A calving law for ice shelves: spreading-rate control of calving rate

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No generally accepted law or rule relates the rate of production of icebergs from a floating ice shelf to physical controls of the process. The lack of such a ³calving law² for ice shelves restricts accurate modeling of the behavior of ice sheets and their effect on sea-level change (e.g., Meier, M.F., 1990, Role of land ice in present and future sea-level change, Ch. 10 in Sea-level change, National Academy Press, Washington, DC; note that more work has been on calving from non-floating tidewater termini, although a generally accepted calving law is also lacking there.)

For example, the friction from ice-shelf contact with a high spot in the sea-bed contributes to buttressing of flow from the ice sheet, slowing ice motion so that sea level is lower and the ice sheet larger than in the absence of such buttressing. Whether an ice shelf will extend to a potential pinning point cannot now be modeled accurately because of lack of a calving law (except through specification as an initial condition), so the buttressing effect of ice shelves and thus the volume of ice sheets cannot be modeled confidently.

A ³calving law² almost certainly depends in a highly complex way on several things, including: i) forcings contributing to calving (tidal fluctuations, storm surges, collisions from icebergs, meltwater wedging of crevasses); ii) pre-existing populations of flaws along which calving occurs (and which in turn depend on past forcings perhaps in different locations‹for example, the tidal flexing of ice at the grounding line contributes to basal crevasses that may contribute to calving after being advected through an ice shelf to near the ice front); iii) ice properties that affect fracture propagation (temperature, c-axis fabric, impurity loading, thickness, density); and iv) healing of fractures (with temperature likely most important as a control on refreezing of water in basal or surface crevasses). This incomplete list surely shows the daunting task facing anyone proposing a calving law, and explains why an accepted calving law is not available to modelers now.

However, arguably the most important factor in calving from cold ice shelves (those in which meltwater wedging is not dominant) is the spreading tendency of the ice; if crevasses did not tend to open, we can speculate that ice shelves would be very different. This leads to our hypothesis, that the first-order control on the rate at which ice shelves fall apart is their tendency to fall apart.

To test the hypothesis, we note that in most cases the calving rate is very close to the velocity near the ice front. (With notable exceptions such as the Larsen B in early 2002, maps of ice shelves made at different times are recognizably similar after years or decades, allowing a steady-state approximation averaged over the time for a few calving events to occur.) The ice-front-normal spreading stress (which is approximately the along-flow spreading stress except very close to shear margins) is probably the most relevant variable but in general is not measured, whereas the corresponding strain rate is measurable, increases monotonically with the stress, and might be the most important controlling variable in some physical formulations (e.g., if the competition between opening and refreezing of basal crevasses is most important, strain rate rather than stress may be the key variable). We thus hypothesize that, across a range of ice shelves, the observed velocity near the ice front (which approximates the calving rate) will increase with the along-flow spreading rate near the ice front, using data taken away from intense shear zones along ice-shelf margins or pinning points where complex stress states may complicate the situation.

We are in the process of assembling data, primarily from ice shelves in Antarctica but including shelves in Greenland. Our preliminary results are encouraging; shelves with stronger spreading at their ice fronts are faster-moving, implying that the rate at which ice shelves fall apart is controlled primarily by their tendency to fall apart (calving rate increasing as a power of the spreading rate near the calving front). This does not explain all of the variance in the data set, but explains enough of the variance that we are hopeful of obtaining a useful relation.

We have not yet been able as a group of authors to discuss all of the available data, or to agree on exact meanings of terms such as ³near the calving front² (although it appears that almost any reasonable assumptions will yield the same basic answer), nor have we agreed on a preferred form of the probationary ³calving law². We are making a public presentation of the preliminary results at this time in part to encourage holders of other data sets to contribute them, and to stimulate discussion. An ice-shelf calving law is fundamental to ice-flow modeling, has thus far been unavailable, but might prove to be relatively easy in first approximation, although with numerous second-order terms.