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Impact of environmental input on iceberg drift simulations for an exemplary trajectory in the Barents Sea

Lia Herrmannsdörfer[1], Biye Yang[1]
[1] Norwegian University of Science and Technology (NTNU) (Department of Civil and Environmental Engineering, Trondheim, Norway)

ABSTRACT

Simulations of iceberg drift help anticipate and prevent potential impacts on ships and offshore structures. However, the simulations are highly uncertain and sensitive to the model settings and environmental input. We characterise the error of simulated iceberg drift trajectories under varied environmental input using the state-of-art model OpenBerg for the example of a short iceberg trajectory observed by satellite in the northern Barents Sea in 2023. In this example, simulated icebergs drift too short (-16 km) and too far towards the south (+4°). Different environmental inputs led to varying errors, with reduced drift distance errors (-14 km, 0 km) but increased drift direction errors (+7°, +11°) using Topaz ocean and ERA5 wind data. Barents-2.5 and CARRA inputs reduced drift direction errors (+1°, -3°) but increased drift distance errors (-17 km, -31 km). The trajectory shape was captured more accurately using Topaz and ERA5, however the evaluation is limited by the number of observation points and unknown real environmental conditions.

KEY WORDS: Iceberg; Simulation; Barents Sea, Ocean, Atmosphere.

INTRODUCTION

Understanding iceberg drift is crucial for maritime safety and infrastructure protection. Accurate forecasting of iceberg trajectories helps mitigate risks to ships and offshore structures, with numerical simulations providing valuable insights under varying environmental conditions. Used iceberg drift and deterioration models were progressively developed (e.g. White 1980, Bigg 1997, Savage 2001, Kubat 2005, Keghouche 2010, Eik 2009, Monteban 2020). Still, the simulations are highly uncertain and depend significantly on model settings, initial conditions and environmental inputs. Kubat (2005), Eik (2009) and Keghouche (2010) found that variations in atmospheric and oceanic forcing can lead to substantial differences in predicted iceberg trajectories. These uncertainties highlight the need for careful selection and validation of input data, as well as sensitivity analyses to assess the robustness of simulation results. Herrmannsdörfer et al. (2025, in review), investigated the impact of environmental input on simulations of iceberg drift and deterioration in the Barents Sea in a statistical approach.

In this study, we characterise the error of simulated iceberg drift trajectories under varied ocean, sea ice and atmospheric input, on the example of a satellite-based iceberg observation in the Barents Sea. Thereby, we re-simulate the observed trajectory using open-source model *OpenBerg* (https://opendrift.github.io/) and ocean, sea ice and atmospheric data from the *Arctic Ocean Physics Reanalysis* (Topaz) (Xie et al., 2017), *Arctic Ocean Wave Hindcast* (WAM) (MDS, 2024) *Barents-2.5 forecast system* (Met-Norway, 2025), the *global atmospheric reanalysis ERA5* (Hersbach et al., 2025) and the *Arctic regional reanalysis*

CARRA (Schyberg et al. 2025). In addition to the environmental input, a selection of model parameters governing how input data is utilised, is varied. Simulated and observed trajectories are compared and errors are related to differences between the environmental data and their known uncertainties.

DATA & METHODS

Iceberg observations

In this study, we re-simulate an iceberg trajectory observed in September 2023 in the Barents Sea (Figure 1). The iceberg was spotted initially and high resolution satellite imagery was order by Equinor for the anticipated positions at the overflight times. The same iceberg could be matched in different satellite imagery at 13 occasions during a 9 days period, from the 10 Sep to the 18 Sep 2023.

