Ice Sheets, Glaciers, and Sea Ice

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Scope of this Workshop: Observational and research needs for adaptation to climate variability and change

- Data availability to inform implementation of adaptation
  - Very limited for most parts; case studies, remote sensing, modeling for extrapolation

- Defining core data sets to maintain stewardship in management of resources
  - Depends on the field of application; examples for sea level uncertainties will be given as examples from the cryosphere

- Adequacy of networks for detection of climate trends
  - In general most areas are under-sampled for accurate assessments in polar regions

- Local capabilities to observe, monitor, rescue, archive, process and sustain climate data and networks
  - In remote areas such as polar regions the local capabilities are missing; replaced by autonomous monitoring and remote sensing
Global Mean Sea Level since 1900

Satellite altimetry era (since 1993)
Rate: $3.3 \pm 0.4$ mm/a

Historical data (Church & White, 2006)
Rate: $1.7 \pm 0.3$ mm/a
Global Sea Level Rise Scenarios

Global mean sea level rise

Mean over 2081–2100

Year

(m)

2000 2020 2040 2060 2080 2100

RCP2.6 RCP4.5 RCP6.0 RCP8.5
Greenland Ice Sheet Mass Balance

Precipitation (550-640 Gt/a)

Evaporation (10-45 Gt/a)

Surface Mass Balance
SMB = P - R - E

Runoff (250-350 Gt/a)

Ice Discharge (320-420 Gt/a)

Negative Balance (-50 to -200 Gt/a)
Greenland and Antarctica

Sea level rise from both ice sheets: 66 m
Ice loss 1992-2001: 34±40 Gt yr⁻¹

Ice loss 2002-2011: 215±58 Gt yr⁻¹

Melt and ice dynamics make up 50% each for the ice loss

Most outlet glaciers have double their flow speed

Warming of ocean temperature around Greenland played an important role in the ice loss
Mass loss by the Greenland ice sheet increased the global sea level by 8 mm since 1992.

The mass loss accelerated since 2002.
Antarctic Ice Sheet

Mass loss 1992-2001: $30\pm67$ Gt yr$^{-1}$

Mass loss 2002-2011: $147\pm74$ Gt yr$^{-1}$

Mass loss in the Antarctic Peninsula and in the Amundsen Sea, West Antarctica
*Ice loss from Antarctica is responsible for 5.5 mm sea level rise since 1992*

*Antarctica gained mass in the 90’s and show an mass loss (ice loss) since 1998*

IPCC, AR5
Mass Loss from Ice Sheets

Cumulative ice mass loss (Gt)

- Greenland
- Antarctica

Year

Cumulative ice mass loss (Gt)
Greenland and Antarctic ice sheets are responsible for a sea level rise of 1.2 mm/yr during the time period 2007 - 2011.
Global distribution of glaciers (yellow, area increased for visibility) and area covered (diameter of the circle), sub-divided into the 19 RGI regions (white number). The area percentage covered by tidewater (TW) glaciers in each region is shown in blue. *Data from Arendt et al. (2012) and Gardner et al. (2013).*
Rhone Glacier 2050
1986: Images show degradation of forest area.

2001: Between 1984 and 1999, 38 per cent of forests were degraded.
Global cumulative (top graphs) and annual (lower graphs) glacier mass change for (a) 1801–2010 and (b) 1961–2010 (IPCC AR5)
Cryospheric Sea Level Contribution
1992 - 2012

Cumulative ice mass loss (Gt)

Year


SLE (mm)

-2 0 2 4 6 8 10 12 14 16

Glaciers
Greenland
Antarctica

IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis
Sea level will increase even if we would stop today all the GHG emissions; the system is not in balance yet with the current warming.
Uncertainties in SLR reduced

Note: Terrestrial Storage terms not included.
Sea Ice

**Arctic**

Extent ($10^6$ km$^2$)

-3.9%/decade

1990 2000 2010

**Antarctic**

Extent ($10^6$ km$^2$)

+1.4%/decade

1990 2000 2010
Sea Ice Variability in both Hemispheres

Arctic

- Bering Sea: +6.4%
- Alaska: -2.0%
- Greenland: -5.0%
- Barents Sea: -10.3%
- 5 km/day

Antarctic

- Weddell Sea: +1.3%
- Ross Sea: +4.3%
- Amundsen Sea: +3.0%
- 10 km/day

Graphs show extent (10^6 km²) from 1990 to 2010 with a trend line indicating a -3.9%/decade decrease in the Arctic and a +1.4%/decade increase in the Antarctic.
Sea Ice in the northern Hemisphere

- Large ice extent retreat in the summer month
- Sea ice cover has been reduced further in recent years

IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis
First-year ice decreased in extent by 13% per decade,
Multi-year ice decreased by even more – 15% per decade
Summary

Observed changes in the climate system:
The atmosphere and the ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentration of greenhouse gases has increased (IPCC SPM).

**Atmosphere**: each of the three decades has been successfully warmer.

**Ocean**: Ocean warming dominates the increase in energy stored in the climate system (90%).

**Cryosphere**: GIS & Ant have been losing mass, glaciers continue to shrink, and NH sea ice decreases.

**Sea Level**: SLR has been larger than the previous two millennia.

**Carbon and biogeochemical cycle**: CO₂, methane, nitrous oxide have increased to levels unprecedented in the last 800,000 years.
Question

Sensitive regions and adaptation:
Where are sensitive regions on Earth where climate change will have an impact first or most significant. Should we implement adaptation in sensitive regions first – or what are the priorities?

Challenge

Regional changes are most important but the least known:
Global sea level rise prediction has little meaning for the Pacific Ocean when the regional footprint is not known or not well understood.