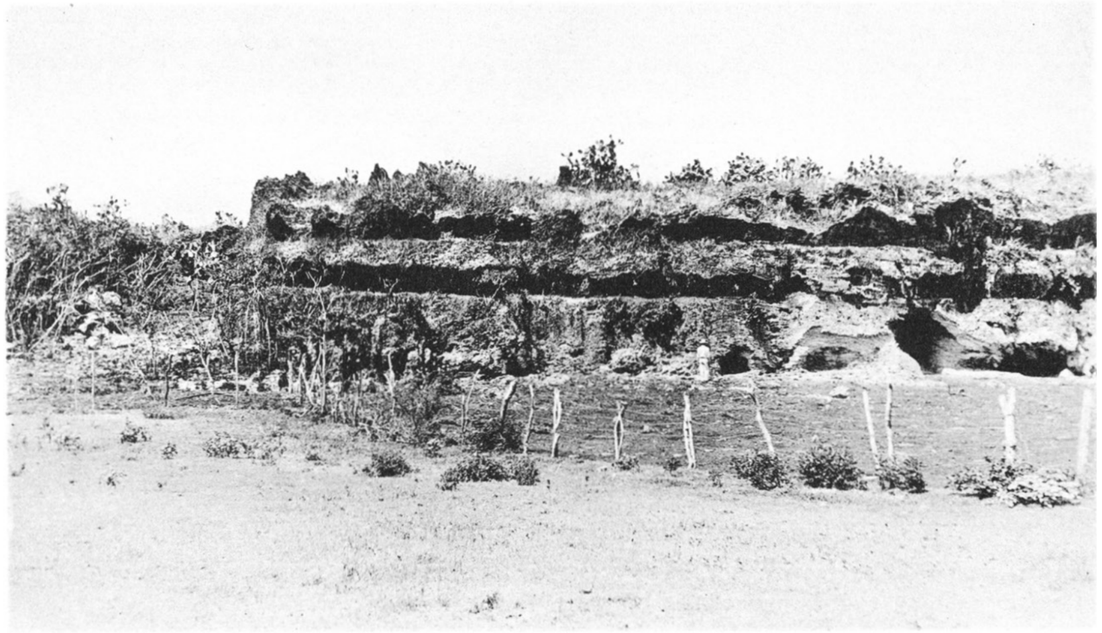
Lectures 9-10: Sea level

- Coastal geology wrap up
- Relative sea level
- Glacial isostatic adjustment
- Viscoelasticity
- Earth as a viscoelastic solid
    - Elastic response (ongoing melt)
        - Fingerprints of ice melt
    - Viscous response (after melting ends)

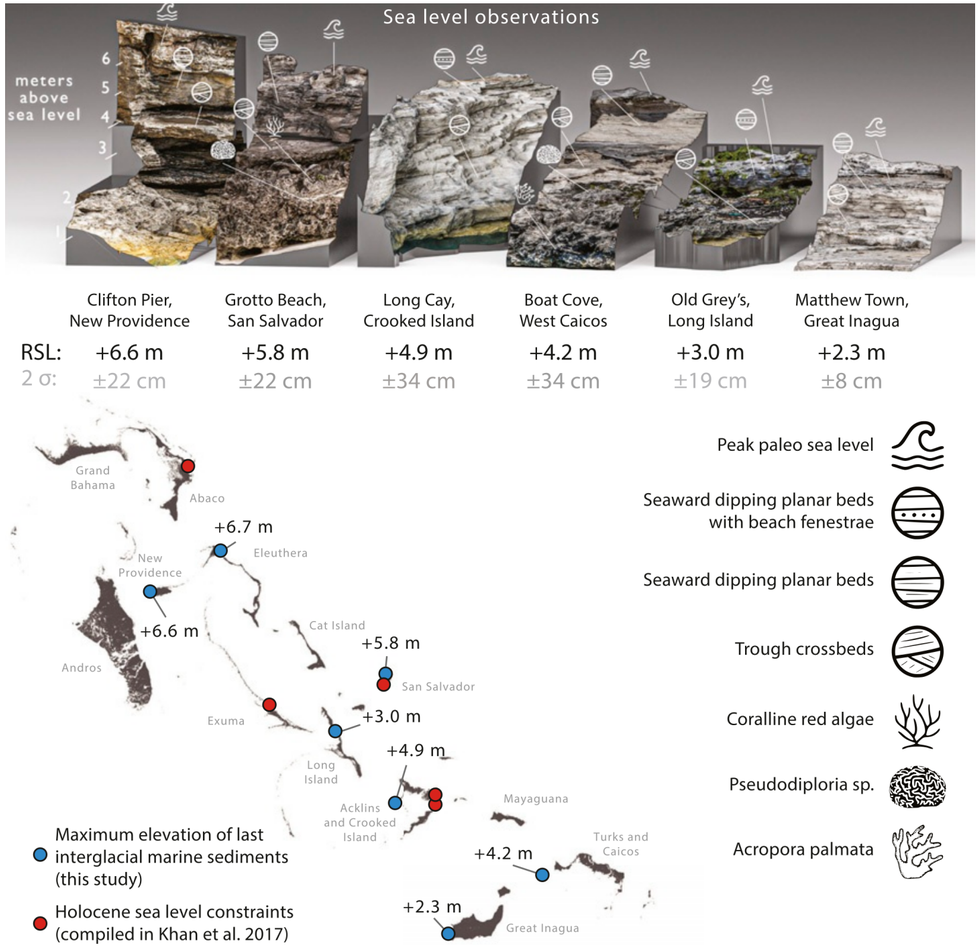
We acknowledge and respect the lək^{w}əŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