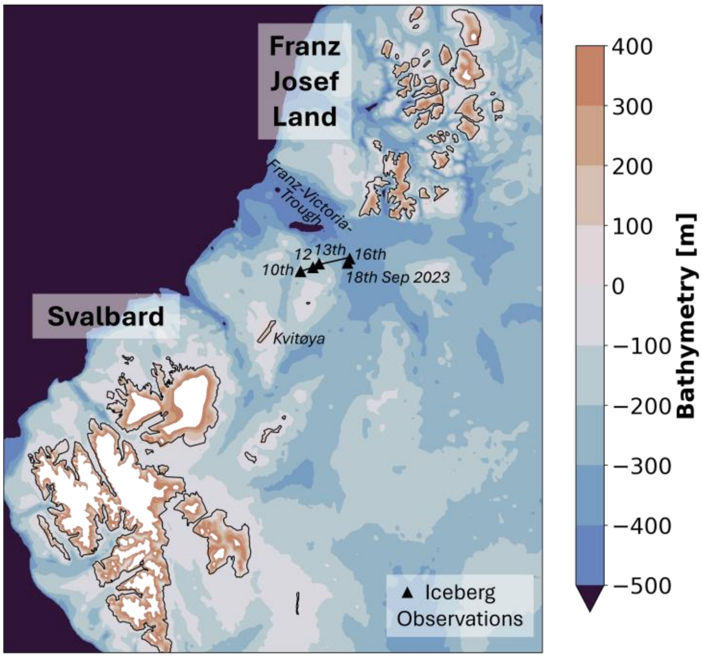

Figure 1. Iceberg observations

Iceberg seeding

The iceberg simulation is initiated at the position of the first observation (37.8 E 80.6 N) on the 10 Sep. The initial size (length, width) is corrected by linear regression through all observation points, as the observed iceberg size is highly uncertain. The total iceberg height is calculated by empirical relations (Dezecot and Eik, 2015) and the relation of sail and keel is calculated by buoyancy.

Iceberg drift model

For simulating the iceberg trajectory, we use the state-of-art, lagrangian, deterministic model *OpenBerg* which is part of the freely available software package OpenDrift (https://opendrift.github.io/). The model simulates the iceberg drift and deterioration due to waves, water currents, wind and sea ice, as described in Keghouche (2010). In more detail, icebergs drift due to form drag by water velocity and wind, due to drag of surrounding drifting sea ice, due to Stokes drift and due to reflecting short-length waves.

Environmental input data

For characterising the impact of the environmental input on the iceberg drift simulation results, the observed iceberg trajectory is re-simulated with four combinations of ocean, sea ice and atmosphere input, namely Topaz-ERA5, Topaz-CARRA, Barents2.5-ERA5 and Barents2.5-CARRA. This environmental data is described in Table 1. The used variables are sea surface temperature (SST), sea water salinity (S), sea ice concentration (CI), sea ice thickness (h_{si}), significant wave height (h_S), wave direction (Φ_{wav}), and the velocities of water (v_w), Stokes drift (v_{stokes}), sea ice (v_{si}),10m wind (v_a).

Table 1. Overview on the environmental input

Model name	Topaz	Barents-2.5	WAM	ERA5	CARRA
Region	Arctic	Barents Sea	Arctic	Global	Barents Sea, Greenland
Horizontal resolution	12.4 km	2.5 km	3 km	31 km	2.5 km
Temporal resolution	Daily	Hourly	Hourly	Hourly	3-hourly
Reference	Xie et al. (2017)	MET-Norway (2025)	MDS (2024)	Hersbach (2025)	Schyberg (2025)
Variables used	SST, S, CI, h_{si}, v_w, v_{si}	SST, S, CI, h_{si}, v_w, v_{si}	v_{stokes} (h_S, Φ_{wav})	v_a	v_a

Experiment setup

In addition, the simulations are conducted for a small selection of model settings, as they influence how the environmental input is used. Varied model settings include using a vertical profile or surface estimate of the water velocity. They also include different combinations of air and water drag coefficients (C_a/C_w), as they can compensate errors in the environmental input data and weight the contribution of wind and current (Diansky, 2018). We adopt recommended combinations of drag coefficients from Diansky (2018), that are calibrated for an iceberg trajectory in the Barents Sea, and the default drag coefficients in OpenBerg (0.7/0.25). Further, we use hourly time steps. The varied model settings and the different environmental input is shown in Table 2. The variations result in 32 combinations of input data and model settings

Table 2. Variations of model configurations, coefficients and input.

Varied aspect	Options
Vertical profile of water velocity	Vertical profile, surface
C_a/C_w	0.7/0.25, 1.3/0.6, 1.3/0.9, 0.5/0.9
Atmosphere, Ocean & Sea ice input	ERA5, CARRA, Topaz, Barents-2.5

Note that Stokes drift is activated in OpenBerg when surface water velocities are used. The Stokes drift (using input from WAM) is therefore included in the simulations using surface water velocity, but showed small impact in further investigations (not shown).

