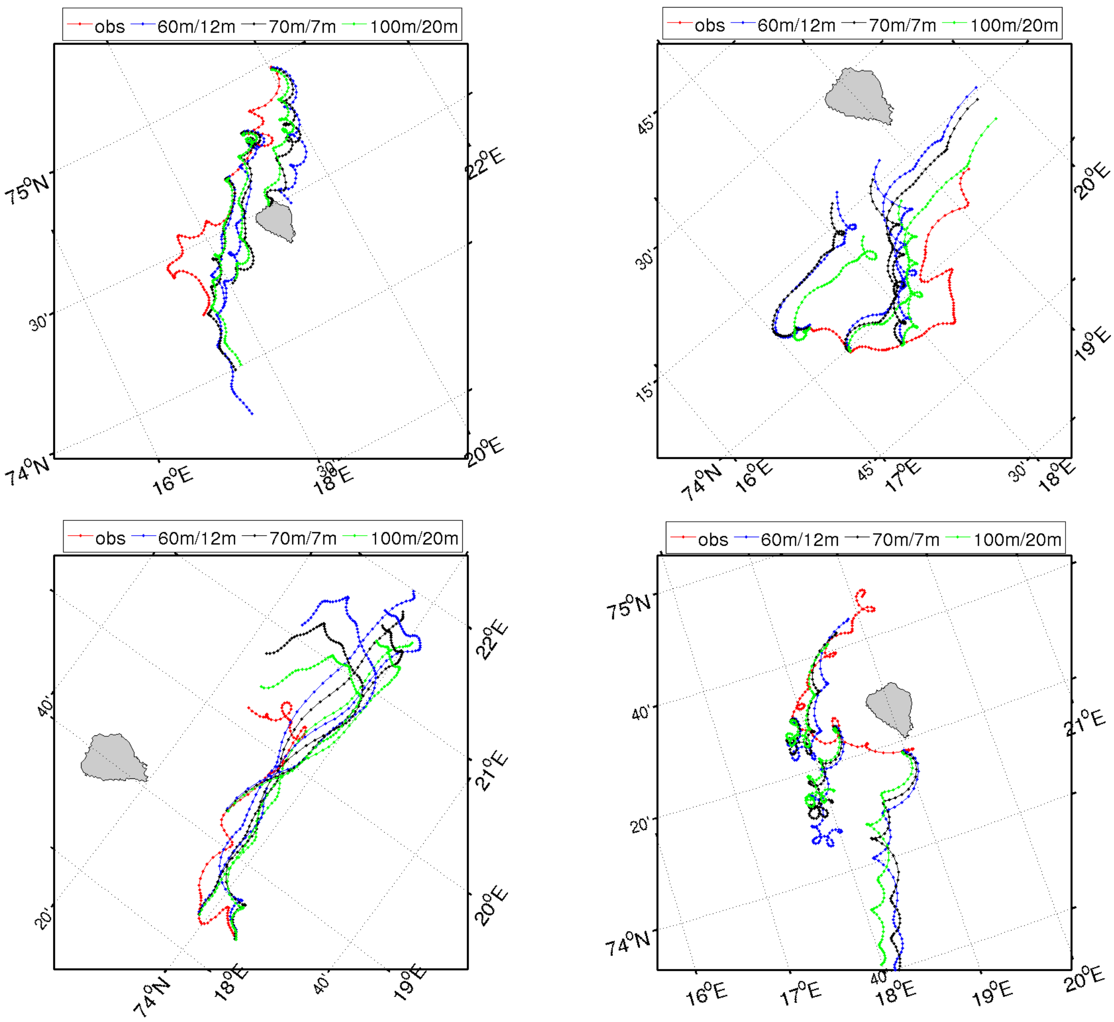

Figure 5: Iceberg trajectories of different tabular icebergs for the period April 18 to April 23 1988. The red trajectories are observed data while the other tracks are from model runs of a tabular iceberg with different keel and sail height. Each run is starting at midnight and runs for 72h. The different keel and sail heights are: blue: 60m/12m, black: 70m/7m, green: 100m/20m.

