# Climate Dynamics (Summer Semester 2019)

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## Today's Lecture (Lecture 9): Land, biosphere, cryosphere

### Reference

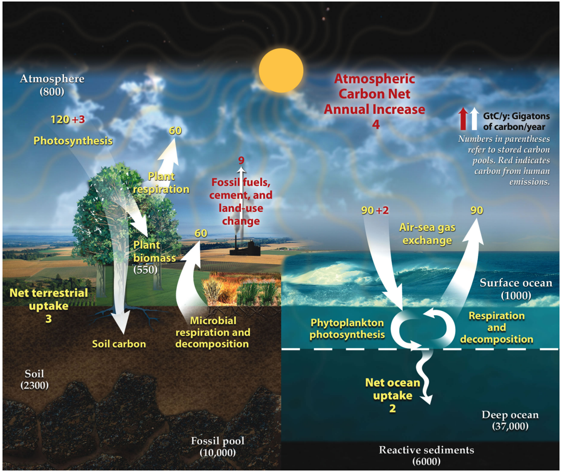
- UNEP *Global Outlook for Ice and Snow* (2007)
- IPCC AR5
- NSIDC
- (all linked from course web page)

# 2.6 – Land, biosphere

- Land is a sink of atmospheric momentum
- Orography shapes circulation (stationary Rossby waves)
- Land–sea temperature contrast shapes circulation
- Land and ocean are a source/sink of sensible and latent heat
- Land and ocean are a source of aerosol
- Land and ocean are a source/sink of trace gases

# 2.6 – Land, biosphere

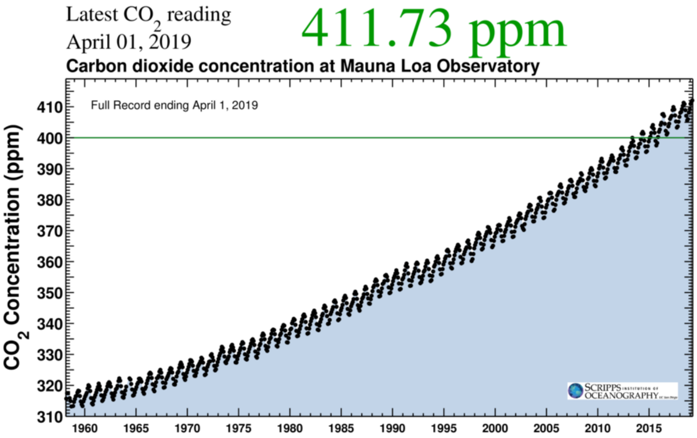
## Carbon cycle and carbon reservoirs

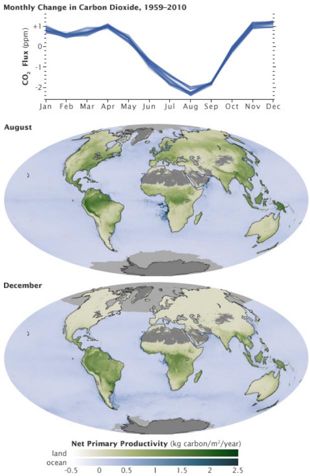



- Carbon reservoirs are large, but cycling is slow
- Anthropogenic carbon fluxes are small compared to the natural fluxes
- But the flux imbalance is large compared to the natural flux imbalance
- Only about 50% of emitted anthropogenic carbon remains in the atmosphere in the short term