Further analysis showed that varied initial size (within the 95% confidence interval around the linear regression) causes small deviations in the iceberg trajectory for this study (Figure

2) and is therefore not analysed further in this paper. The simulation of iceberg deterioration showed no visible impact on the iceberg drift within this short period and is therefore disregarded (not shown).

Further analysis showed large error in the trajectory by simulating the iceberg drift accounting for wave radiation using input from WAM (Figure 2). This may be due to the uncertainty of WAM or due to how the iceberg model describes the interaction of wave and iceberg. Further attempts were not able to reduce the error in the wave radiation force. As the error due to simulating wave radiation is significantly larger than the deviation due to the environmental input, it distorts the results of this study and is switched off in the following analysis.

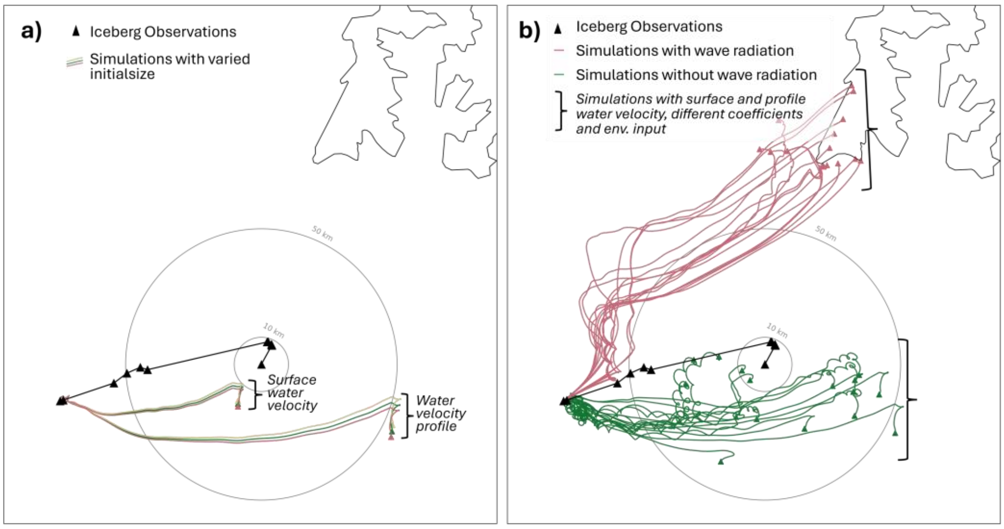

Figure 2. Impact of a) varied initial size and b) wave radiation (on-off) on exemplary iceberg simulations. In a) the initial size (length x width [m]) is 81x72 (green), 75x65 (yellow) and 87x80 (red). The initial size of 81 x72m and the corresponding total height of 23 m are used in all following simulations.

RESULTS

The simulated iceberg trajectories with varied environmental input and model settings are presented in Figure 3.

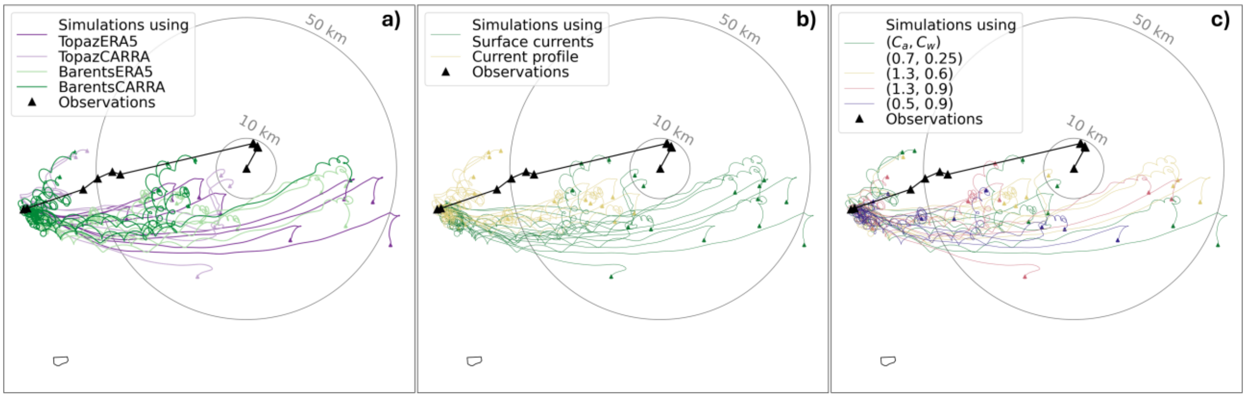

Figure 3. Observed and simulated iceberg trajectories, coloured by a) varied environmental input, b) water velocities as profile or at surface and c) varied drag coefficients.