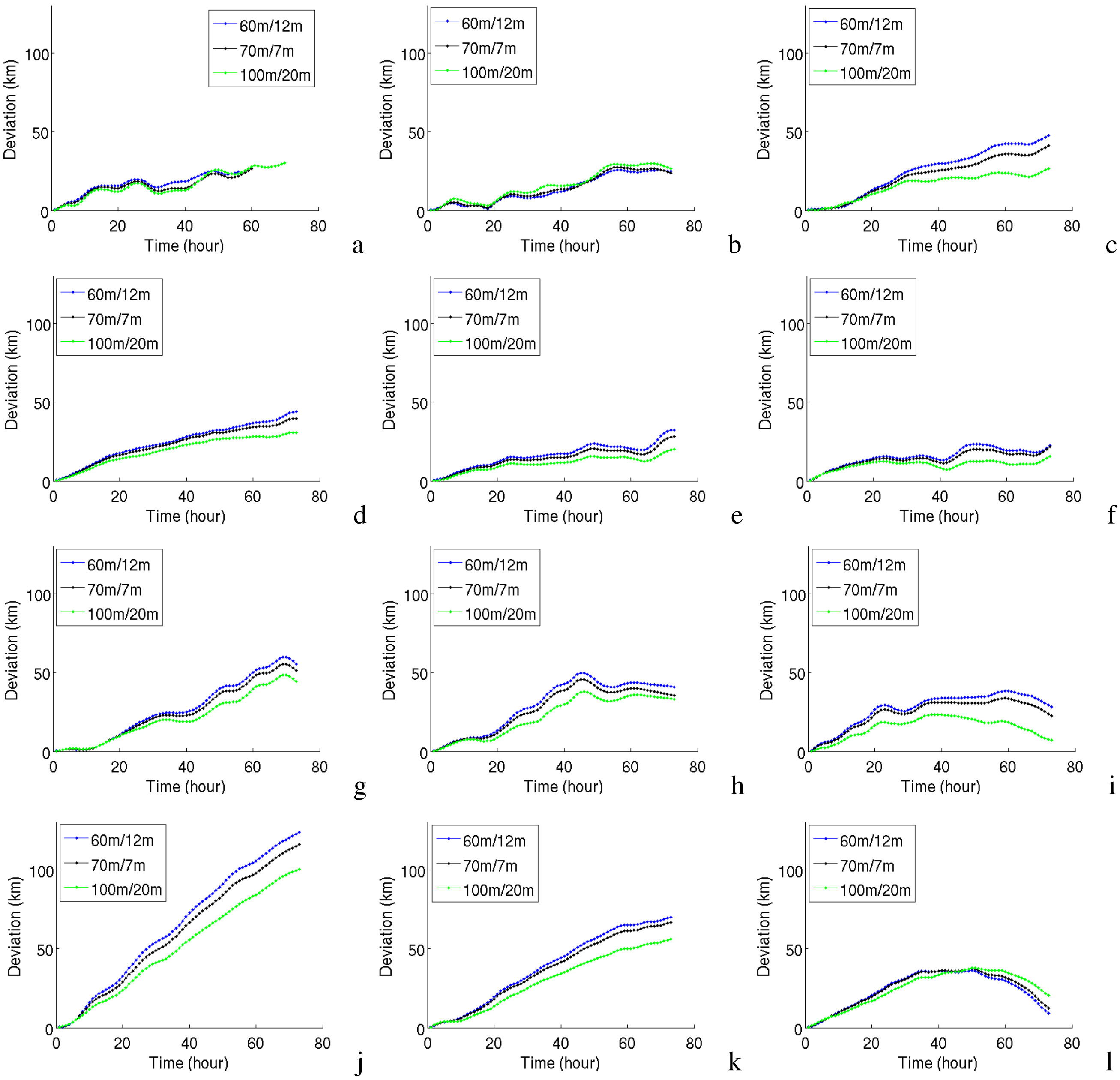

Figure 6: Plots of the deviation between modeled and observed positions for a three day hindcast for a tabular iceberg with keel and sail heights of 60m/12m (blue), 70m/7m (black) and 100m/20m (green). Panel a): release date: April,18 00UTC, b): release date: April,19 00UTC and c): release date: April,20 00 UTC, d): release date: April,24 00UTC, e): release date: April,25 00UTC and f): release date: April,26 00 UTC, g): release date: April,27 00UTC, h): release date: April,28 00UTC and i): release date: April,29 00 UTC, j): release date: May,4 00UTC, k): release date: May,5 00UTC and l): release date: May,6 00 UTC. It is interesting to note that the iceberg with the deepest keel and highest sail (green) in the ”best” iceberg in almost all simulations.

