Het smeltende ijs van Groenland en Antarctica

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Predicted vs. observed sea level change

Predicted:
Expansion: ≈ 1 mm yr⁻¹
Ice caps, glaciers: ≈ 1 mm yr⁻¹

Observed:
≈ 3 mm yr⁻¹

Missing:
≈ 1 mm yr⁻¹ or ≈ 360 Gt yr⁻¹

Source?
GRACE mass trends (2003-2008)

Courtesy: Bert Wouters
13 years of GRACE mass changes

Antarctic ice sheet

-85 ± 42 Gt/yr
-17.9 ± 2.1 Gt/yr²

Greenland ice sheet

-273 ± 58 Gt/yr
-14.3 ± 1.0 Gt/yr²
Two types of ice sheet margins

Ice sheet with maritime periphery...... and land periphery

- equilibrium line
- grounding line
- accumulation zone
- equilibrium line
- ablation zone

- calving
- ice shelf
- basal melting
- bedrock
Greenland in the Arctic

NASA/MODIS
Close-up of south Greenland

NASA/MODIS
Meltwater lake in Greenland ice sheet ablation zone

Photo: Ian Joughin
Moulin on Greenland ice sheet

Photo: Jason Box
Byrd glacier, Antarctica

NASA/MODIS
Polarstern (Germany) at Ekström Ice Shelf

Photo: AWI
Calving of giant iceberg from Ross Ice Shelf, Antarctica
Ice sheet mass balance: $MB = SMB - D$

- **Snowfall**
- **Surface mass balance (SMB)**
- **Equilibrium line**
- **Grounding line**
- **Accumulation zone**
- **Ablation zone**
- **Ice discharge $D$**
- **Meltwater runoff**
- **Calving**
- **Basal melting**
Three methods to determine ice sheet mass balance

1. Altimetry (1991-present)
   **Method:** change in surface elevation provides changes in ice sheet volume
   **Main challenge:** conversion from volume change to mass change

2. Gravimetry (2003-present)
   **Method:** changes in the Earth gravity field provide changes in ice sheet mass
   **Main challenge:** correction for glacial isostatic rebound

   **Method:** difference of surface mass balance and ice discharge gives mass change
   **Main challenge:** small difference of two large components sensitive to large uncertainty
CryoSat-2 elevation change

Helm and others, 2014
Recent Greenland ice sheet mass loss

Enderlin and others, 2014
Recent development: NE Greenland ice stream

Khan and others, 2014
CryoSat-2 elevation change

Helm and others, 2014
Mass loss in West Antarctica is accelerating...

*Sutterley and others, 2014*
...and spreading north
Antarctic bedrock topography

West Antarctica

Wilkes Land

Colors:
- Yellow: > 2 km
- Green: 1 to 2 km
- Light green: 0 to 1 km
- Light blue: -1 to 0 km
- Blue: -2 to -1 km
- Purple: -3 to -2 km
- Violet: -4 to -3 km
- Dark blue: < -4 km
Recent development: East Antarctica

Helm and others, 2014
Estimates of ice sheet mass balance, 1990-2012

Hanna and others, 2013
The 2015 Zwally and others result

Antarctic Ice Sheet

Trusel, 2015
Cumulative land ice contribution to eustatic sea level rise

IPCC AR5, 2013
Conclusions

- Ice sheets have contributed ~1/3 to recent (2002-present) sea level rise
- Mass loss from ice sheets is accelerating and now greater than contribution of small ice caps/valley glaciers
- Greenland ice sheet mass loss is dominated by surface processes (atmosphere driven)
- Antarctic ice sheet mass loss caused by dynamic processes through basal melting of ice shelves (ocean driven)
- Dynamic ice sheet mass loss is extending to northeast Greenland and East Antarctica
- Ice sheet mass balance well constrained for 1992-present, poorly constrained further in the past and into the future