Figure: U.S. Department of Energy Office of Science

# The fast carbon cycle – seasonal cycle of biological primary productivity




Figures: Scripps $CO_2$ program, NASA, NOAA ESRL

# The slow carbon cycle: weathering, biogeochemical pump, metamorphism, volcanoes

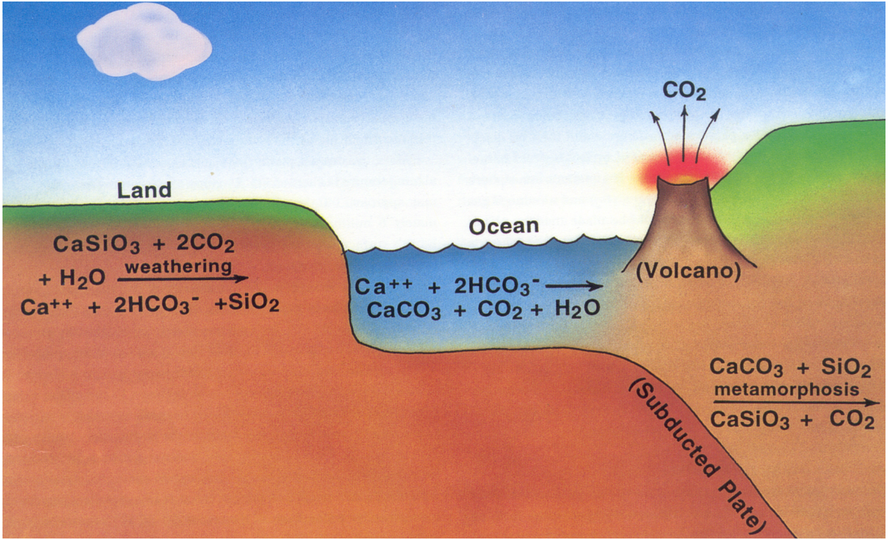
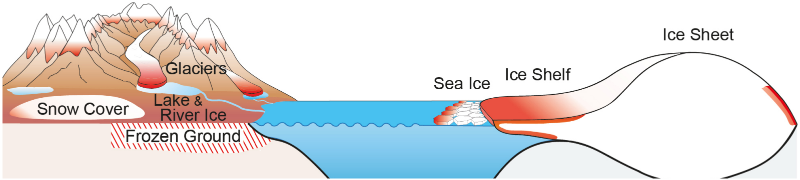



Figure: Kasting 1995

# 2.7 – Cryosphere

- The cryosphere acts as a reservoir for water, which is released on short (annual) and long (> millennial) time scales
- Freezing and melting are strong local influences on ocean salinity
- Albedo of ice affects shortwave flux into ocean
- Low thermal conductivity insulates ocean from atmosphere

## Components of the cryosphere




- Sea ice
- Ice sheets
- Ice shelves
- Glaciers

Which of these (directly) influence the sea level?

Figure: IPCC AR5

# Sea ice

- Annual cycle of freezing and melting
- First-year and multi-year ice; ice thickness, persistence through melt season
- Ice albedo (depends on snow cover)
- *Polynyas* as source of sensible and latent heat

# Annual cycle of sea ice extent

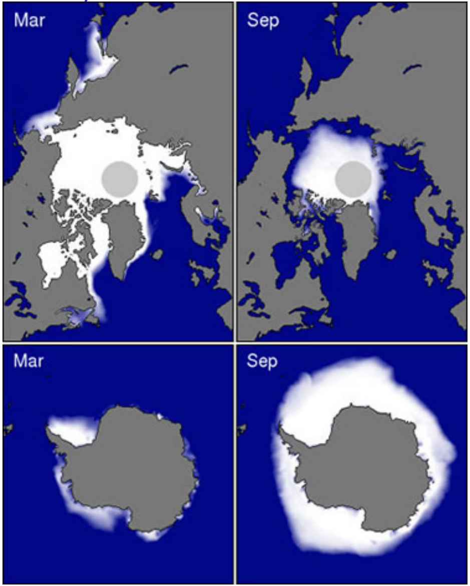
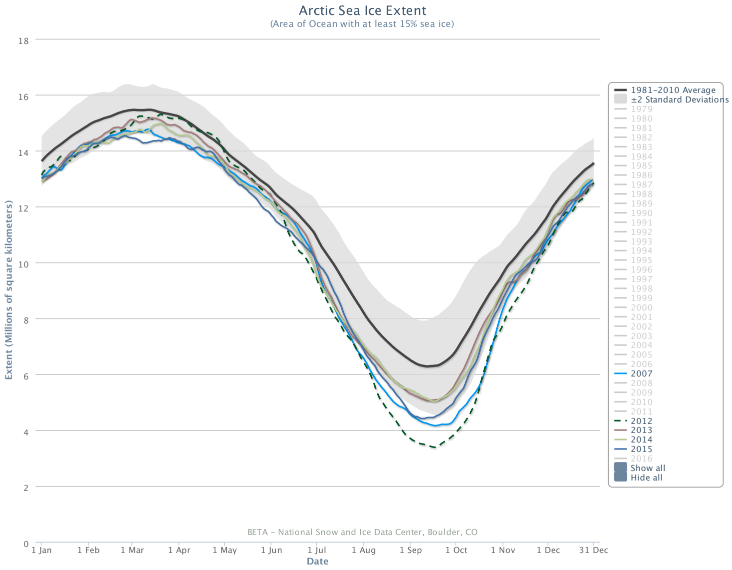


