The recent retreat of glaciers in the world

Consequences for the global environment
Glaciers are part of the cryosphere

Cryosphere is very sensitive to climate change

Polar Ice sheets and ice shelves – Sea ice (summer/winter) – Mountain glaciers – Permafrost – Snow covers

52-55% of land areas
Major components of the cryosphere

52–55% of the land areas

5–7% of sea surfaces

+99% of ice volumes in the polar ice sheets

From IPCC 2013

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Antarctica
East – West – Peninsula - Sea ice : 30 M km$^3$

5 main components

1. **Eastern ice sheet**: 88% of land ice volume. 75% of outlet glaciers falling on ice shelves

2. **Western ice sheet**: 10% of ice volume

3. **Peninsula**: 2% of Antarctica ice volume

4. **Ice shelves**: 1.2 M km$^2$

5. **Sea ice**: 18 M km$^2$ in September (seasonal maximum)

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Antarctica

better estimations of mass balance of polar ice sheets since the early 2000

A contrasted mass balance according to the regions

Continent (30 M km\(^3\))

- **Eastern ice sheet**: stable or slightly positive
  Due to increasing precipitation close to the coasts (sea and atmospheric temperature rose up during the last decades)

- **Western ice sheet**: becoming unstable (75% of ice loss of Antarctica).
  Main processes: acceleration of outlets glaciers and retreat of grounding lines (tens of km !)

- **Peninsula**: Rapid retreat of glaciers and desintegration of ice shelves (25 % of ice loss of Antarctica. Strong temperature increase (+2,5°C since 1950)

Mean loss estimated to ~50-60GT ice/year over the 1992-2011 period
Antarctica

West Antarctica region and peninsula loss mass at a strong rate: can ice sheets become unstable if ice shelves break down?

Ice shelves: 1.2 M km². The biggest are still stable, only the small ones are retreating by: 1) basal melting and 2) calving.

Breakdown of the Larsen B (Peninsula) Winter 2002

Breakdown of the Pine Island Glacier (Western Antarctica) October-November 2013
Grounding line retreated 31 km (2005-2009)
Antarctica sea ice seasonal and thin

Austral sea ice is globally stable or slightly increasing!

+ 1.5% per decade (not everywhere)

Why ???

Red: : increasing sea ice

IPCC 2013

King, 2014 Nature

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Greenland melts at fast rates...

Greenland is ~10 times less than Antarctica in volume 3 M km$^3$ i.e. equivalent of 7 m sea level (in case of complete melting)

Why Greenland is becoming vulnerable?

- strong warming of the Arctic zone since 30 years: +2,4°C at Summit (3200 m)
- Important warming in the North Atlantic ocean (through the Gulf stream)
- Rapid retreat of sea ice and snow cover at high latitude over the 30 last years: strong positive feedback with the albedo

Hanna et al., 2011

Meteorological station network in 2011

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Greenland: surface melting and ice discharge are ~ equivalent to

Greenland loss: ~142 MGt ice/yr
(equivalent of 0.39mm/yr of sea level rise from 1992 to 2011)

Two processes are dominant:

1. Melting rates on the surface have increased due to the recent air warming (~50% of the ice loss). In 2012, melting was observed for the first time at the Summit station.

2. Ice discharge in ocean has increased thanks to an acceleration of the outlet glaciers (50% of the ice loss)

Melting in contact with ocean water was underestimated.
Greenland: a more and more negative mass balance

Acceleration of the outlet glaciers, retreat of the grounding line and melting on contact with ocean

Jakobshavn Isbrae: 1851-2006 – 40 km

Jakobshavn Isbrae (6 to 12 km/yr from 1992 to 2003)

Disintegration of ice shelves Ward Hunt (nord)

Increasing melting at the surface: 30-50% of Greenland in summer in average (98% in 2012)
The most impressive picture of Arctic warming is the rapid retreat of sea ice

- Loss of 40% area and 50% volume during the last 30 years
- ~ - 11% per decade during the 1979 – 2012 period
- The pack ice is becoming thinner (the « old ice » is disappearing)

Why ?
1) Increasing summer temperature and
2) Important albedo feedback
Important consequences of the arctic sea ice collapse

Warming feedback (albedo)