Drift distance, direction and endpoint error

We analyse the effective drift distance d [km], iceberg drift direction δ [°], their error to the observations in different simulations Δd and Δδ, and the geographical distance of observed and simulated position at the time of the last observation (18 Sep 2023, "endpoint distance") d_{end} [km] (Figure 4, Table 3). We find that in the simulations, in average, icebergs drift too short (-16 km), too much towards the south (+4°), resulting in a distance to the last observed iceberg position (36 km) that is half as long as the trajectory. We note that incorporating wave radiation forces would increase the drift distance and adjust the drift direction northward in this example, but the present parameterizations lead to an unrealistic magnitude of the effect.

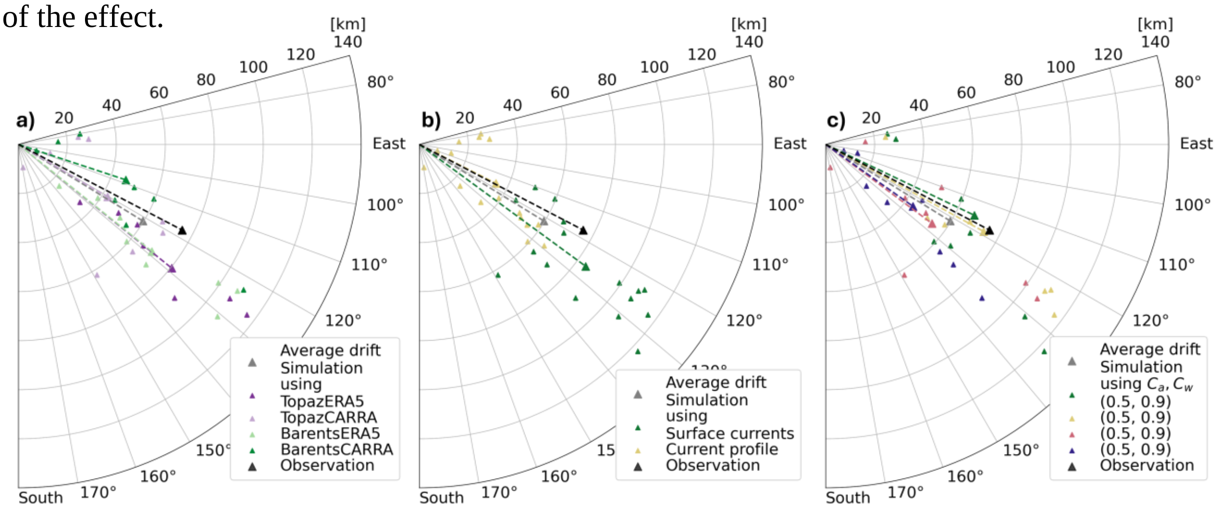

Figure 4. Iceberg drift distance (radial axis) and drift direction (angular axis) for iceberg simulations with a) varied environmental input, b) water velocities as profile or at surface and c) varied drag coefficients.

Table 3. Statistics of iceberg drift in the observations, the simulations and the simulation error for different environmental input and model settings. Drift distance d, drift direction δ and geographical distance of observed and simulated position d_{end} at the 18 Sep 2023.

