Annual renewal of Ilulissat Icefjord: observations and model

Carl V. Gladish (NYU Abu Dhabi), David M. Holland (NYU), Aqqalu Rosing-Asvid (Gr'lnd Inst. Nat. Res.)

Introduction

Jakobshavn Isbrae (JI), at the head of the Ilulissat Icefjord, appears to be sensitive to oceanic temperature changes and, since the late 1990's, has been losing mass rapidly [1, 2].

The main fjord basin into which JI discharges is quite deep (750 − 800 m) but the fjord entrance has a shallow sill with a maximum depth of 260 m, [3] which could modulate the variability of water in the fjord as compared to water masses outside the fjord in Disko Bay. Surveys inside the fjord have been prevented by the presence of large icebergs blocking the fjord mouth.

Temperature variability in the region has been associated with gyre scale variability [1, 4] yet the final transfer of heat to the glacier depends on flow through the shallow-silled Ilulissat Icefjord. Therefore, understanding the specific fjord dynamics controlling the exchange of water between the fjord and Disko Bay is important for quantifying oceanic thermal forcing on JI.

Methods

In order to monitor thermal forcing near the marine terminus of JI, we obtained vertical profiles of temperature and salinity just outside the fjord mouth of the fjord using a Seabird CTD and inside the fjord using expendable probes (XCTD) deployed from a helicopter in summers of 2009 to 2012. In addition, hydrographic data collected by the Greenland Institute of Natural Resources in Disko Bay during the same summers was compared with fjord observations (Fig 2).

Using the MIT general circulation model, we simulated the response of the fjord to changing boundary conditions outside the fjord mouth. In a control run we were able to simulate the renewal of fjord waters in response to boundary conditions that are held fixed for one model year at the 2009 values, then 2010 values, then 2011 values. In the control run, the physical processes activated are: surface wind stress, ice-ocean interaction at the glacier front, a parameterization of iceberg melting, freshwater surface fluxes, KPP vertical mixing, and subglacial discharge of freshwater. We also performed runs with baroclinic forcing outside the fjord (with and without subglacial discharge). Tidal forcing was not included.

A series of runs were performed in which the various physical processes were individually suppressed in order to determine which were necessary to carry out the observed annual renewal of the fjord basin waters. The temperature responses of the modelled fjord basin waters for all runs is shown in Fig 4.

Ilulissat Icefjord

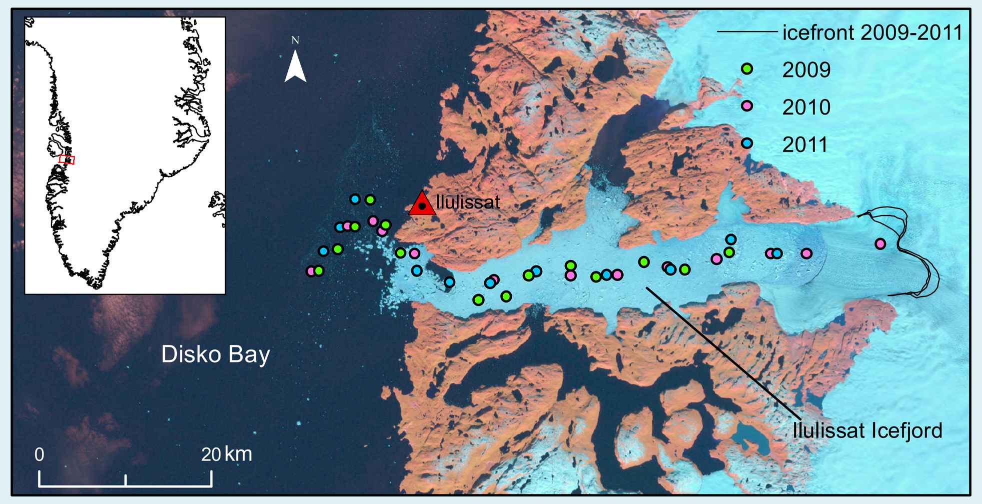

Fig 1. **Map of Ilulissat Icefjord** Locations of profiles shown in Fig 2 are shown.