Hawaii

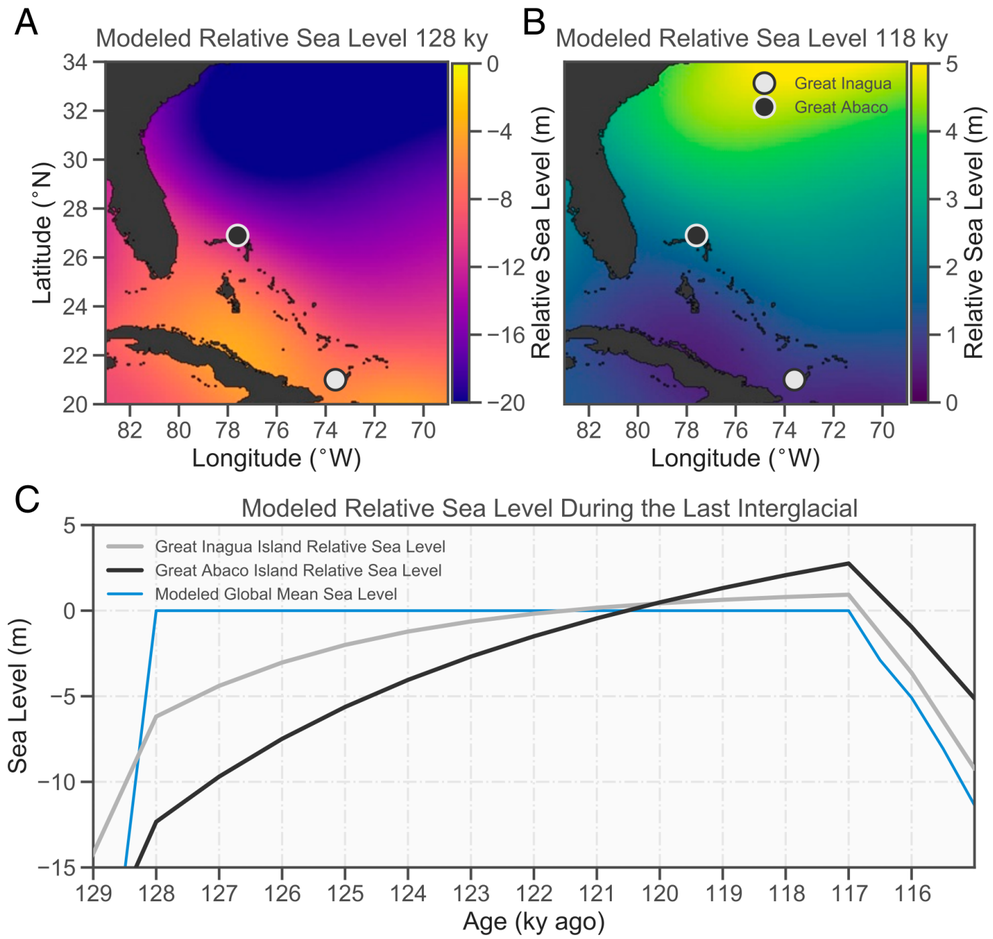


Linear features in lithified carbonate dunes at 6.7 meters and 8.2 meters

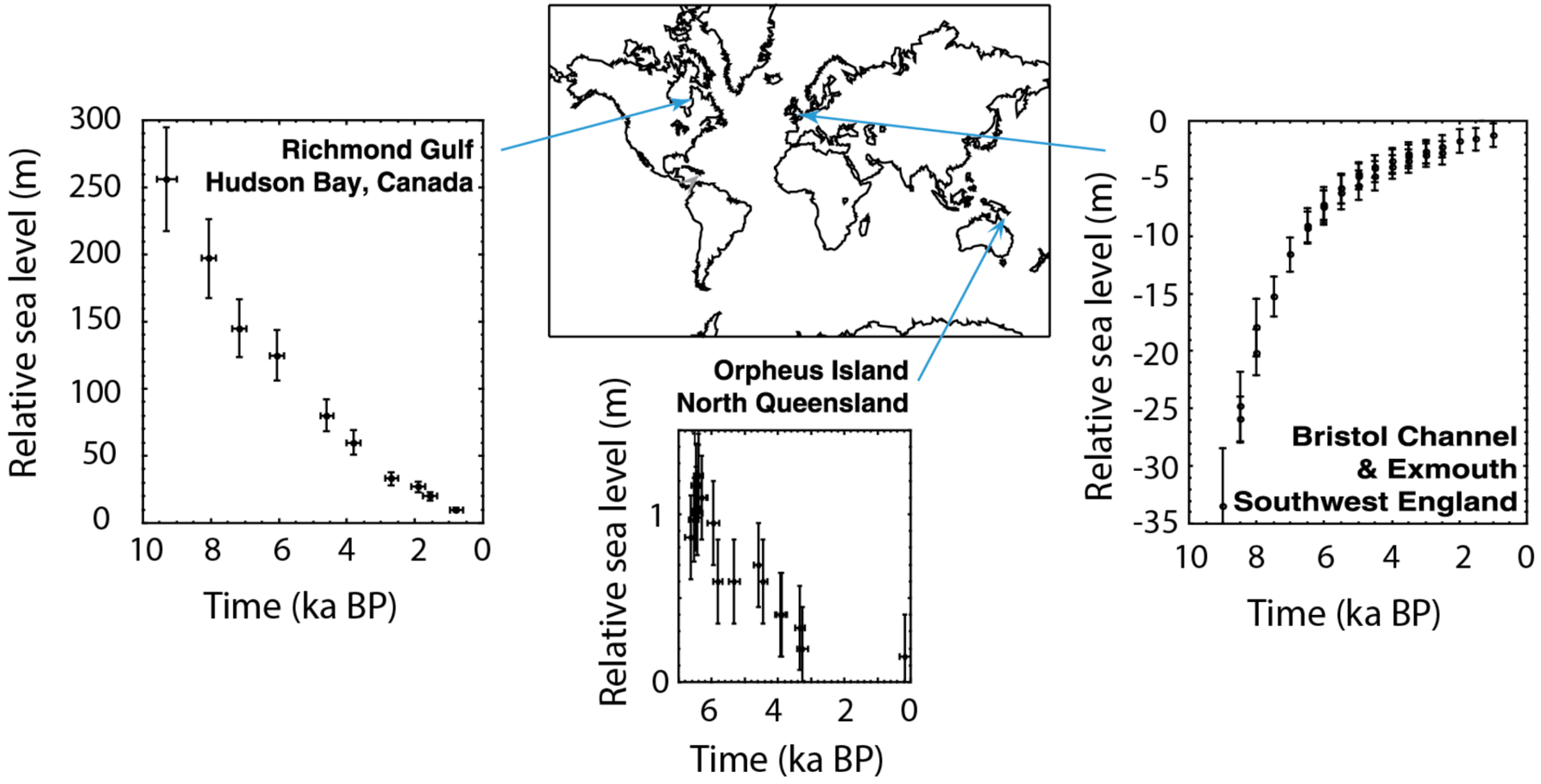
The Bahamas


Sea level observations
meters above sea level
6
5
4
3
2
1
Clifton Pier, New Providence
Grotto Beach, San Salvador
Long Cay, Crooked Island
Boat Cove, West Caicos
Old Grey's, Long Island
Matthew Town, Great Inagua
RSL:
+6.6 m
+5.8 m
+4.9 m
+4.2 m
+3.0 m
+2.3 m
2 σ:
±22 cm
±22 cm
±34 cm
±34 cm
±19 cm
±8 cm
Grand Bahama
Abaco
+6.7 m
Eleuthera
New Providence
+6.6 m
Cat Island
+5.8 m
San Salvador
Andros
Exuma
+3.0 m
+4.9 m
Long Island
Acklins and Crooked Island
Mayaguana
Turks and Caicos
+4.2 m
+2.3 m
Great Inagua
Maximum elevation of last interglacial marine sediments (this study)
Holocene sea level constraints (compiled in Khan et al. 2017)
Peak paleo sea level
Seaward dipping planar beds with beach fenestrae
Seaward dipping planar beds
Trough crossbeds
Coralline red algae
Pseudodiploria sp.
Acropora palmata