on iceberg 3105 the wind is relative strong. The figures are showing results for a 100m long pinnacle iceberg. The scaling of the wave drag that are used are 0.7 and 0.5 together with the default value of the wave drag. In these experiments, a weaker wave radiation stress leads to a smaller velocity. This effect will be more apparent in situations with strong wind speed where the wave forcing and wind forcing are the dominant forcing factors. For situations with weaker wind, the effect of the scaling will be smaller. Fig.8 shows deviation plots for all experiments in Fig.7. In nearly all cases the iceberg with weaker wave radiation stress (green curve) has the smallest deviation from observation, while the strongest radiation stress (the default value) has the highest deviation. This is mainly due to the decrease in velocity of the iceberg giving a more realistic iceberg movement as we have seen in earlier experiments.
Fig.9 are showing three experiments with stronger water drag for a 100m long pinnacle iceberg. The scaling of the water drag that are used are 1.4 and 1.8 together with the default value of the water drag. Since the ocean currents is not only providing a mechanism to force the iceberg, but also provide a drag, an increase in the water drag will slow down the iceberg when other forces try to accelerate the movement. In situations with strong wind fields, the scaling of the water drag will have a bigger effect than in calm situations. Fig.10 shows deviation plots for all experiments in Fig.9. In almost all cases the iceberg with the strongest water drag (green curve) has the smallest deviation from observation, while the weakest water drag (the default value) gives the highest deviation. Fig.11c and Fig.11d shows the mean model-observation deviation from all 58 experiments preformed in this study with different scaling values of the wave drag and water drag. We can see that a weaker wave drag and a stronger water drag gives the smallest deviations to the observed tracks in most situations. In table1 we can see that a pinnacle iceberg with a wave drag of 0.5, achvies the smallest model-observation deviation in 86% of the cases with different scaling of the wave drag after a 24 hour hindcast, and in 79% of the cases after a 72h hindcast. For a pinnacle iceberg with an increased water drag of 1.8, the table show that these simulations has the smallest model-observation deviation in 95% of all runs with different scaling of the water drag after a 24h hindcast, and in 88% of the cases after a 72h hindcast.