	∅ d [km]	∅Δ d [km]	∅ δ [°]	∅Δ δ [°]	∅Δ d_{end} [km]
Observations	75	-	118	-	-
Simulations	60	-16	122	+4	36
Topaz	61	-14	125	+7	37
Barents-2.5	58	-17	118	+1	36
ERA5	75	0	129	+11	33
CARRA	44	-31	114	-3	40
Surface current	84	+9	126	+9	29
Current Profile	35	-40	117	-1	44
C_a, C_w (0.7, 0.25)	67	-8	115	-2	34
C_a, C_w (1.3, 0.6)	74	-2	119	+1	31
C_a, C_w (1.3, 0.9)	54	-21	127	+9	40
C_a, C_w (0.5, 0.9)	44	-32	125	+8	41

We further analyse the shape of the trajectory and find that the observed iceberg trajectory can be characterised by drift towards 123° for 5 days (10-16 Sep, 81 km), changing direction on the 16th Sep and a drift towards 202° for 2 days (16-18 Sep, 10 km) (Table 4). The average simulated drift direction is very similar to the observations in the first part and has a larger error of -29° in the second part (Table 4). Further analysis revealed (not shown) that 22% of the simulations showed change in direction similar to the observed one (at least 50° to the right) on the same day.

Table 4. Statistics of iceberg drift as in Table 3, but for the time periods 10 Sep-16 Sep (T1) and 16 Sep to 18 Sep (T2). No differentiation of varied model settings shown, as no significant difference (between model settings and to Table 3) was found.

T1/ T2	$\sum$ d [km]	$\Delta \sum$d [km]	ø δ [°]	Δ δ [°]
Observations	81/ 10	-	123/ 202	-
Simulations	57/ 23	-24/ +13	120/ 173	-3/ -29
Topaz	38/ 11	-43/ +1	95/ 178	-27/ -24
Barents-2.5	76/ 35	-4/ +25	144/ 169	+21/ -33
ERA5	59/ 17	-21/ +7	113/ 204	-10/ +2
CARRA	55/ 29	-25/ +19	127/ 143	+4/ -59

As the true environmental conditions are not known, the errors in, e.g., drift distance and direction cannot be explained easily. However, we may relate the characteristics of the trajectory to known uncertainty of the environmental models and the case-specific differences between the environmental data. Therefore, we compare the different environmental data along the simulated iceberg trajectories (Figure 5) and in the region and time (Figure 6).

Environmental input

Out of the environmental input variables SST, S, CI, h_{si}, h_S, Φ_{wav}, v_w, v_{stokes}, v_{si}, v_a needed for the simulations, only the impact of v_w, v_{stokes}, and v_a is analysed in this Section. No sea ice is present in Topaz and Barents-2.5 in the simulation time and region. Sea ice observations (Ice charts, https://cryo.met.no/) reveal a sea ice extension in the Franz-Victoria-Trough that reaches as far as 80.5°N at the 18 Sep. The difference of SST and S in Topaz and Barents-2.5 is not analysed, as it does not influence the drift significantly in this example. This is because iceberg melt is not simulated and following SST and S only contribute to water density and buoyancy, resulting in a maximum variation of 2 cm in keel depth. Wave data is not analysed as the drift due to wave radiation and melt by wave erosion are switched off in the used model settings. The analysis of v_w by Topaz and Barents-2.5, v_a by ERA5 and CARRA and v_{stokes} by WAM are shown in Figure 5 and 6.

The environmental conditions can, for example, explain the changing drift direction on the 16 Sep, when the iceberg drifts into deeper waters of Franz-Victoria-Trough with different direction and decreasing speed in water currents, Stokes drift and wind (Figure 5,6). However, the change in iceberg drift direction is not large enough in the simulation, which may be caused by too small gradients in the environmental data or a response by the iceberg model that is not large enough (e.g. due to too small C_w).