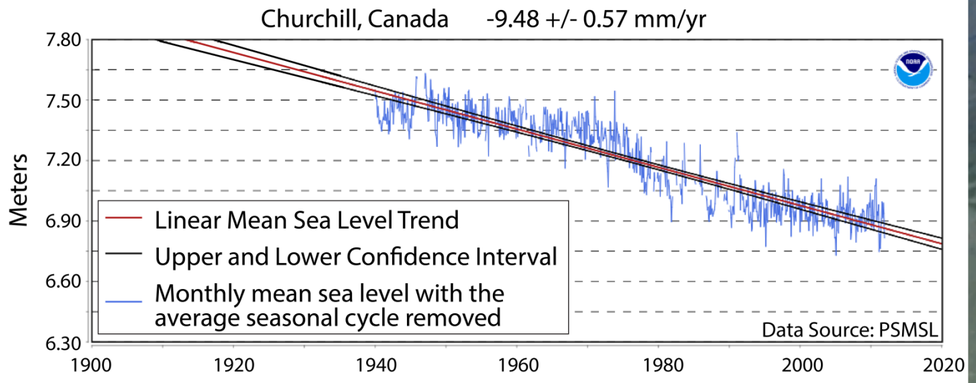
The Bahamas

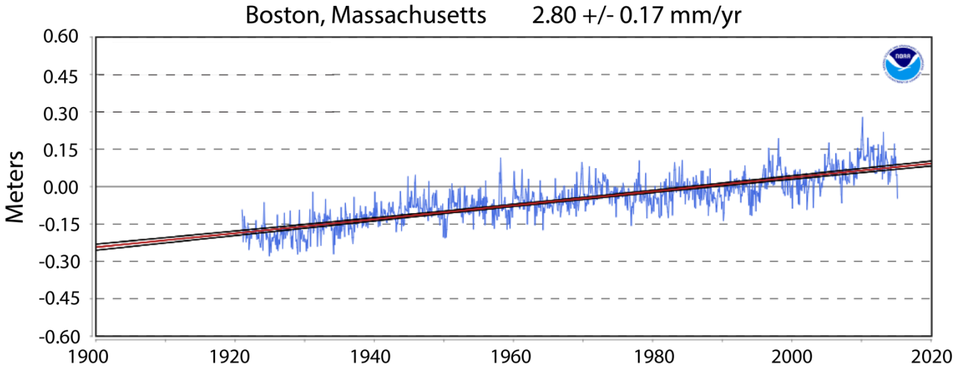

A
Modeled Relative Sea Level 128 ky
Latitude (°N)
Longitude (°W)
B
Modeled Relative Sea Level 118 ky
Great Inagua
Great Abaco
Relative Sea Level (m)
Longitude (°W)
C
Modeled Relative Sea Level During the Last Interglacial
Great Inagua Island Relative Sea Level
Great Abaco Island Relative Sea Level
Modeled Global Mean Sea Level
Sea Level (m)
Age (ky ago)