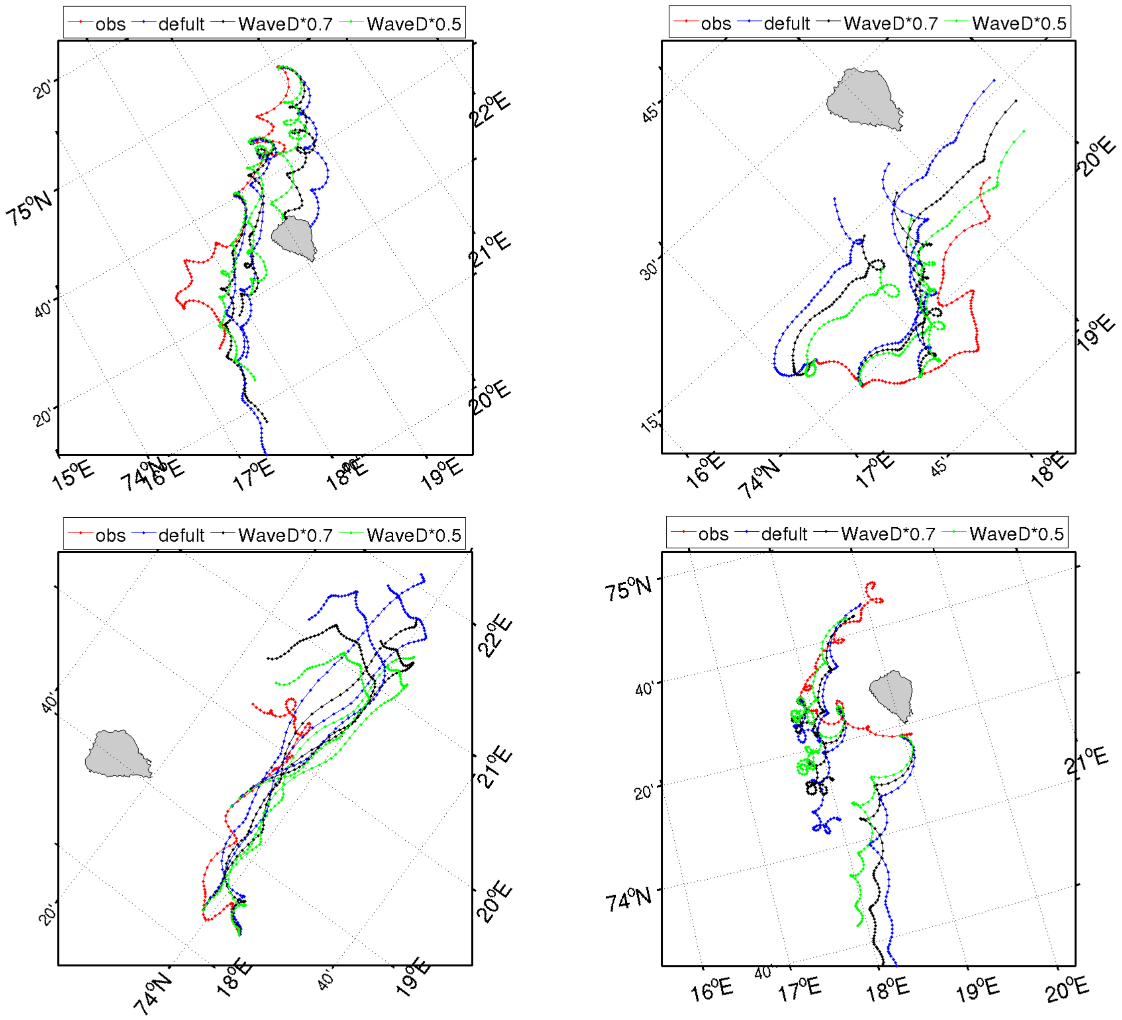

Figure 7: Iceberg trajectories of different pinnacle icebergs for the period April 18 to April 23 1988. The red trajectories are observed data while the other tracks are from model runs with different wave drag. Each run is starting at midnight and runs for 72h where all iceberg has a length of 100m. The wave drag are: blue: default run, black: WaveDrag*0.7, green: WaveDrag*0.5.