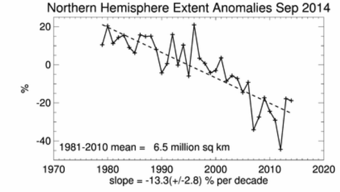

Figure: NSIDC

- Arctic sea ice occupies the Arctic Ocean, including the pole; partly persists for multiple years
- Antarctic sea ice forms equatorward of the Antarctic continent and consists mostly of first-year ice
- Freezing of the Arctic Ocean restricts moisture flux $\rightarrow$ Arctic sea ice is polar desert with low snow cover (bare ice albedo: 0.5)
- Southern Ocean provides moisture source for snowfall on Antarctic sea ice (snow-covered ice albedo: 0.9)

# Annual cycle of arctic sea ice extent




- Annual cycle is much larger than interannual variability
- Interannual variability is also large compared to the trend
- The trend is very large compared to zero (anomaly sign is the same year after year)




Figures: NSIDC

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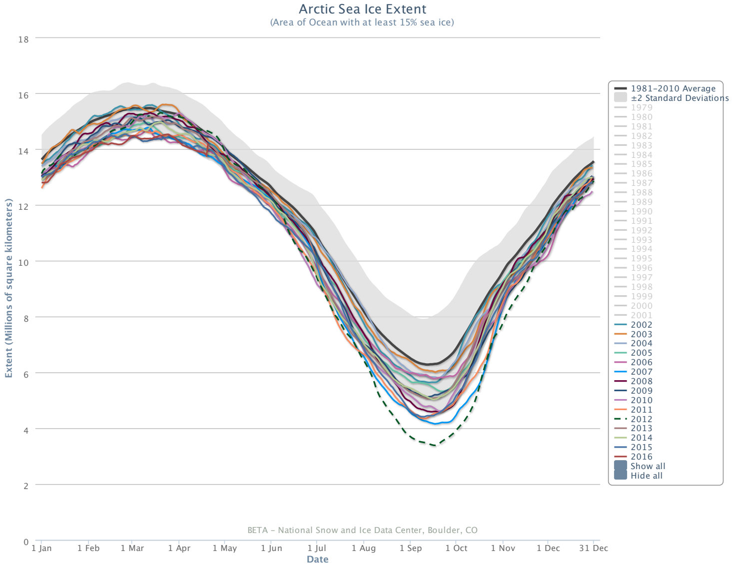


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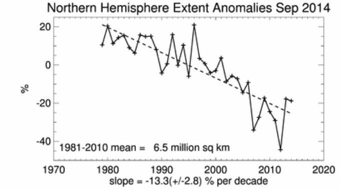
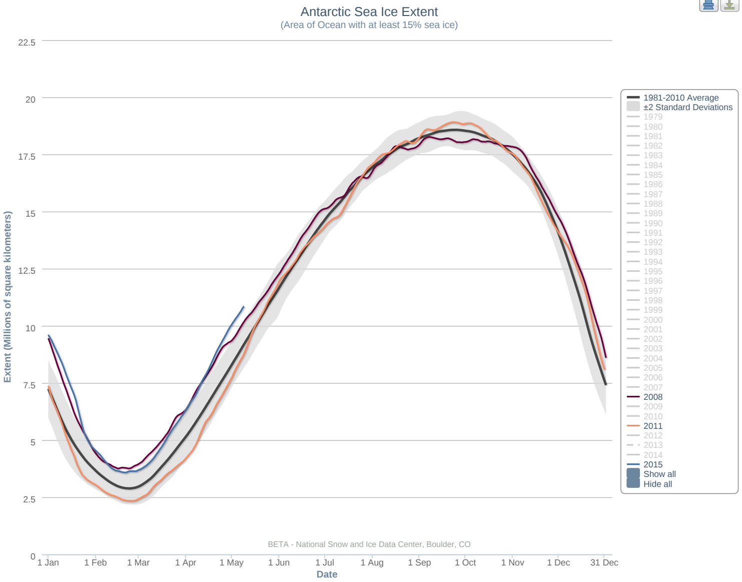
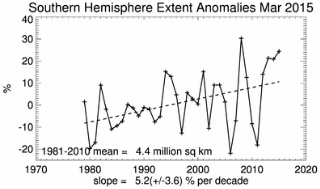



Figures: NSIDC

# Annual cycle of antarctic sea ice extent




- Annual cycle is much larger than interannual variability
- Interannual variability is also large compared to the trend
- The trend is small (anomaly sign is often different between years) and positive