Relative Sea Level

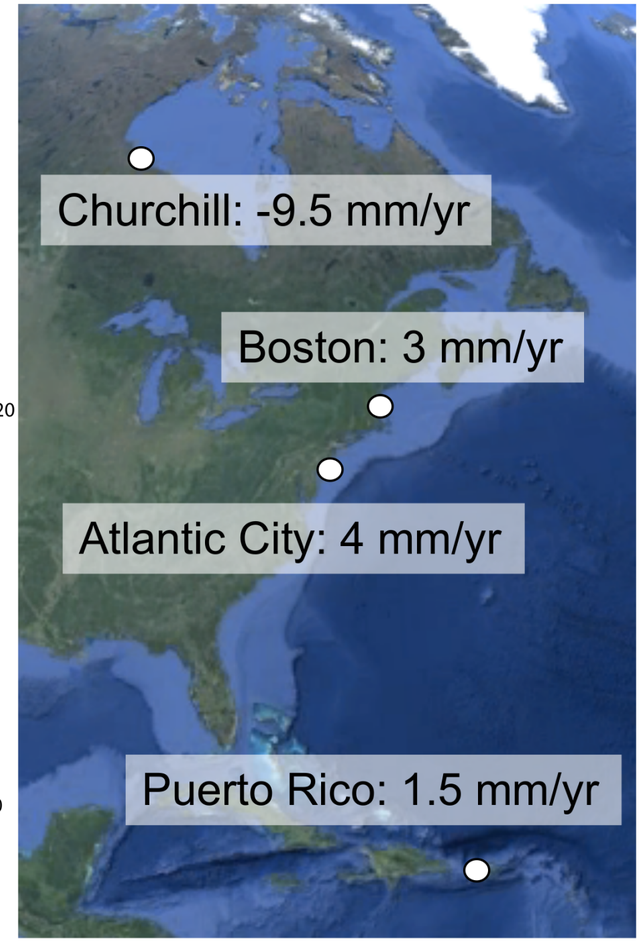


Relative Sea Level



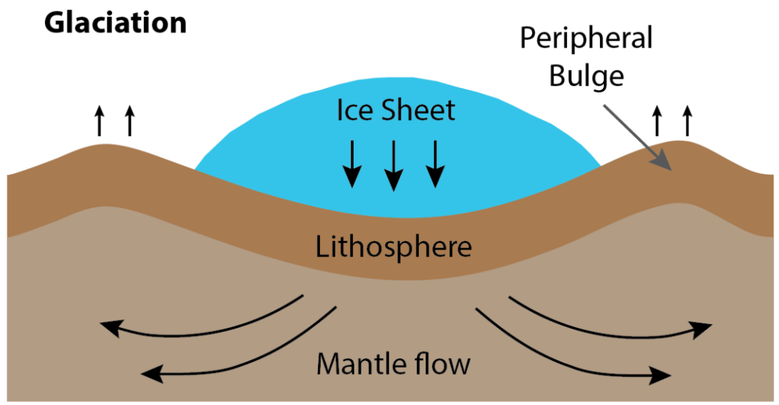


http://tidesandcurrents.noaa.gov



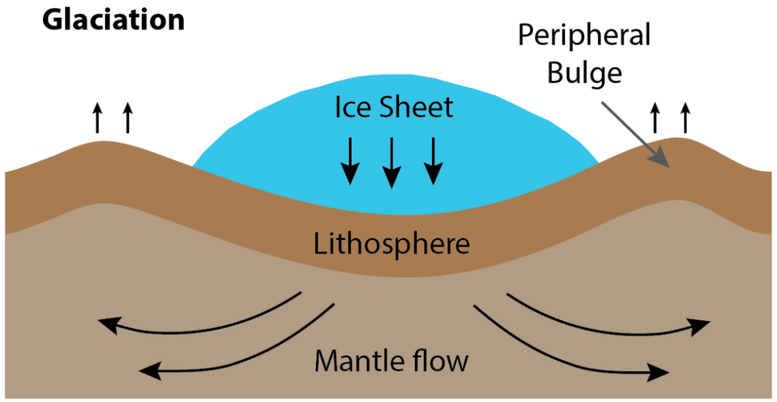
Glacial isostatic adjustment

During the glacial

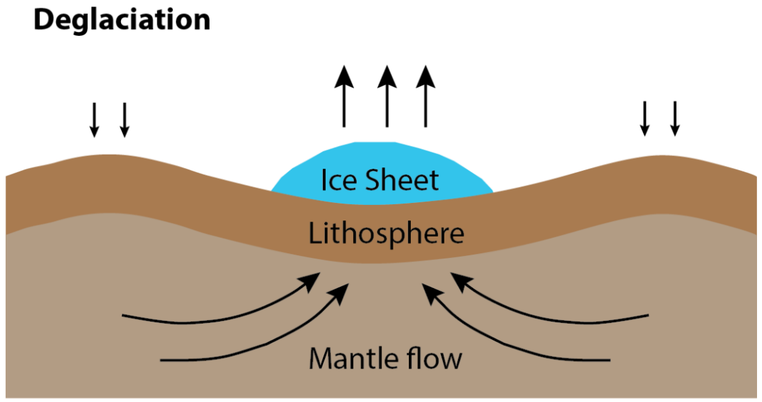


Glacial isostatic adjustment

During the glacial

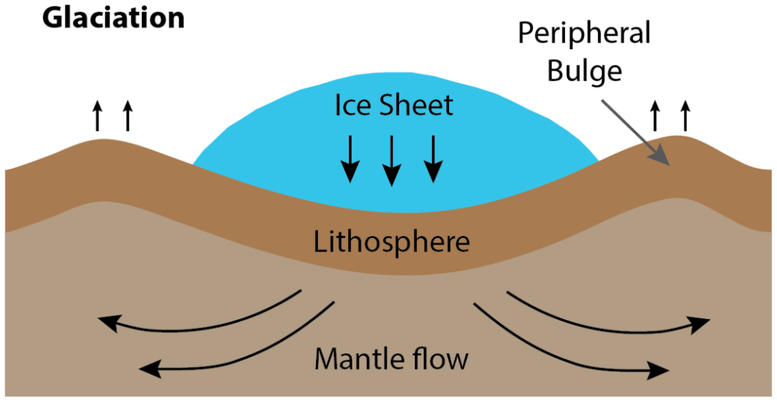


During the interglacial