Evidence for annual renewal

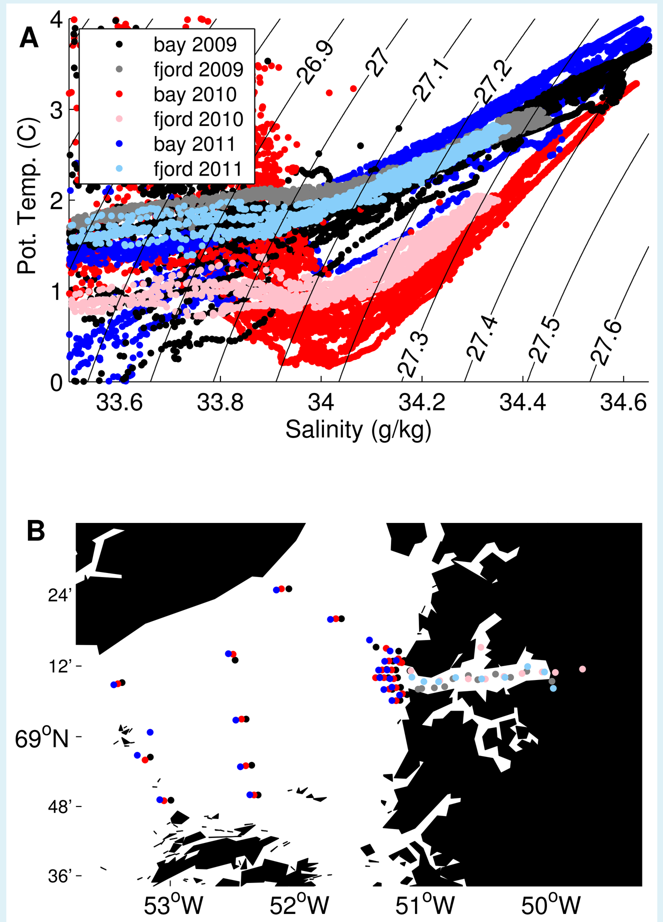

Fig 2. **Temperature-Salinity** TS properties show a distinct water mass filling the fjord and Disko Bay in 2010, compared to 2009 and 2011, which were similar.

Model Description, in brief

- vertical planar domain, no Coriolis acceleration
- idealized bathymetry (Fig 4) representing the deep fjord basin, shallow sill, and Disko Bay
- non-hydrostatic, KPP mixing, Orlanski open boundary to the west
- zonal wind stress of -1.3×10^{-2} Pa
- $3.4\,\mathrm{km^3 a^{-1}}$ subglacial discharge (from [5])
- $5\,\mathrm{km^3 a^{-1}}$ surface flux of freshwater (postulated terrestrial runoff and aerial melting of icebergs)
- for baroclinic forcing, 50 m oscillations of pyconocline with two week period
- horiz. eddy diffusivity and viscosity of $10\,\mathrm{m^2 s^{-1}}$
- 10 m vertical levels, horizontal grid spacing varies from 1000 m outside fjord to 200 m next to glacier

Along-fjord Pot. Temp. Obs.

