How climate model biases skew the distribution of iceberg meltwater

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- Iceberg meltwater fluxes are computed using an iceberg model forced with climate conditions from (i) GCM output and (ii) an observational state estimate.
- Large-scale differences in meltwater fluxes are found to be driven by relatively small-scale differences in ocean currents.
- The impact of a high wind bias in the GCM is reduced through compensating effects of wind-driven erosion and drift.

1. OBSERVATIONAL STATE ESTIMATE AND GCM INPUT FIELDS

GCM:

20th century "Historical" simulation of NCAR Community Climate System Model Version 4 **(CCSM4)**. Horizontal resolution: ~ 1° in atmosphere and ocean.

State Estimate:

Global ocean state estimate Estimating the Circulation and Climate of the Ocean Phase II **(ECCO2)**. Calculated using a least squares fit of available observational data to an ocean GCM. Horizontal resolution: 18 km.

The ocean is forced with surface winds from the Japanese 25-year ReAnalysis (JRA-25), (~1° native resolution).

2. ICEBERG MODEL

Drift:

We use an iceberg drift model [1] that is adapted from the canonical family of drift models used by Bigg et al. (1997) [2] and subsequent studies. The momentum equation is simplified as follows:

$$M = -Mfk \times \vec{v}_i + F_w + F_a + F_p + F_r + F_r$$
Coriolis water air pressure gradient sea ice

This allows for an analytical solution of iceberg velocity, v_i , in terms of surface ocean current and wind velocities, v_w and v_a :

$$ec{v}_i = ec{v}_w + C(lpha k imes ec{v}_a + eta ec{v}_a)$$

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ight) \ & \mathbf{eta} = \mathbf{eta} \left(L, |ec{\mathbf{v}}_{a}|
ight) \end{aligned}$$

Here, c_a and c_w are bulk drag coefficients and L iceberg length.

Decay:

Iceberg decay evolves as $\frac{dL}{dt} = \frac{dW}{dt} = M_w + M_t$ and $\frac{dH}{dt} = M_b$ where



3. MODEL ICEBERG TRAJECTORIES AND FRESHWATER FLUX

We consider 10 initial iceberg sizes, with dimensions ranging from $100 \times 67 \times 67$ m to $1500 \times 1000 \times 300$ m. 1000 icebergs of each size are released in the North Atlantic over simulation years 1992-2005. The icebergs move as Lagrangian particles following the precomputed circulation fields.

TRAJECTORIES AND TOTAL FRESHWATER FLUX FROM ICEBERG MELT



25 iceberg trajectories simulated using (a) ECCO2 output fields or (b) CCSM4 output fields for 5 different size classes. (c) ECCO2 freshwater flux in cm per 100 km³ of iceberg volume released; red square indicates the iceberg seeding region. (d) As in panel c but for CCSM4. (e) Difference in freshwater flux between CCSM4 and ECCO2, with red shading indicating more ECCO2 flux and blue shading indicating more CCSM4 flux.



ICEBERG TRAJECTORY LENGTH AND LIFE SPAN IN ECCO2 AND CCSM4 SIMULATIONS

(a) Total distance traveled by icebergs at the time of final melt, d_m, showing that ECCO2
 icebergs (blue) travel farther than CCSM4 icebergs (red) for most size classes. Each square shows the average over all trajectories for one initial size class, and error bars indicate 1σ. (b) Time of final melt, t_m, for each size class, showing that ECCO2 icebergs live longer than CCSM4 icebergs.

4. DIFFERENCES IN ICEBERG TRAJECTORIES, FRESHWATER FLUX, AND SURFACE CONDITIONS

We find that ECCO2 icebergs stay closer to the coast and reach more southern latitudes than CCSM4 icebergs, which remain in more northern and eastern regions.

The most pronounced difference in the circulation fields is that **wind speeds are considerably higher in CCSM4 than in JRA-25/ECCO2.** This is representative of GCMs in CMIP5, which tend to simulate mid-latitude westerlies that are too strong compared to observational estimates [3].

Differences in ocean current velocities appear to be small, with CCSM4 simulating the western boundary currents in Greenland and Labrador reasonably well.



SSTs, surface currents, and surface winds, averaged over 14 years from 1 Jan 1992 (start of the ECCO2 dataset) to 31 Dec 2005 (end of the CCSM4 Historical simulation)

One might expect that the bias toward stronger westerlies in CCSM4 would lead to a greater spread of iceberg meltwater. However, the opposite occurs: despite much weaker winds, ECCO2 icebergs travel slightly farther than in CCSM4.



ii. the faster flowing Labrador Current in ECCO2 advects icebergs more rapidly southward close to the coast.

5. IMPACTS OF MODEL BIASES IN SURFACE WINDS AND BOUNDARY CURRENTS

Surface wind velocities play an important role in the distribution of iceberg meltwater: they are dominant drivers of both iceberg drift **and** iceberg decay.

ICEBERG CHARACTERISTICS VERSUS AVERAGE WIND SPEEDS IN THE "WIND-ONLY" MODEL RUNS



(a) Mean iceberg speeds versus mean wind speeds. Each dot corresponds to the alongtrack average of one individual iceberg trajectory. 500 trajectories are shown. ECCO2 and CCSM4 icebergs are indicated in blue and red. (b) Iceberg life span versus wind speed. (c) The total distance traveled for each iceberg versus wind speed.

ICEBERG CHARACTERISTICS VERSUS AVERAGE WIND AND OCEAN CURRENT SPEEDS IN "FULL" MODEL RUNS



The top row is as in the previous figure, but for output from the full model runs that include ocean currents. The bottom row shows the same iceberg characteristics as the top row, but plotted against ocean current speeds.

CONCLUSIONS

- The rate of iceberg decay is dominated by surface wind speeds, while the spread of iceberg meltwater is also strongly dependent on the ocean currents.
- The release of iceberg meltwater computed from the CCSM4 model output is limited to a region that is too far north and east.
- This may have important consequences for the simulation of the Atlantic Meridional Overturning Circulation.

REFERENCES

- 1. Wagner, Dell, Eisenman (2017), J. Phys. Oceanogr, in review
- 2. Bigg et al. (1997), Cold Reg. Sci. Tech. 26 (2)
- 3. Lee et al. (2013) J. Clim. 26 (16)