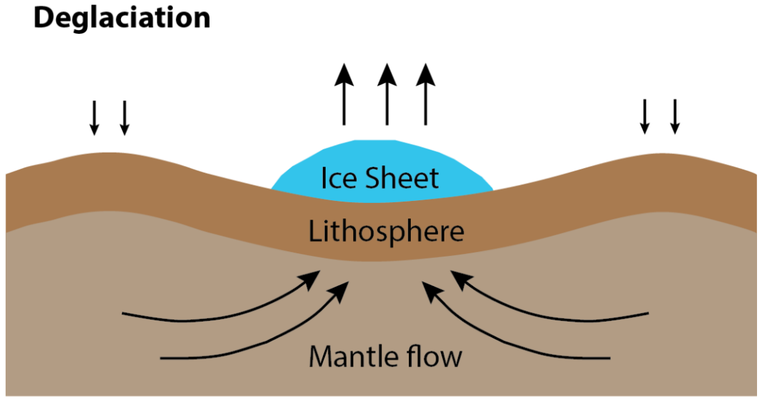


Glacial isostatic adjustment

During the glacial



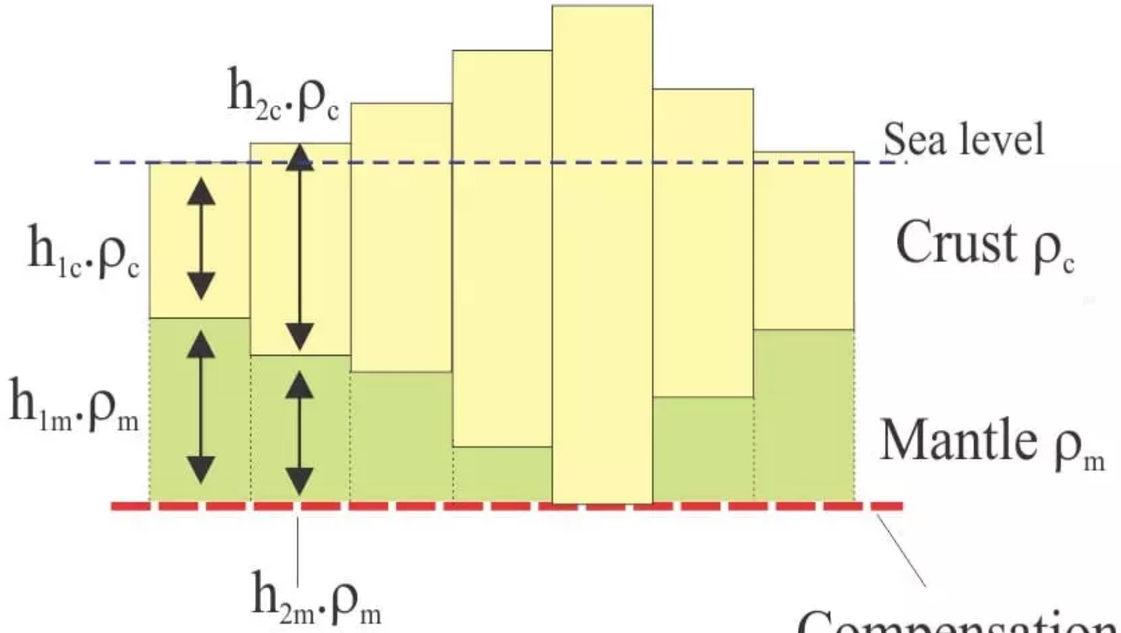
During the interglacial



- Postglacial rebound: **viscoelastic** response of the solid Earth after ice melt
- Glacial isostatic adjustment: the **viscoelastic** response of the Earth's solid surface, its gravity field, and rotation axis to changes in ice and ocean load