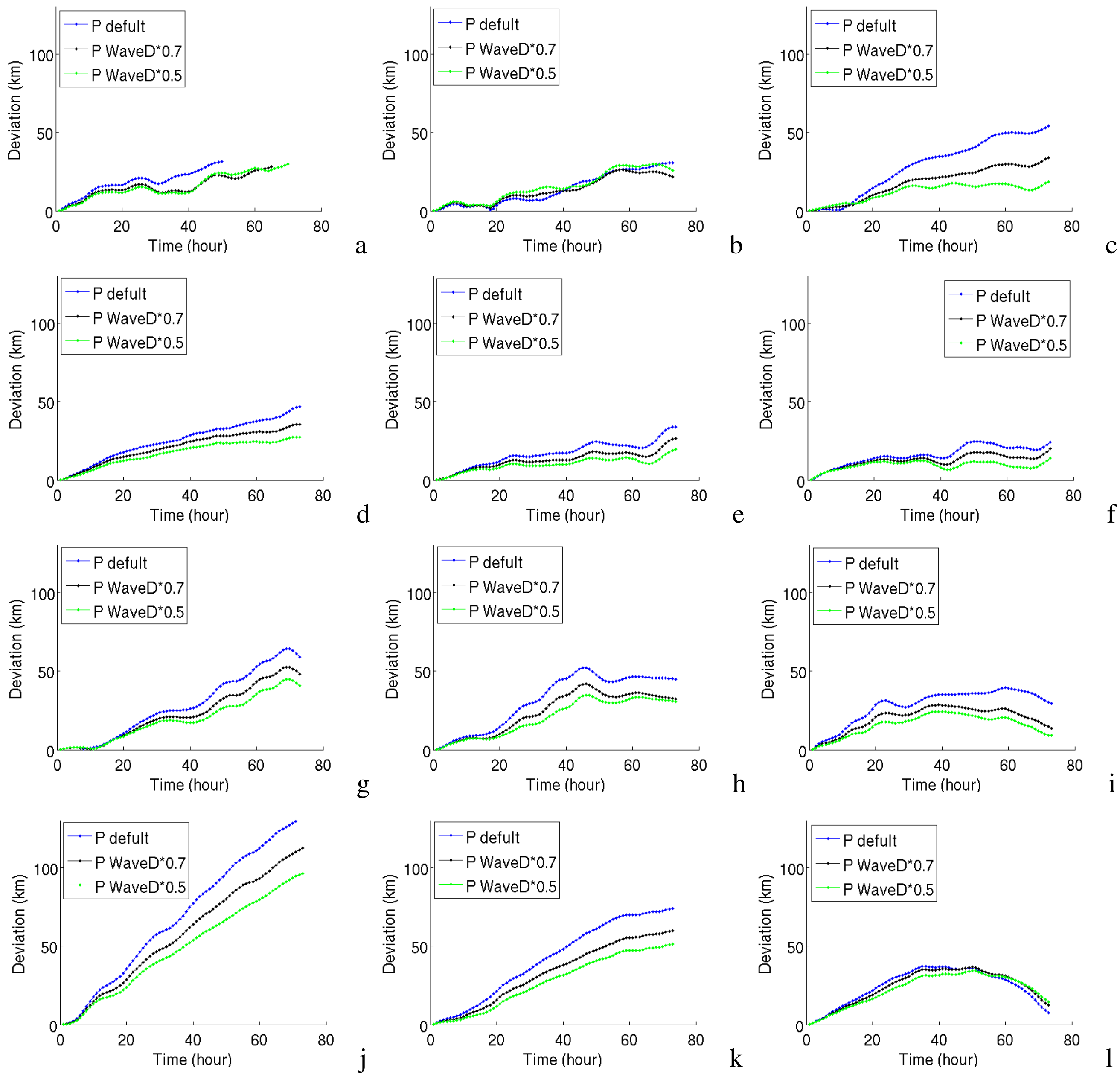

Figure 8: Plots of the deviation between modeled and observed positions for a three day hindcast for a pinnacle iceberg with wave drag: default (blue), WaveDrag*0.7 (black) and WaveDrag*0.5 (green). Panel a): release date: April,18 00UTC, b): release date: April,19 00UTC and c): release date: April,20 00 UTC, d): release date: April,24 00UTC, e): release date: April,25 00UTC and f): release date: April,26 00 UTC, g): release date: April,27 00UTC, h): release date: April,28 00UTC and i): release date: April,29 00 UTC, j): release date: May,4 00UTC, k): release date: May,5 00UTC and l): release date: May,6 00 UTC. Note that the prediction of iceberg path consistently is better for the same wave drag scaling.

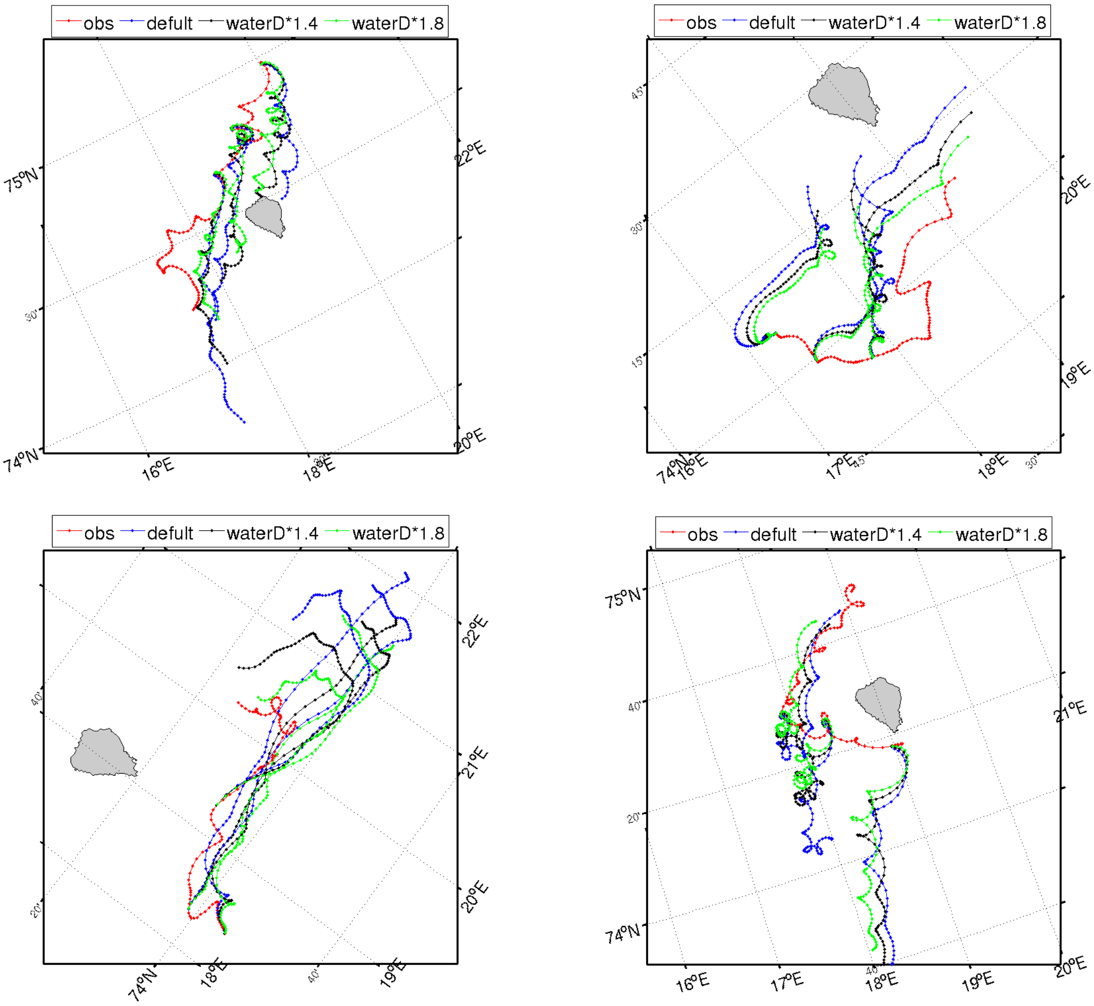

Figure 9: Iceberg trajectories of different pinnacle icebergs for the period April 18 to April 23 1988. The red trajectories are observed data while the other tracks are from model runs with different water drag. Each run is starting at midnight and runs for 72h and all iceberg has a length of 100m. The water drag are: blue: default run, black: WaterDrag*1.4, green: WaterDrag*1.8. The left column show results for the period April 18 to April 23 1988, the right column show results for the period March 23 to March 28 1988.

