The Earth’s ice cover in a warming climate

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“Many glaciers, the Greenland Ice Sheet, the Antarctic Peninsula, permafrost, Arctic sea ice, snow cover are exhibiting dramatic changes that are of significant concern for science and international policy.”

“These indicators of climate remain one of the most under-sampled domains in the climate system.” (IGOS Cryo 2007)
Forms of ice in the climate system


Seasonal Snow - NH

Frozen ground ("Permafrost")

Glaciers and Ice Sheets (snow piled up on land year after year…until it flows under its own weight)

Sea Ice and Lake Ice - frozen water that melts every spring, except in the high Arctic
Sea Ice - max and min extent, effect on absorption of sun light, and global ocean circulation
Arctic Sea Ice
Antarctic Ice Shelves

Made of thick floating ice that formed from snowfall on land and flowed through glaciers to the sea - much thicker than Sea Ice

(hundreds of meters vs 1-4 meters)
Larsen B Ice Shelf (Antarctica) 2002
Larsen B Ice Shelf (Antarctica)  2002

Photo: S. Tojeiro, Fuerza Aerea Argentina, 13 March 2002.
Land Ice

Photographed in 1941

Photographed in 2004
Rate of future sea level change: hard to predict

A report of Working Group I of the Intergovernmental Panel on Climate Change Summary for Policymakers:

“Models used to date do not include … the full effects of changes in ice sheet flow, because a basis in published literature is lacking.

… if this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios … would increase by 0.1 to 0.2 m. …

Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise."
Science Objectives: Land ice

- Determine the mass balance of ice sheets in Greenland and Antarctica and their contribution to sea level change.
- Understand the physical controls on ice dynamics to develop a predictive capability for ice-sheet evolution and contribution to sea level change.
In the last decade there have been large changes in Antarctica and Greenland. These changes in outlet glacier flow are due to forcings that have climate connections.

The questions driving glaciological research on the large ice sheets have broadened from a focus on measuring large-scale mass balance to include a focus on understanding rapid changes in that balance, including:

1 - drivers of rapid change in outlet glacier flow (climate system interactions)

2 - mechanisms responsible for the response (ice flow, water influence, calving)

3 - how changes in outlet systems will couple back into the the ice sheet proper => seeking predictability
Large-scale change in outlet systems can be found many places in Greenland
Outlet systems may exhibit large annual changes: Jakobshavns Isbrae - two years of flow, advance, and retreat (summers omitted from series) (I. Joughin - RADARSAT imagery)
Changes at the terminus can be large and rapid - such as this calving event on Jakobshavns Isbrae

(J. Amundson, UAF)
JAK has retreated for centuries - was the mid-twentieth century pause (stable front position) due to cool climate?

Figure from Joughin, 2005
The recent retreat has been accompanied by a doubling of ice flow speed and ice flux as ice bergs into the ocean.
Satellite and field measurements in Greenland have shown us that many outlet glaciers have accelerated in the last decade. As a direct result, many outlet glaciers have shown rapid thinning due to the increased ice loss. The rate of mass loss is around 100 km³ per year. The acceleration may be due to increased surface melt water reaching the bed, or a change in the ocean/land ice interaction.
Land Ice and Sea Level

A Glaciologist’s view of sea level math:

1 km³ of ice = 2.54 microns of S.L.
100 km³ = 0.254 mm S.L.
10,000 km³ = 2.54 cm = 1 inch

half a meter of S.L. rise over the next 50-100 years: 200,000 km³