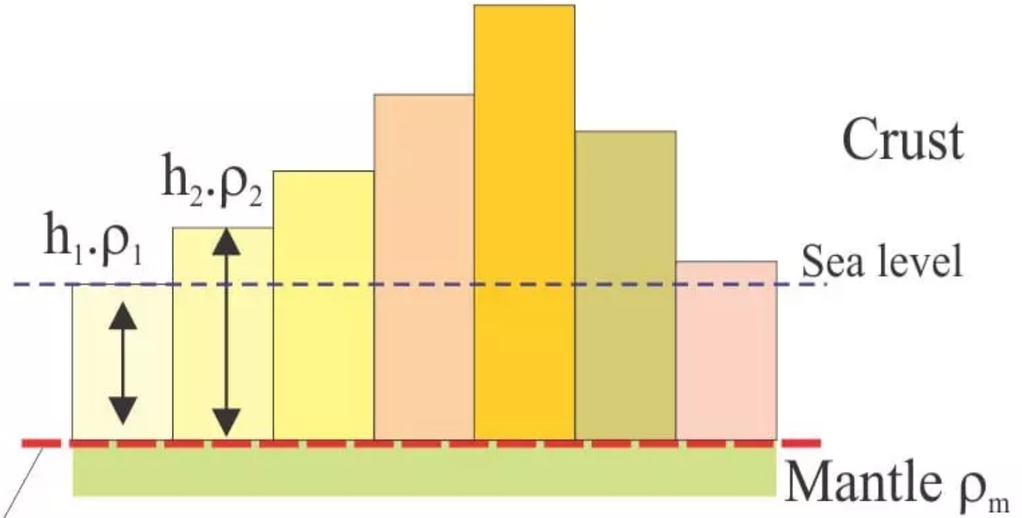
Our previous considerations of isostasy

Airy model of local isostasy



$$\mathbf{P} = (h_{1c}.\rho_c.g + h_{1m}.\rho_m.g) = (h_{2c}.\rho_c.g + h_{2m}.\rho_m.g) = \ldots$$

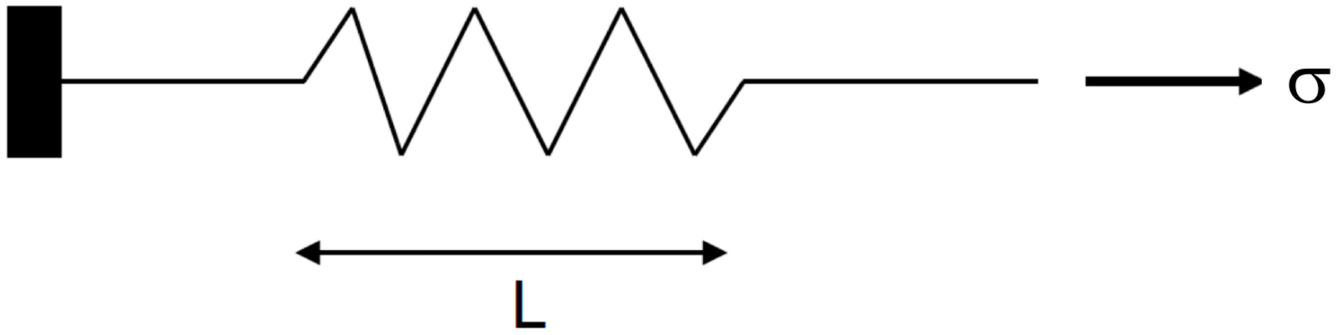
Pratt model of local isostasy



Compensation depth

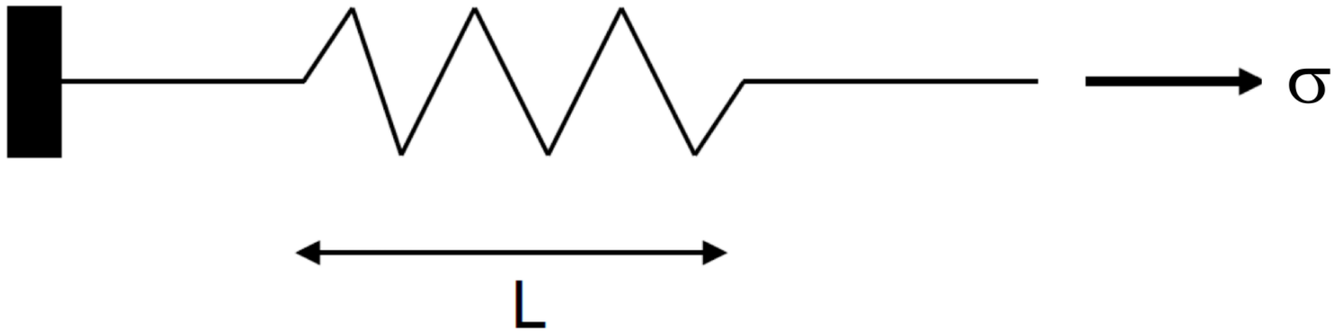
$$\mathbf{P} = (h_1.\rho_1.g) = h_2.\rho_2.g) = \ldots$$