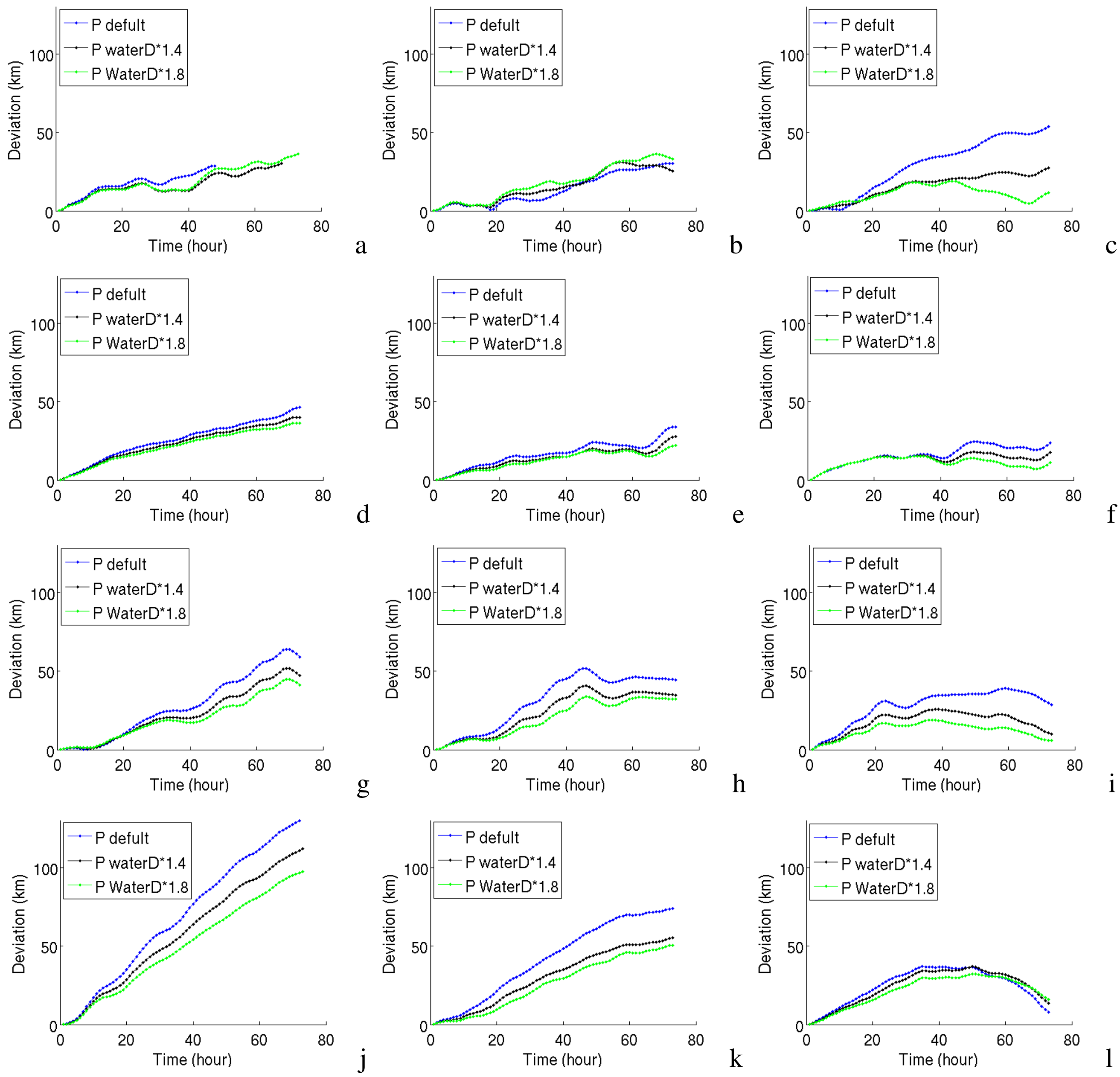

Figure 10: Plots of the deviation between modeled and observed positions for a three day hindcast for a pinnacle iceberg with different water drag: default (blue), WaterDrag*1.4 (black) and WaterDrag*1.8 (green). Panel a): release date: April,18 00UTC, b): release date: April,19 00UTC and c): release date: April,20 00 UTC, d): release date: April,24 00UTC, e): release date: April,25 00UTC and f): release date: April,26 00 UTC, g): release date: April,27 00UTC, h): release date: April,28 00UTC and i): release date: April,29 00 UTC, j): release date: May,4 00UTC, k): release date: May,5 00UTC and l): release date: May,6 00 UTC. Note that the prediction of iceberg path consistently is better for the same water drag scaling.