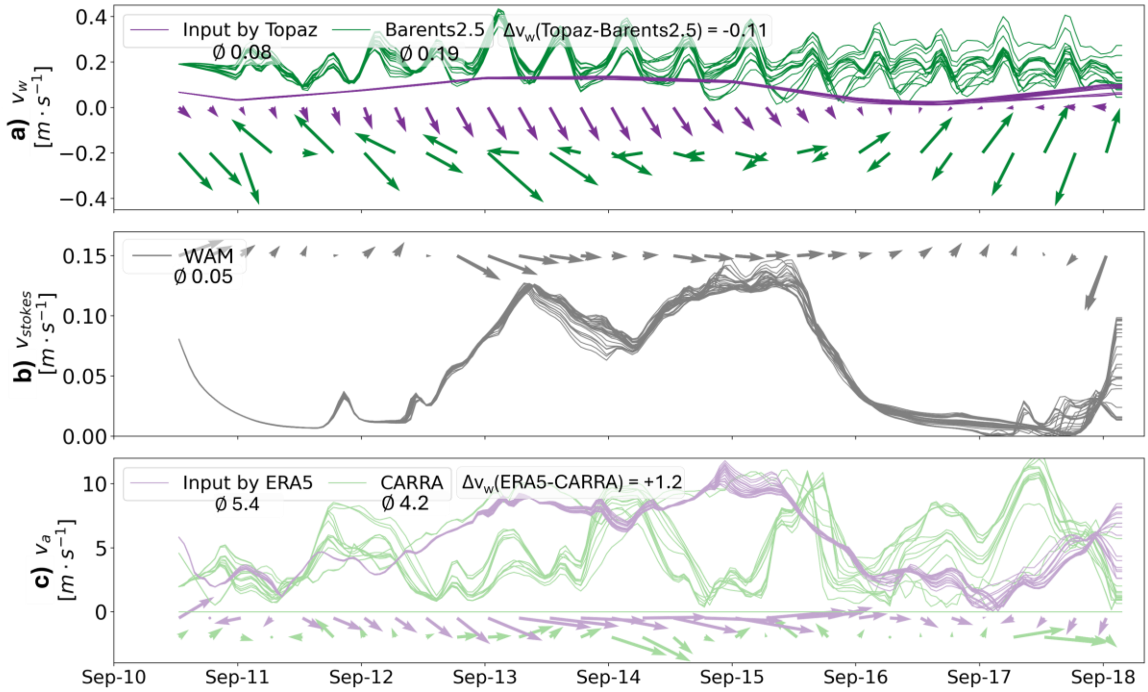

Figure 5. Timeseries of environmental conditions along the simulated iceberg trajectories. The lines correspond to simulations with different model settings. The directional data is averaged for all respective simulations.

Impact of Topaz and Barents-2.5

Water velocities are characterised by daily temporal resolution, missing tidal component, low horizontal resolution, issue with topographically-steering and generally low speeds due to low resolution in Topaz (Xie, 2017b). Water velocities in Barents-2.5 are characterised by hourly resolution, a strong tidal component, large regional gradients and generally too high velocity compared to observations due to its high horizontal resolution (Röhrs 2023, Idzanovic 2023). The difference in temporal resolution, tidal representation, horizontal resolution can be seen in Figure 5 and 6. Due to the lack of observations and the chaotic nature of the system both models yield large uncertainties in v_w (Röhrs 2023b).

Negative bias in water speeds and coarse horizontal resolution in Topaz cause the too short iceberg drift distance (-14 km) and deviations in drift angle (+7°) for simulations using Topaz input. The errors due to Topaz input reflect the average for all simulations.

High horizontal resolution and the tidal component likely cause a small error in drift direction in simulations with Barents-2.5 input (+1°). However, the tidal looping of the iceberg cause larger error in drift distance than all other input (-17 km) despite (+0.11 m/s) larger water velocities.

Despite the smaller horizontal gradients in Topaz, changing water conditions during the drift into Franz-Victoria-Trough is captured more clearly by Topaz (Figure 5,6) and therefore the general shape of the trajectory (with change in direction on the 16 Sep) is captured more accurately in simulations with Topaz input (Figure 3, Table 4). The missing tidal loops in Topaz input and the sparse observation points make the Topaz-trajectories appear more accurate in Figure 3. However, the exact drift trajectory is not known and we expect the trajectory to have tidal loops, in reality. In general, decreased uncertainty in the v_w data would improve the iceberg simulations.