Viscoelastic deformation



Stress is proportional to **strain** and a constant of proportionality (the Young's modulus or spring constant, *k*)

Viscoelastic deformation



Stress is proportional to **strain** and a constant of proportionality (the Young's modulus or spring constant, *k*)

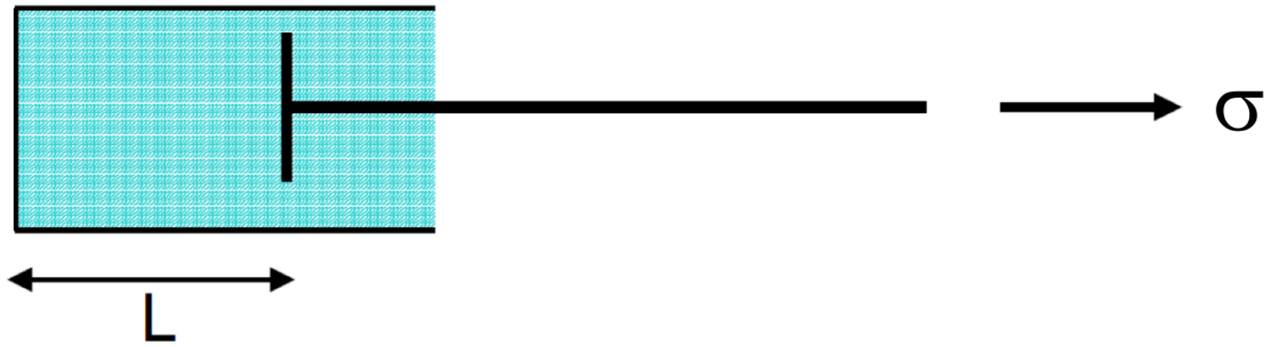
$$\sigma = k\frac{\Delta L}{L} = ke$$

Hooke's law

$\sigma = \text{stress}$

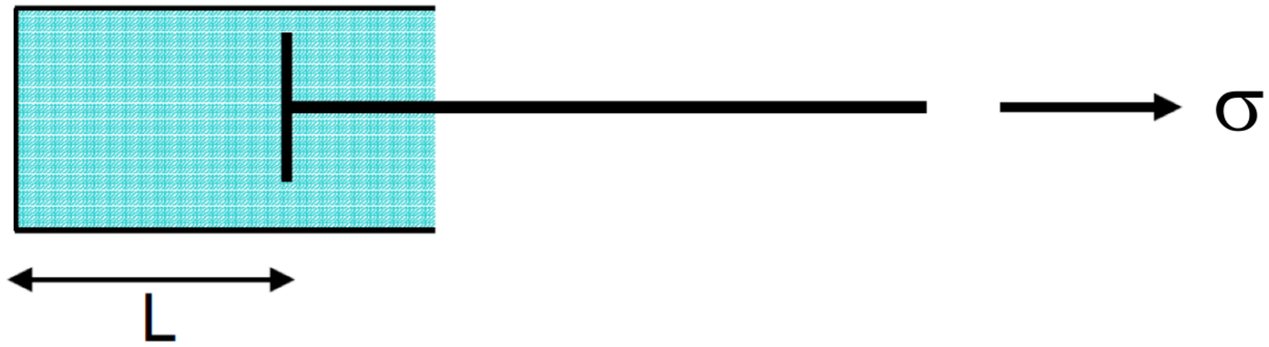
$e = \text{strain}$

Viscoelastic deformation



Stress is proportional to **strain rate** and a constant of proportionality (the coefficient of viscosity, η)

Viscoelastic deformation



Stress is proportional to **strain rate** and a constant of proportionality (the coefficient of viscosity, η)

$$\sigma = \eta \frac{d}{dt}\left(\frac{\Delta L}{L}\right) = \eta \frac{de}{dt}$$

σ = stress

e = strain

For a fluid whose viscosity is not dependant on strain rate (Newtonian fluid)

Viscoelastic deformation

In the simplest model of viscoelastic deformation (a Maxwell body), the total strain is the sum of a viscous term and an elastic term that feel the same stress.