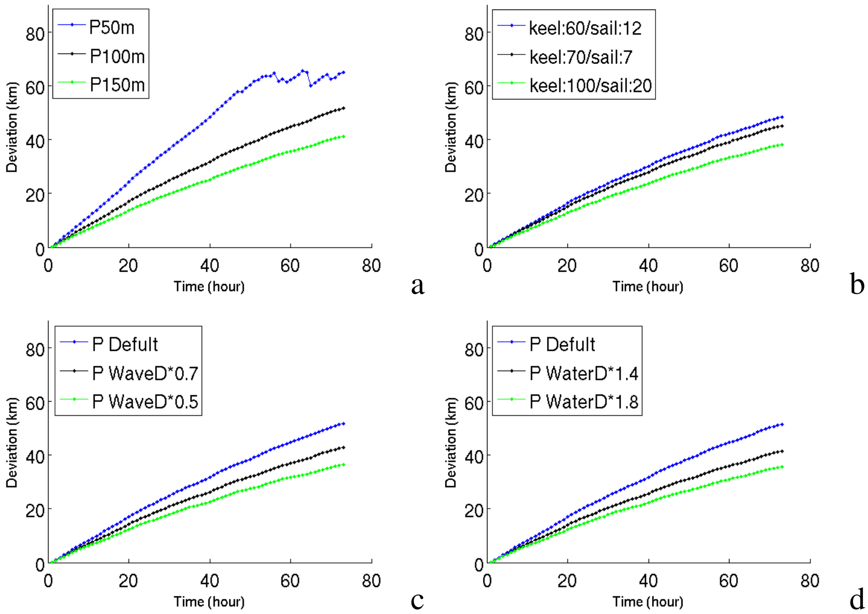

Figure 11: Mean model-observation deviation of all experiments with different length, keel/sail height, wave and water drag. Panel a): different iceberg lengths, b): different keel depths and sail heights, c): different scaling values of wave drag and d): different scaling values of water drag

Table 1: The table shows for how many cases (N) the longest, the deepest, and the iceberg with the largest water drag and weakest wave drag have the smallest deviation from the observed tracks after hindcast hour +24, +48 and +72, for a total of 58 cases for each experiment suite. The simulations are based on iceberg 3105, 3106, 3108 and 8895 for each experiment. The percentage is computed as follows (N*100)/58, and is calculated for each experiment suite and hindcast hour (for instance, experiments with different lengths and different wave drag has not been considered together).

Experiments	Geometry/Scaling
Pinnacle; Iceberg length:	150m
+24h	52 (90%)
+48h	51 (88%)
+72h	49 (84%)
Tabular; Iceberg keel/sail height:	100m/20m
+24h	56 (96%)
+48h	53 (91%)
+72h	51 (88%)
Pinnacle; Scaling of wave drag	0.5
+24h	50 (86%)
+48h	47 (81%)
+72h	46 (79%)
Pinnacle; Scaling of water drag	1.8
+24h	55 (95%)
+48h	54 (93%)
+72h	51 (88%)

6 Summary and Conclusion

This report present results from different experiments with the CHC iceberg model (Kubat et al. (2005), Kubat et al. (2007)), to see if we can improve the forecast of iceberg trajectories by adjusting the geometrical shape of the iceberg or by scaling the wave and water drag and our sensitivity experiments shows that this is possible.

The iceberg model is forced with atmospheric wind, oceanic currents and temperature, ice coverage, ice thickness, ice speed and direction, and wave radiation stress. More details on the hindcast data can be found in Broström et al. (2009a). Data of iceberg movements recorded during the IDAP program has been used to analyse the model results. The different experiments applied in this study are:

- Simulations with different iceberg lengths (50m, 100m and 150m).
- Simulations with different sail and keel heights for tabular icebergs (keel:60m/sail:12m, keel:70m/sail:7m (default) and keel:100m/sail:20m).
- Simulations with different scaling factors for wave drag (waveD*1 (default), waveD*0.7 and waveD*0.5) and water drag (waterD*1 (default), waterD*1.4 and waterD*1.8).

For each experiment, 58 cases has been simulated based on iceberg 3105, 3106, 3108 and 8895 as shown in Fig.2. Each model run is a three day hindcast (72h), where the release position is taken from observation in the IDAP study. The iceberg shapes studied are pinnacle and tabular.