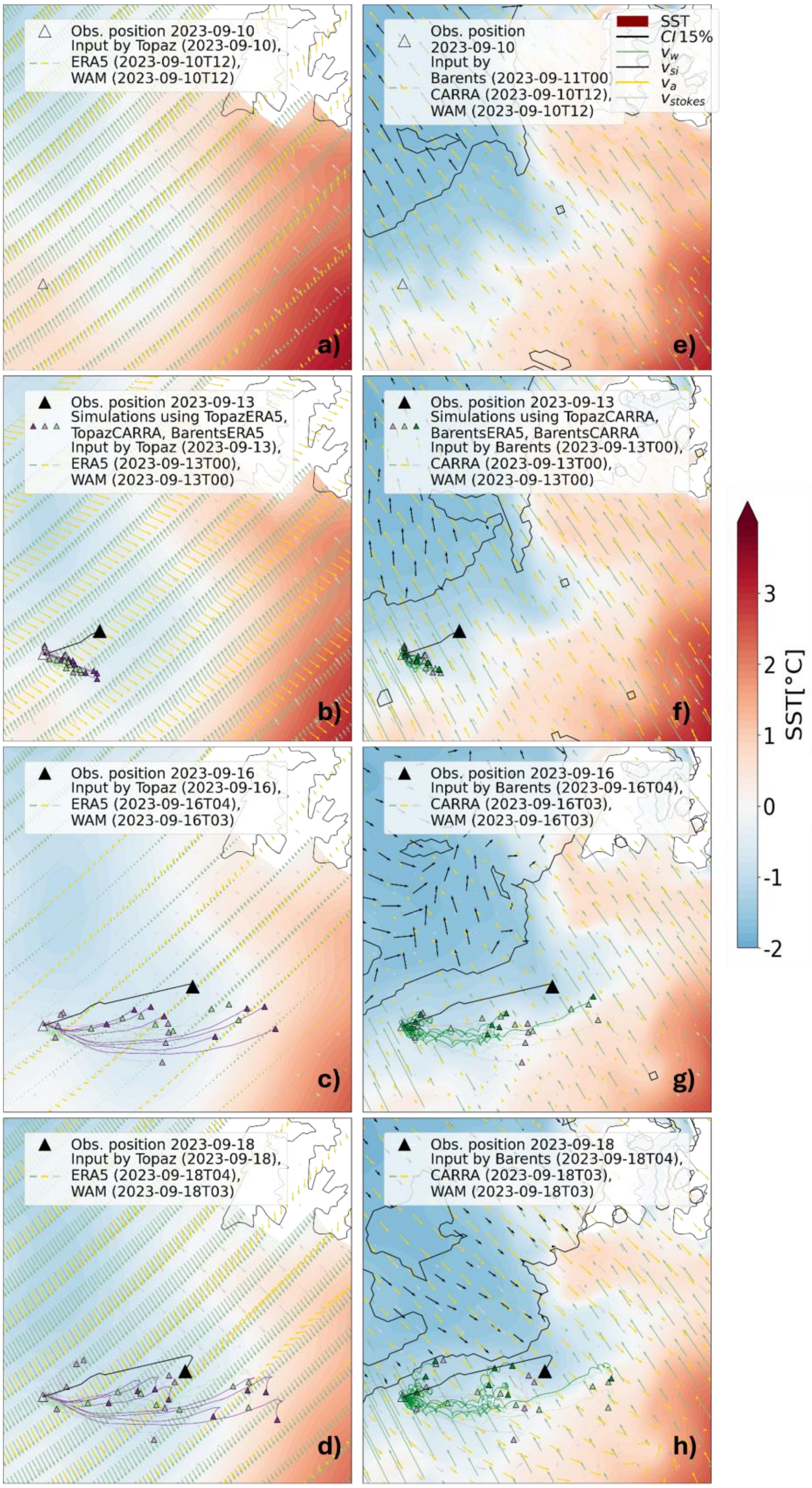

Figure 6. Environmental conditions in the Northern Barents Sea on the 10th (a,e), 13th (b,f), 16th (c,g) and 18th Sep 2023 (d,h), by Topaz and ERA5 (a-d), Barents-2.5 and CARRA (e-h). Observed (black triangles) and simulated trajectories (green, purple) that used the respective environmental data.

Impact of ERA5 and CARRA

In the literature, ERA5 and CARRA 10m winds are described with small uncertainty and high similarity, especially over open ocean (e.g. Køltzow, 2022). However, large differences can be seen in wind direction, speed along the trajectories (Figure 5), which cause large differences in the drift statistics (Table 3). Using ERA5 winds yields in average correct drift distance, but the largest error in direction (+11°). Using wind input from CARRA yields the largest errors in drift distance (-31 km) and endpoint distance (40 km), which are almost as large as the absolute simulated drift using CARRA (44 km). However, CARRA yields small error in drift direction and yields the only simulations with average drift to the north (-3°). The difference in drift distance results from average (1.2 m/s) lower wind speeds in CARRA and different timing of "wind events" along the trajectories (Figure 5).