Figures: NSIDC

# Ice thickness

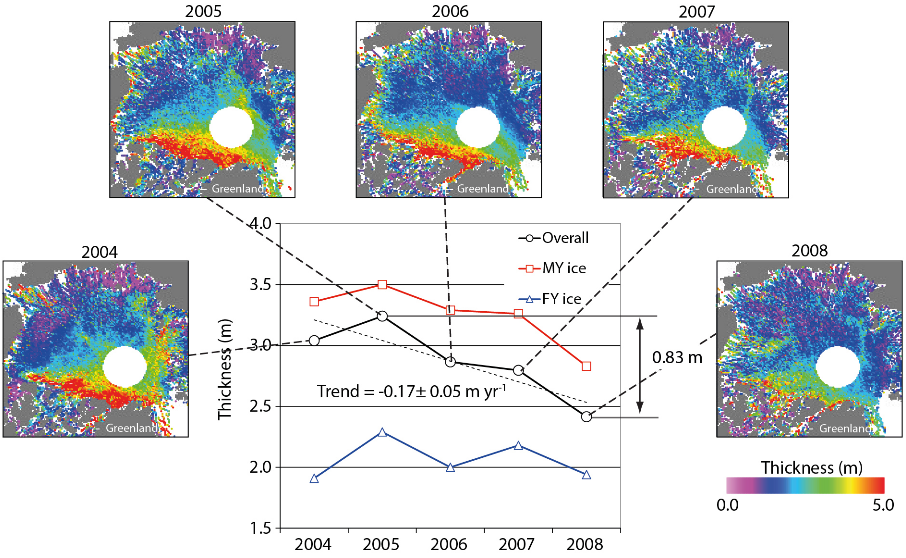



Figure: IPCC AR5

# Continental ice sheets and ice shelves

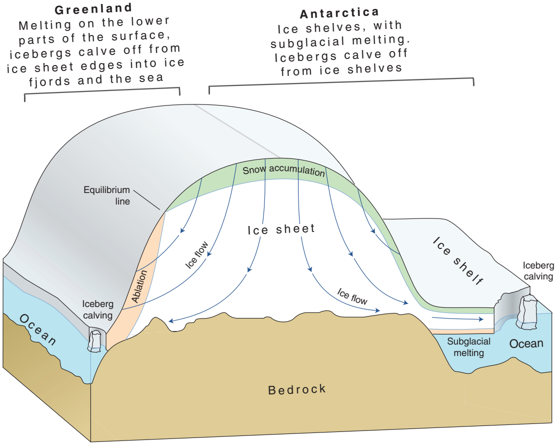



Figure 6A.1: Ice sheets.

*Source: based on material provided by K. Steffen, CIRES/Univ. of Colorado*

- *Ice sheets* are accumulations of permanent (i.e., non-seasonal) ice of continental size
- In the present-day climate, there are two: Greenland and Antarctica

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Figure: UNEP *Global Outlook for Ice and Snow* (2007)

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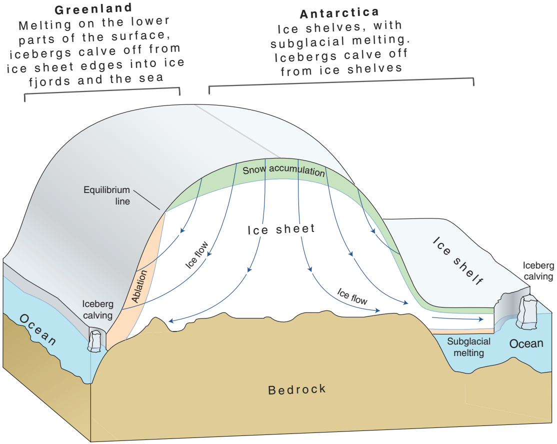


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- In the present-day climate, there are two: Greenland and Antarctica
- Whether their mass increases or decreases (the *mass balance*) depends on snow accumulation rate (mass source) and melting and iceberg calving (mass sinks).
- Depending on temperature, warming can result in mass gain (due to increased snow fall) or mass loss (melting, faster ice flow, reduced back pressure from collapsed ice shelves)

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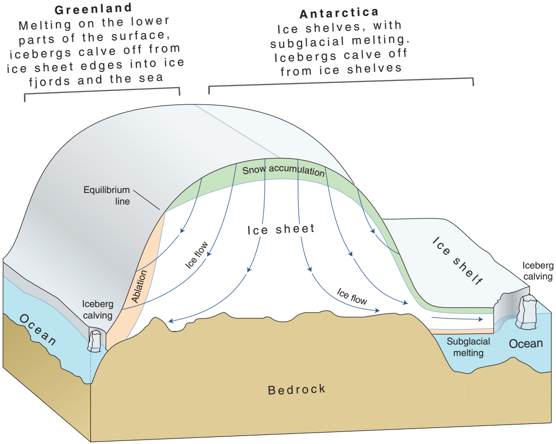