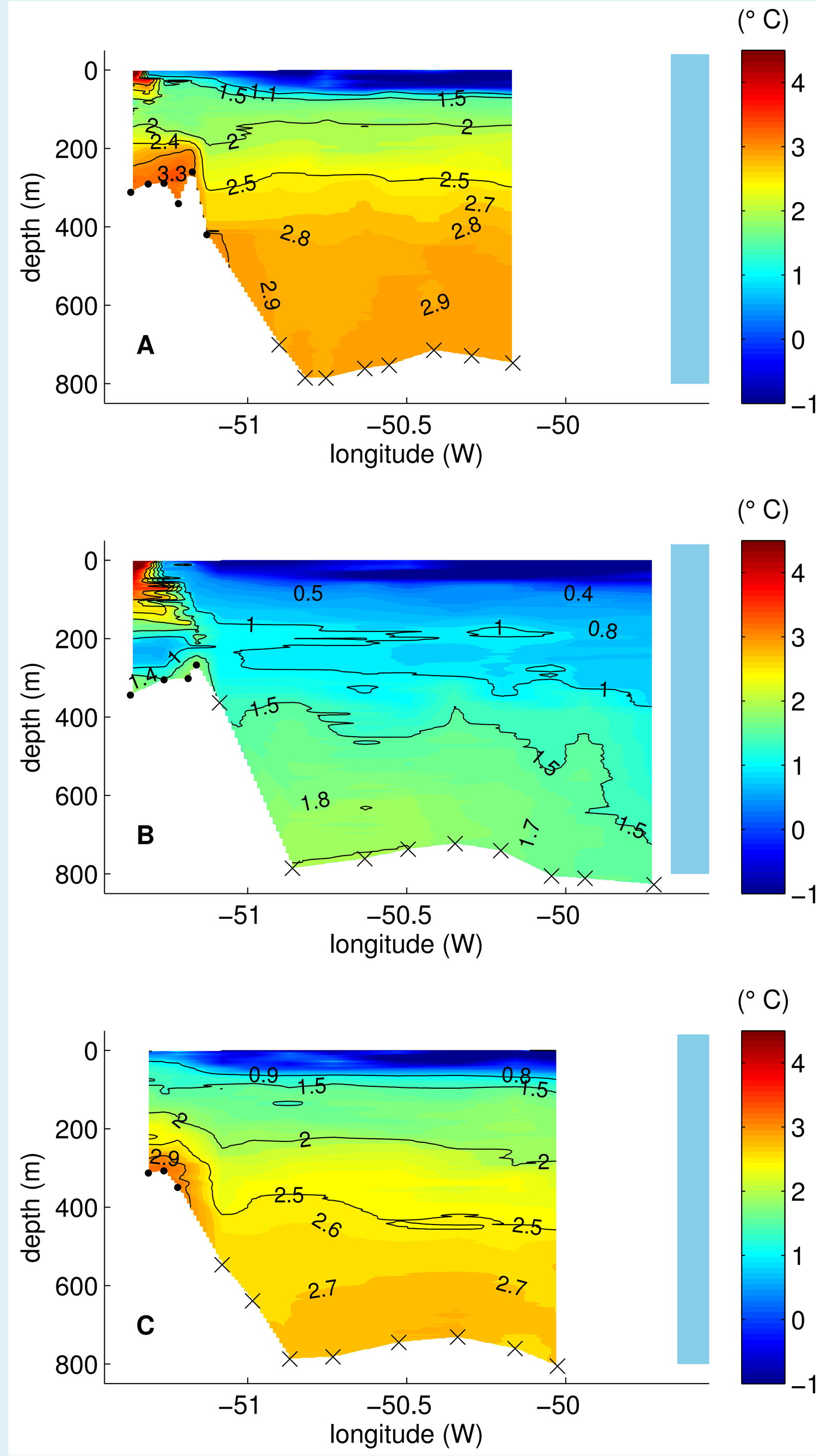

Fig 3 **Potential Temperature** A. Pot. temp. late July 2009. Profile locations (marked by X or dot) as in Fig 1. Glacier terminus is indicated by the light blue bar. B. Same, early Aug 2010. C. Same, mid July 2011.