Decreasing wind and changing direction on the 16th Sep are represented by both atmospheric models (see Figure 5,6), however iceberg trajectories using ERA5 input capture the shape better (Table 4).

Most accurate trajectories

The errors due to individual ocean, sea ice and atmospheric input can add up or cancel out. Thus, the trajectory with the most accurate drift direction and endpoint-distance (+0.56° and 8 km) used the combination of Topaz and CARRA input. A combination of Barents-2.5 and ERA5 yielded the smallest error in drift distance (4 km).

Impact of model settings

The errors due to the environmental input are on the same scale as the error due to the chosen model settings. Thereby, simulations using surface water velocities yield in average smallest errors of drift distance and endpoint-distance (+9 km, 29 km vs +40 km, +44 km) and using the profile of the water velocities yields in average smaller error of drift direction (-1° vs +9°). The most accurate (in d, d_{end}, δ) individual trajectories use surface water velocities. The drag coefficients $C_{a,}/C_w$ = 0.7/0.25 and 1.3/0.6 yield smaller errors than the coefficients $C_{a,}/C_w$ = 1.3/0.9 and 0.5/0.9. Lower C_w weight highly uncertainty water velocity data (Röhrs, 2023b) less than more certain wind data (e.g. Køltzow, 2022) and is likely accurate in mostly wind-driven situations.

Limitations

The goal of this study is to characterise the impact of environmental input on iceberg drift trajectories for an example of an observed trajectory, as continuation of the statistic characterisation in Herrmannsdörfer et al. (2025, in review). The results of this analysis concerning environmental input and model settings are highly case-specific and the presented errors may not be applicable on other regions or time periods with different environmental conditions and, e.g., long trajectories in which the influence of melt is non-negligible. The analysis of the performance of environmental input is limited by the number of observations along the trajectory and the unknown drift in between those points.

CONCLUSIONS

Iceberg drift simulations are important for forecasting and preventing potential impacts on ships and structures, yet they are highly uncertain and sensitive to model settings and environmental inputs. The significance of the error in the drift simulations depends on the nature of the operation, ice management approach and its response time. We characterise the error of iceberg drift simulations with different environmental input for an example in the northern Barents Sea. The satellite-based observations show a 9-days drift with an abrupt change in course after 5 days.

In this example, the simulated icebergs trajectories are in average (16 km) too short, (4°) too far to the south and their change in course is not as large as in the observation. The environmental input is associated with distinct advantages and disadvantages. On average most accurate drift distances were simulated using ocean input by Topaz and wind input by ERA5 (Δd=-14km, 0 km), however the input causes large error in drift direction ($\Delta\delta$=+7°, +11°). Average most accurate drift directions could be simulated using ocean input from Barents-2.5 and wind input by CARRA ($\Delta\delta$=+1°, -3°), however the input causes large error in drift distance (Δd=-17 km, -31 km). The trajectory shape was captured more accurately using Topaz and ERA5, however the evaluation is limited by the number of observation points, which discriminates the simulation of tidal loops.

The example also showcases an exception to a typically small difference between wind data and a typically small impact of wind input on the iceberg simulations. Instead, the example showed large differences in input wind data and simulated drift.

Further, using water velocity at the surface yielded more accurate drift distance than using a vertical profile of the velocities. However, using the velocity as profile yielded more accurate drift direction, while reducing the weighting of the water drag reduced both errors.

We find that the greatest potential for improving iceberg drift simulations lies in enhancing ocean velocity data and incorporating wave forces at a realistic scale. This study is highly case-specific but may be repeated for more iceberg observations, a larger selection of environmental input and model settings.

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The ERA5 (Hersbach et al., 2023) and CARRA data (Schyberg et al.) were downloaded from the Copernicus Climate Change Service (2025). The results contain modified Copernicus Climate Change Service information 2025. Neither the European Commission nor ECMWF is responsible for any use that may be made of the Copernicus information or data it contains. This study has been conducted using E.U. Copernicus Marine Service Information, (Xie et al. 2017, MDS 2024).

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