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- Depending on temperature, warming can result in mass gain (due to increased snow fall) or mass loss (melting, faster ice flow, reduced back pressure from collapsed ice shelves)
- Equivalent sea level rise is 60 m (Antarctica) and 7 m (Greenland); crucial to know whether, when, and how much of the ice sheets will melt
- Dynamics depend on basal lubrication (difficult of observe), but satellite gravimetry and altimetry provide the flow field (since ca 2000, with gaps)

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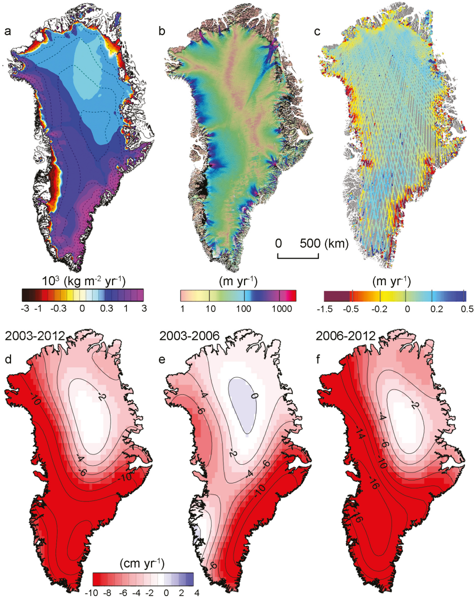
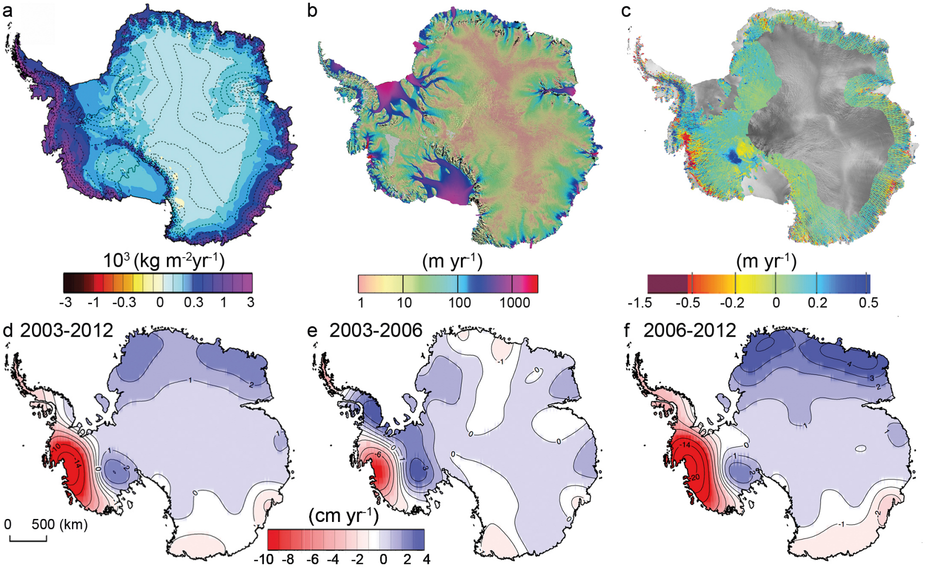
# Observed mass balance of Greenland




- a Model-derived accumulation
- b Flow speed (satellite)
- c Elevation change (satellite)
- d Ice loss (cm water yr$^{-1}$, gravimetry), 2003–2012
- e Ice loss (cm water yr$^{-1}$, gravimetry), 2003–2006
- f Ice loss (cm water yr$^{-1}$, gravimetry), 2006–2012