Model Results

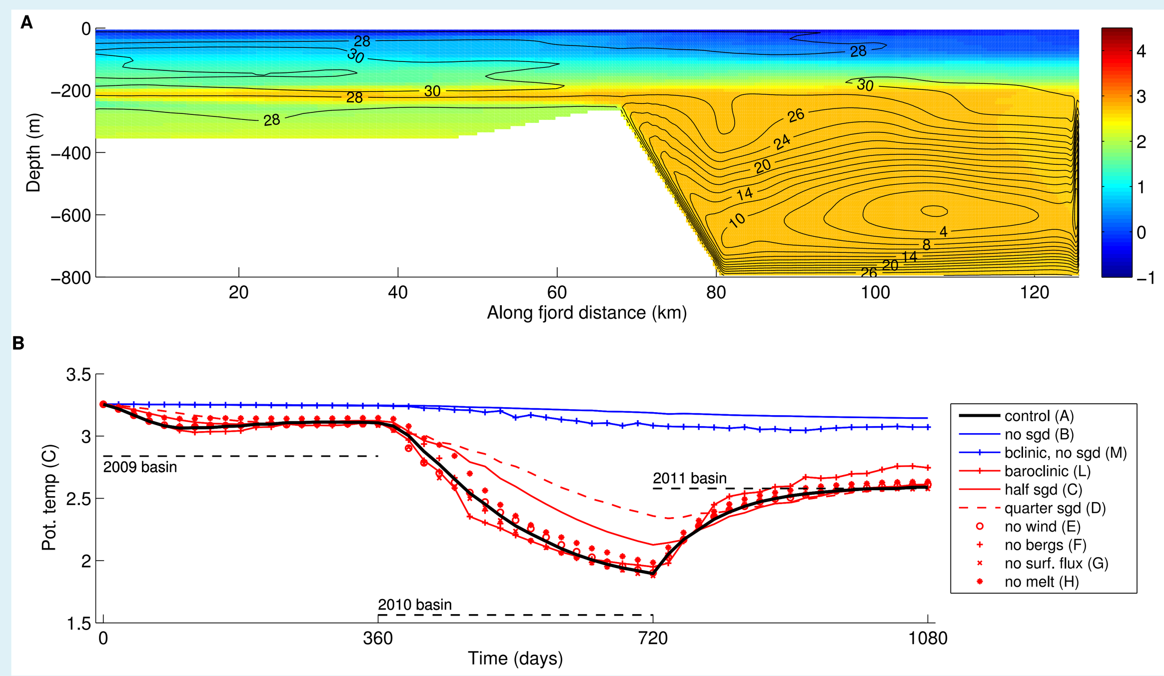

Fig 4 **Model results** A. Pot. temp. and stream-function ψ (velocity $(u, w) = (-\partial\psi/\partial z, \partial\psi/\partial x)$) at day 450 of the simulation. B. Mean potential temperature of model fjord basin waters (below 300 m). Western boundary conditions for T and S were held fixed during each of the three 360 day segments along the horizontal axis (at 2009, 2010, and 2011 values, respectively).

Conclusions

In all summers, water properties in the fjord basin approximately matched a subset of those observed in Disko Bay (Fig 2). Water temperatures in 2009 and 2011 were about a degree warmer than in 2010 (Fig 3), which is similar in magnitude to the temperature shift occuring in 1997 in the region [1, 6]. The warmest waters in 2009 and 2011 (over $3.5°C$) and 2010 (over $3.0°C$) observed in the Bay were not observed in the fjord. These bottom waters are presumably blocked by bathymetric highs (in particular, the fjord sill) from entering the fjord. The bottom 400 m of the fjord basin was generally quite homogeneous (in obs. and in the model, Figs 3 and 4A).

The model results suggest that renewal of the fjord water may be driven mainly by buoyancy provided at the glacier's grounding line by discharge of subglacial freshwater. With such buoyancy forcing, the fjord basin temperature tracks the observed values relatively well (Fig 4) with the suppression of wind, iceberg melting, glacier terminus melting, or surface freshwater flux (Fig 4) having no significant effect on the renewal rates. If subglacial discharge is suppressed, however, renewal does not occur, even with the addition of baroclinic forcing at the fjord mouth (blue curves, Fig 4), which quickly flushes out water above the sill depth and increases shear relative to the deeper basin water.

The model suggests (see closed stream-lines in Fig 4) there is a "washing-machine"-like overturning circulation below the sill depth such that water cycles around the basin several times before it is modified enough by subglacial discharge to be ejected over the sill.

Average modelled melt rates along the glacier terminus were 130,90, and $120\,\mathrm{m\,a^{-1}}$ with 2009, 2010, and 2011 conditions, respectively. There was therefore a 25% variation in total melt associated with the temperature change at the fjord mouth. These melt rates are probably underestimates, since re-running the 2009 simulation at higher resolution (25 m near the ice front) and with eddy diffusivities and viscosity of $1.0\,\mathrm{m^2 a^{-1}}$ resulted in a mean melt rate of $450\,\mathrm{m\,a^{-1}}$, which is closer to estimates for nearby glaciers [7].

References

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