For simulations with different iceberg lengths, we find that for tabular icebergs where keel depth and sail height is constant with iceberg length, all simulations are similar and the trajectories does not depend on iceberg length. For pinnacle icebergs we achieve some spreading between the different simulations, since sail and keel depth for pinnacle iceberg depend on the iceberg length. By increasing the size of the pinnacle iceberg, we observe that the iceberg moves more to the right of the main direction of the modeled iceberg compared to the smaller iceberg, which is more in agreement with observations. However it is not possible to change the main direction of the trajectories by more than a few degrees when changing the characteristics of the iceberg. Furthermore, we observe that by increasing the size of the pinnacle iceberg, the speed of the iceberg decreases and we get a more realistic velocity compared to observations in nearly all 58 cases. The same results are obtained by increasing the keel depth and sail height for tabular iceberg.

The wave radiation stress may be different for small icebergs than for large icebergs and is also dependent on how the iceberg is oriented with the wind. For water drag, the force on the iceberg is dependent on the size of the keel, and since we don't know the size of the iceberg, how it is oriented or the keel depth, a scaling factor is implemented in the iceberg model for both wave and water drag. We find that the velocity is very sensitiv to the scaling, specially in situation with strong wind fields.

This study shows that it is possible to improve the forecast of iceberg trajectories by adjusting/assimilating the geometrical shape, particularly the velocity. We have only adjusted one parameter at the time in the experiments. By consider more parameters at the same time, it is likely that we can improve the forecast even further. However, it should be noted that changing iceberg geometry or scaling the different forces can only change the drift direction/speed with up to, say 20%. If the basic model system is not correct enough, adjusting geometry will not improve the forecast.

References

Albreten, J. & I. Burud, Assimilation of sea surfaces temperature and sea ice concentration in a coupled sea ice and ocean model. 2006, In: H: Dahlin, N.C. Flemming, P. Marchand and S.E. Petersson (Editors), Europpean Operational Oceanography: Present and Future. 4th International Conference on EuroGOOS, Brest, France, pp.663-668.

Barker, A., M. Sayed & T. Carrieres, Determination of Iceberg Draft, Mass and Cross-Section Areas. 2004, 14th Internat. & Offshore Polar Eng. Conf., ISOPE, Toulon France.

Broström, G., A. Melsom & A. Carrasco, Iceberg modeling at met.no: Validation of hindcast experiment. 2009a, met.no report (Norwegian Meteorological Institute), 16, pp.63.

Broström, G., A. Melsom, M. Sayed & I. Kubat, Iceberg modeling at met.no: Validation of iceberg model. 2009b, met.no report (Norwegian Meteorological Institute), 17, pp.35.

Dowdeswell, J. A., T. Benham, T. Strozzi & J. Hagen, Iceberg calving flux and mass balance of the Austfonna ice cap on Nordaustlandet, Svalbard. 2008, J. Geophys. Res., 113. F03022, (doi:10.1029/2007JF000905).

Engedahl, H., Implementation of the Princeton Ocean Model (POM/ECOM3D) at the Norwegian Meteorological Institute. 1995, Research Report 5, Norwegian Meteorological Institute, Oslo, Norway.

Flather, R.A., Results from a model of the north-east Atlantic relation to the Norwegian coastal current. 1981, In:R. Sætre and M. Mork (Editors), The Norwegian Coastal Current: Vol II. University of Bergen, Norway, pp. 427-458

Gjevik, B., E. Nøst & T. Straume, Atlas of tides on the shelves of the Norwegian and the Barents Sea. 1990, Rep., Department of Mathematics, University of Oslo, Oslo, Norway.

Komen, G., J.L. Cavaleri, M. Donelan, K.Hasselmann, S.Hasselmann, & P.A.E.M. Janssen, Dynamics and Modeling of Ocean Waves, 1994, Cambridge University Press, 533 pp.

Kubat, I., M. Sayed, S.B. Savage & T. Carriers, An operational model of iceberg drift. 2005, International Journal of Offshore and Polar Engineering, 15, 125-131.

Kubat, I., M. Sayed, S.B. Savage, T. Carriers & G. Crocker, An operational iceberg deterioration model. 17'th International Offshore and Polar Engineering Conference.

Røed, L.P. & J. Debernard, Description of an integrated flux and sea-ice model suitable for coupling to an ocean and atmosphere model. 2004, Research Report, 4, Norwegian Meteorological Institute, Oslo, Norway, pp.51.

Sayed, M., Code documentation of iceberg drift and detoration model, 2008, Canadian Hydraulic Institute.

Spring, W., Ice data acquisition program (IDAP) summary report. 1994, Dallas E&P Engineering: Dallas, pp.90.

Undén, P., L. Rontu, H. Järvinen, P. Lynch, J.Calvo, & coauthors, HIRLAM-5 Scientific Documentation. 2002, Swedish Meteorological and Hydrological Institute.