# Observed mass balance of Antarctica




Figures: IPCC AR5

# Ice shelf collapse (Larsen B, 2002)

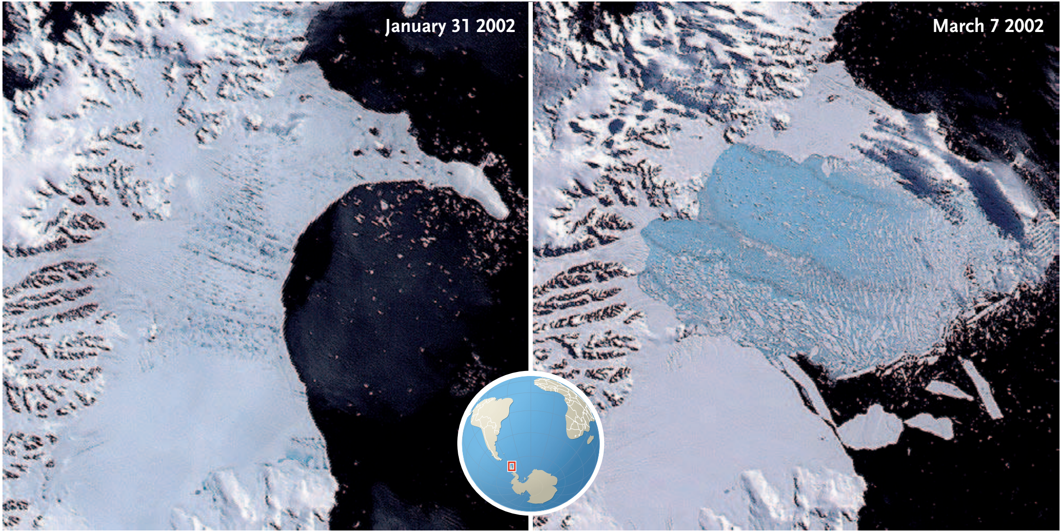
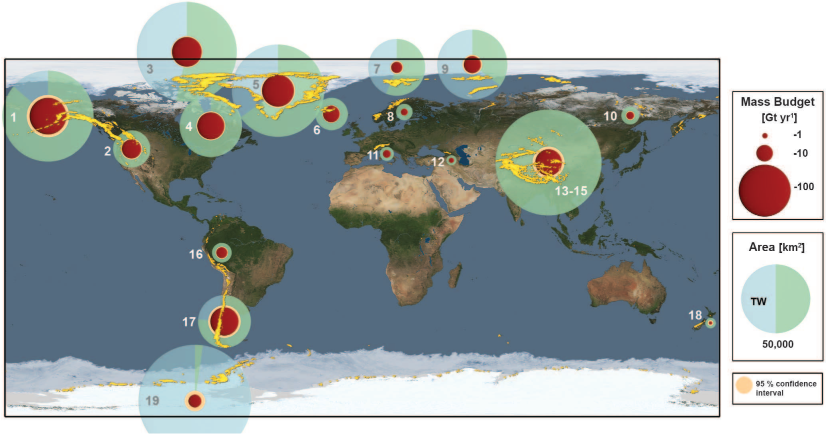
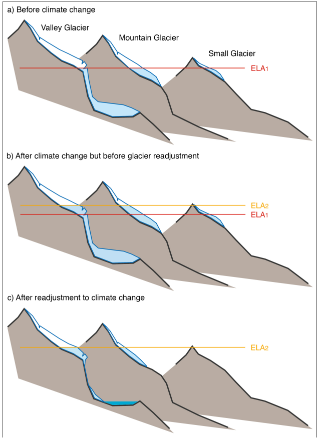



Figure: UNEP *Global Outlook for Ice and Snow* (2007)

# Glaciers




- Sea level equivalent is small ($<$ 1 m)
- But the are an important water source in tropics and subtropics
- Universally in decline, with very few exceptions
- Glacier response lags warming, so further decline is *committed*

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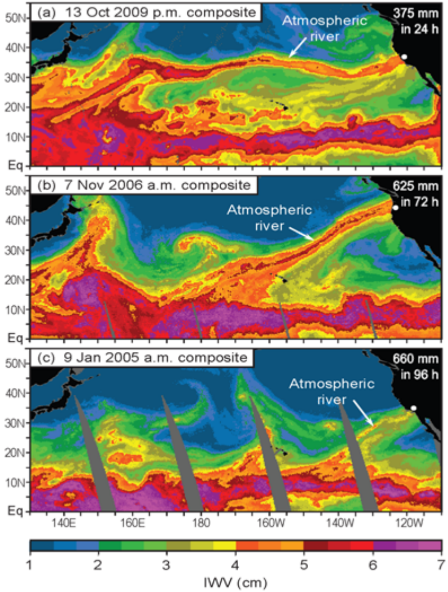
Figures: Gardner et al. (2008), IPCC (2013)

# Importance of the subtropical and tropical snow pack for water supply




- Seasonal variation of precipitation $\rightarrow$ water storage required
- Example: atmospheric rivers and the importance of snow pack for water supplies in California