The Greenland Ice Sheet
Overview

- Greenland in context
- History of glaciation
- Ice flow characteristics
- Variations in ice flow
- Extent and consequences of melting
Greenland in context
Why is there so much more ice on Greenland than on other land masses at the same latitude? (e.g. Ellesmere Is., Baffin Is., Iceland, Svalbard, northernmost Russia)
Ice thickness
Ginny’s photos from last month
Precipitation from observations: (ice-cores, manned weather stations in coastal areas and automatic weather stations)
Profiles of the Antarctic and Greenland Ice Sheets

- **West Antarctic Ice sheet**
- **East Antarctic Ice sheet**
- **Greenland Ice sheet**

**Drawings:**
- East-west profile at 90° S
- East-west profile at 72° N

- **GISP-2**
- South Pole
- Trans-Antarctic Mountains

- 4000 m
- 3000 m

**Scale:**
- Both drawings at same scale
- 3 km
- 1000 km

**SE-2012**
History of Greenland and Antarctic glaciation
Modelled extent of Greenland ice during last interglacial and last glacial maximum

Marshall and Cuffey, 2000
Greenland ice flow patterns and velocities

Ice velocity animation

Changes in flow rates

A recent paper, “21st-century evolution of Greenland outlet glacier velocities”, (Moon et al., 2012), presented observations of velocity on all Greenland outlet glaciers – more than 200 glaciers – wider than 1.5km.

1) Most of Greenland's largest glaciers that end on land saw small changes in velocity.
2) Glaciers that terminate in fjord ice shelves didn't gain speed appreciably during the decade.
3) Glaciers that terminate in the ocean in the northwest and southeast regions of the Greenland ice sheet, where ~80% of discharge occurs, sped up by ~30% from 2000 to 2010 (34% for the southeast, 28% for the northwest).
Greenland ice mass-balance data
(from Ringot and Kanagaratnam, 2006)

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<th>Region</th>
<th>area (km$^3$)</th>
<th>1996</th>
<th>2000</th>
<th>2005</th>
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<td>North</td>
<td>464,876</td>
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<td>East</td>
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<td>47</td>
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<tr>
<td>Total</td>
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<td>92</td>
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| Total corrected | 91 ($\pm 31$) | 138 ($\pm 31$) | 224 ($\pm 41$) |

Fig. 1. Ice-velocity mosaic of the Greenland Ice Sheet assembled from year 2000 Radarsat-1 radar data, color coded on a logarithmic scale from 1 m/year (brown) to 3 km/year (purple), overlaid on a map of radar brightness from ERS-1/2 Radarsat-1/2mssat. Drainage boundaries for flux gates in Table 1 are in red. Drainage boundaries with no flux estimates but discussed in the text are in blue. Numbers refer to drainage basins in Table 1.
From data in Ringot and Kanagaratnam, 2006
The sum of the interpolated mass loss over the 10-year period from 1996 to 2005 is 1518 km$^3$.

The total volume of Greenland’s ice sheet is about 2,900,000 km$^3$. This 10 years of loss is equivalent to 0.05% of that volume.

However, mass-loss rates are increasing, and the cumulative loss by the end of this century is likely to be a few per cent.

The loss of 5% of Greenland’s ice would be equivalent to a sea-level rise of ~35 cm.
Ice-shelf calving is typically caused by warmer air and water, but it can contribute to increased ice-sheet velocities.
GREENLAND MELTING: To some extent, there has always been seasonal melting, and moulins (meltwater) have formed in the past. But those formations were nothing like what is happening now. In recent years, the melting has accelerated dangerously. In 1992 scientists measured this amount of melting in Greenland as indicated by the red areas on the map. Ten years later, in 2002, the melting was much worse. And in 2005 it accelerated dramatically yet again. If Greenland melted or broke up and slipped into the sea -- or if half of Greenland and half of Antarctica melted, sea levels worldwide would increase by between 18 and 20 feet.
Moulin
Just kidding!
Impact of melting on ice-flow rates

- A large proportion of surface melt-water is transmitted to the base of the ice sheet, either in small cracks or larger conduits (moulins)
- At the ice-rock contact this water helps to lubricate the sliding surface, and if it’s under pressure from water above, it can significantly reduce the friction, resulting in dramatically increased ice-flow rates
Summer ice-flow velocities are up to twice that of winter velocities

Sundal et al., 2011, Melt-induced speed-up of Greenland ice sheet offset by efficient subglacial drainage, Nature, V. 469
Flow rates can be directly linked to runoff rates

Run off (blue) versus ice velocity (bars) for years with low melting rates

But flow rates decrease later in the melt season in years of high runoff

Run off (yellow) versus ice velocity (bars) for years with high melting rates

Sundal et al., 2011
The important factor appears to be the nature and timing of the melt-water flow

- Early during the melt season, and when flow rates are relatively low, the flow will be diffuse (through small fractures) and this will ensure that water pressure remains high
- Later in the season, or if there is a strong melting event, the flow becomes focussed into sub-ice channels and since the drainage is more efficient, the effective water pressure drops and the ice slows down

Evidence for water flow in a sub-glacial cavity on the Howe Sound glacier at Squamish
In general, melting promotes rapid ice-advance, but very strong melting can lead to channelization of sub-glacial water and a drop in water pressure (which slows the ice down).

Rapid ice advance is favoured at relatively low melt rates, or if the melting is episodic over the melt season, and channels do not develop fully.