A disaster for ecology and traditional societies

New maritime routes, new resources and potential conflicts
As sea ice, the seasonal snow cover has been reduced during the last decades....
Evidences of the snow cover decline in the northern Hemisphere

- Deterioration of the snow cover in March-April from the 1980s
- Deterioration faster in June
- Since 1972-1973, loss of 5 days/decade = (25 days), particularly in spring

Glaciers and ice caps

Around 200 000 glaciers in the world [equivalent of 41 cm of sea level]

- Glaciers and ice caps currently represent the major contribution to sea level rise (out of thermal expansion): 0.76 mm/an

- Great diversity (from poles to tropics)

- The huge « oceanic glaciers » (calving directly to ocean) have the major impact on the sea level rise (North Canada, Alaska, Patagonia, Svalbard…)

- « Continental glaciers « (high elevation) are retreating slowly and their impact to sea level rise is less

- The total loss of glaciers is estimated to be ~ 30 cm/yr in water equivalent

©B.F. Tierra de Fuego

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Mountain glaciers and ice caps

A coherent (negative) signal coming from 57 glaciers measured in the world

The great majority of glaciers experience a negative balance since 1976-1986 or 1991-2000
Why are glaciers retreating?

Glaciers shrink because they are not in equilibrium with the present climate.

Retreat of La Mer de Glace, French Alps (1958-2012) : ~0.8 km

Main cause: increasing summer temperature

Simulations for 2020, 2030 and 2040:
The glacier continues to decline even if temperature remains steady.
Mer de Glace
French Alps

1895

2010

2040

Model

Christian Vincent
Aletsch glacier (Switzerland)
The biggest glacier of the continental Europe

Scenario +2°C (2100) – retreat: 10 km (of the 22 km) and 90% volume loss

« Steady scenario »: volume loss: 40%

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CHACALTAYA glacier (5400m, Andes of Bolivia)

Pictures of a disappearing glacier: 1994-2010

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The global warming (1980-2015) is the main cause of the current decline of glaciers in the world.

**Combined temperature (continents et oceans combinés) depuis 1850**

IPCC, 2013

Temperature increased more on continent than in oceans. (mesures + models).

Goddard Institute for Space Studies IPCC, 2013

+0.8°C (averaged) since 1880 and +0.7°C since 1970 (acceleration)

Warming is amplified on continents and in polar regions

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Multiple impacts of ice recession
What is the impact of ice retreat on sea level at global scale?

**PRESENT**

<table>
<thead>
<tr>
<th>sources</th>
<th>1993-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal expansion</td>
<td>1,1 ± 0,3</td>
</tr>
<tr>
<td>Glaciers, ice caps</td>
<td>0,76 ± 0,4</td>
</tr>
<tr>
<td>Greenland</td>
<td>0,33 ± 0,08</td>
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<tr>
<td>Antarctica</td>
<td>0,27 ± 0,11</td>
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<tr>
<td>Continental waters</td>
<td>0,38 ± 0,11</td>
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<tr>
<td>Sum of contributions</td>
<td>2,80 ± 0,5</td>
</tr>
<tr>
<td>Observations (by altimetry)</td>
<td>3,2 ± 0,4</td>
</tr>
</tbody>
</table>

Individual contributions to sea level since 1993 and altimetric observations (in mm)  
Source: Casenave et al., 2015

**FUTURE**

Increasing sea level depending on warming scenarii (RCP)  
IPCC, 2013

Ice component : 49%  
Glacier component (of 49%) : 56%

Contribution of glaciers could remain dominant in 2100 (except if contributions of Greenland and West Antarctica strongly increase!)

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What are the other impacts of ice and glacier recession

- **Increasing warming:** a planet with less covered ice and snow areas absorbs more solar energy (albedo feedback) (→ polar regions)

- **Water resource:** glaciers and snow covers are natural reserves of water which regulate runoff in mountain basins (→ Andes, US. Rockies, Alps, Himalaya, Tien Shan, etc.)

- **Natural hazards:** the risk of glacier lakes burst out and glacier avalanches increase (Peru, Nepal, Alps).

- **Impact on ecological equilibrium and traditionnal indigenous survivals** (Inuit populations)

- **New routes, new economic perspectives and new boundaries** around the Arctic region (new resources but politic tensions increase)
GRACIAS !