Cryospheric Sea Level Rise

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Cryosphere

- Ice sheets
- Glaciers & Ice Caps
- Permafrost
- Snow
- River Ice

Legend
- Sea Ice
- Sea Ice 30 Yr Ave Extent
- Snow Extent Line
- Continuous Permafrost
- All Permafrost
- Ice Sheet

Joey Comiso, NSAS/GSFC
What Causes Sea Level to Change?

- Terrestrial water storage, extraction of groundwater, building of reservoirs, changes in runoff, and seepage into aquifers
- Surface and deep ocean circulation changes, storm surges
- Subsidence in river delta region, land movements, and tectonic displacements
- As the ocean warms, the water expands
- Exchange of the water stored on land by glaciers and ice sheets with ocean water
Cryospheric Sea Level Rise

Volume = 28.4 M km³

Sea Level Rise (IPCC 2007)
100% = 1.28 mm/yr

Sea Level Rise (Grace 2010)
100% = 2.2 mm/yr

Comparison of total volume (left), and total contribution to sea-level rise from glaciers & ice caps and the ice sheets in Greenland and Antarctica.
Global mean sea level evolution since 1870

Historical data (Church & White, 2006)
Rate: 1.7 ±0.3 mm/yr

Satellite altimetry era (since 1993)
Rate: 3.3±0.4 mm/yr

Coupled climate models
IPCC, 2007

Today
Snow accumulation

Ablation

Iceberg calving

Equilibrium line

typical for

Greenland ↔ Antarctica

Ice sheet

Iceberg calving

max 3028 m

max 4775 m

mean 2034 m

Ice thickness

Ice thickness

Ice thickness

subglacial melting

Rock

Ocean

Dimension: 500 - 1000 km
Area: 1.7 M km²
Volume: 2.9 M km³, 7.3 m SLE
Total Acc.: 500 Gt a⁻¹, 1.4 mm SLE

Dimension: ca. 2000 km
Area: 12.3 M km²
Volume: 24.7 M km³, 56.6 m SLE
Total Acc.: 1850 Gt a⁻¹, 5.1 mm SLE

Dimension: 100 - 600 km
Runoff \((250-350 \text{ Gt/yr})\)

Precipitation \((550-640 \text{ Gt/yr})\)

Evaporation \((5-63 \text{ Gt/yr})\)

Surface Mass Balance \(\text{SMB} = P - R - E\)

Ice Discharge \((320-420 \text{ Gt/yr})\)

Im-Balance \((50-200 \text{ Gt/yr})\)
Mean annual air temperature increased by 4 °C since 1991 (~2 °C/decade)
Surface mass balance is negative since 1996
Total Greenland ice sheet melt area increased 65% since 1979 over the 30 year record; on average 2%/year. The increasing trend in the total area of melting bare ice is at 13% per year.
Changes in the elevation over the Greenland ice sheet measured by ICESat for 2003-2006 (W. Abdalati, J. Zwally, NASA/GSFC)
Mass loss increased in 05.

Mass loss increased in 04/05. Decreased in 07/08.

Rate of total mass loss: 240 Gt/a, equivalent to 0.66 mm/yr sea level rise.

J. Wahr, I. Velicogna
Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters
David Holland, Robert Thomas, Brad de Young, Mads Ribergaard, and Bjarne Lyberth
AVHRR 1982 - 2004 analysis (Joey Comiso, NASA/GSFC)
Changes in ocean circulation and ocean temperatures will produce changes in basal melting, but the magnitude of these changes is currently not modeled or predicted.

West Antarctic ice sheet (7 m SLE) grounded below sea level on marine sediment experiencing high geothermal heat flow.
Antarctic Ice Velocity and Mass Loss

Rate of mass change during April 2002 - Feb 2009

Rate of mass change after removing ICE5G rebound model:
- All Antarctica: \(-169 \text{ Gt/yr}\)
- West Antarctica: \(-128 \text{ Gt/yr}\)
- East Antarctica: \(-36 \text{ Gt/yr}\)

Uncertainty of post-glacial rebound correction:
- All Antarctica: \(\pm 75 \text{ km}^3/\text{yr}\)
- West Antarctica: \(\pm 20 \text{ km}^3/\text{yr}\)
- East Antarctica: \(\pm 50 \text{ km}^3/\text{yr}\)

\(-169 \text{ Gton/yr} = 0.47 \text{ mm/yr sea level rise}\)

The results depend critically on which rebound model is removed.
- After removing ICE-5G rebound prediction
  - All Antarctica: \(-169 \text{ Gton/yr}\)
- After removing Ivins&James rebound prediction
  - All Antarctica: \(-122 \text{ Gton/yr}\)

John Wahr, Univ. Colorado
Ice Sheet Mass Change Acceleration 1992-2010

- In 2006, the Greenland and Antarctic ice sheets experienced a combined mass loss of $475 \pm 158$ Gt/yr, equivalent to $1.3 \pm 0.4$ mm/yr sea level rise.
- Acceleration in ice sheet loss over the last 18 years was $21.9 \pm 1$ Gt/yr$^2$ for Greenland and $14.5 \pm 2$ Gt/yr$^2$ for Antarctica, for a combined total of $36.3 \pm 2$ Gt/yr$^2$.
- Acceleration is 3 times larger than for mountain glaciers and ice caps ($12 \pm 6$ Gt/yr$^2$).

Rignot et al., 2011, GRL
Glaciers and Ice Cap Changes since 1970

Effective Glacier Thinning (m / yr)
Glaciers and Ice Caps

Leclercq et al., 2011, Surv. Geophys.
Currently, accumulation areas are too small, forcing glaciers to lose 27% of their volume to attain equilibrium with current climate, resulting at least $184 \pm 33$ mm SLR.

Based on data from Dyurgerov and Meier (2005)
Rhone Glaciers 1856
Conclusion

- Mean SLR from Greenland and Antarctica ~ 1mm/yr (2000-2010)
- Mean SLR by glaciers and ice caps ~1.4 mm/yr (2000-2010)
- Total cryospheric SLR 2.4 mm/yr; increasing to 2.8 mm/yr (2010)
- Acceleration of ice loss from ice sheets 3 times larger than from glaciers and ice caps