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$$\frac{de}{dt} = \frac{1}{k}\frac{d\sigma}{dt} + \frac{1}{\eta}\sigma$$

An instantaneous elastic response and a time-dependant viscous response for a fluid whose viscosity is not dependant on strain rate (Newtonian fluid)

σ = stress

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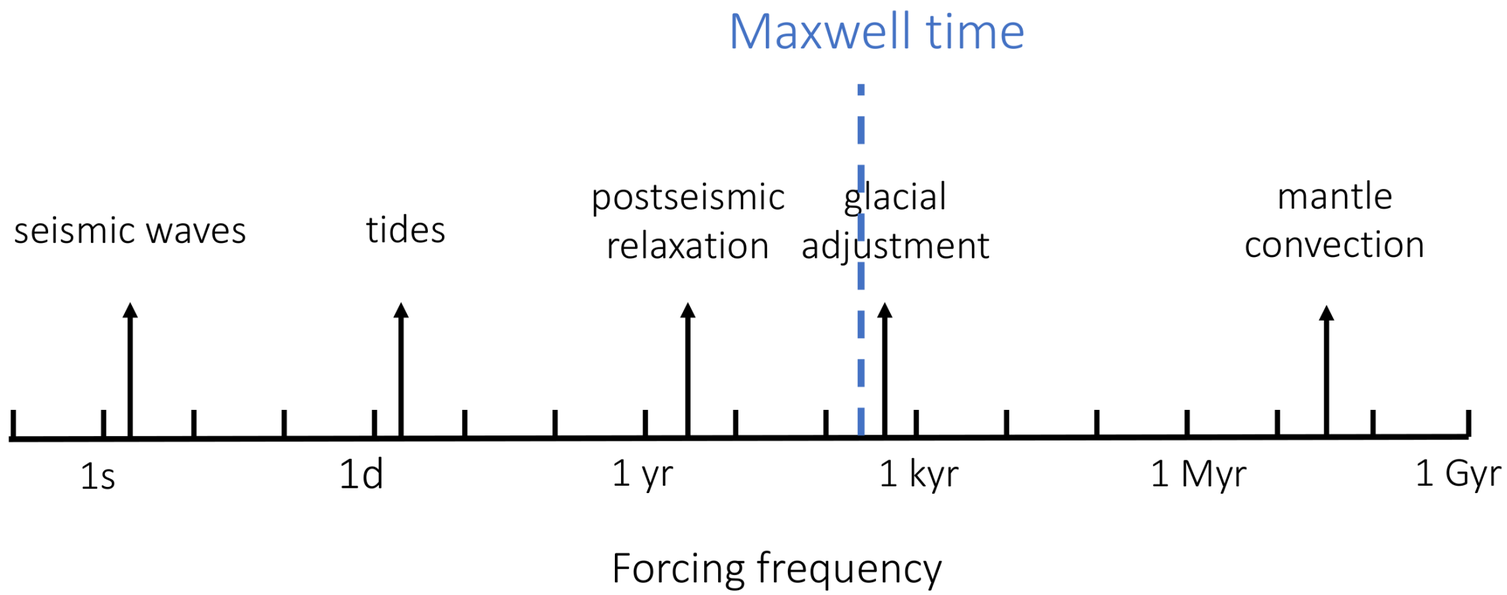
σ = stress
e = strain

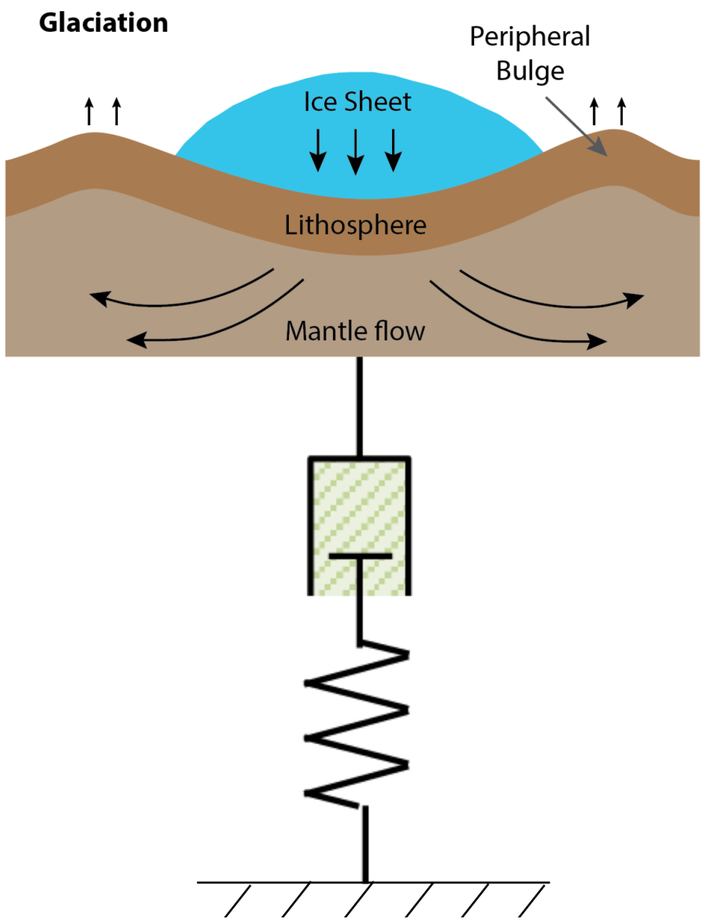
Why is the spring constant paired with the time-dependant term? Consider the end-members of infinitely stiff springs or infinitely high viscosity.

Earth as a viscoelastic solid



- Maxwell time: time after which half of the deformation is elastic and half is viscous. A body is often considered elastic for $t << t_{\text{Maxwell}}$ and mainly viscous for $t >> t_{\text{Maxwell}}$.

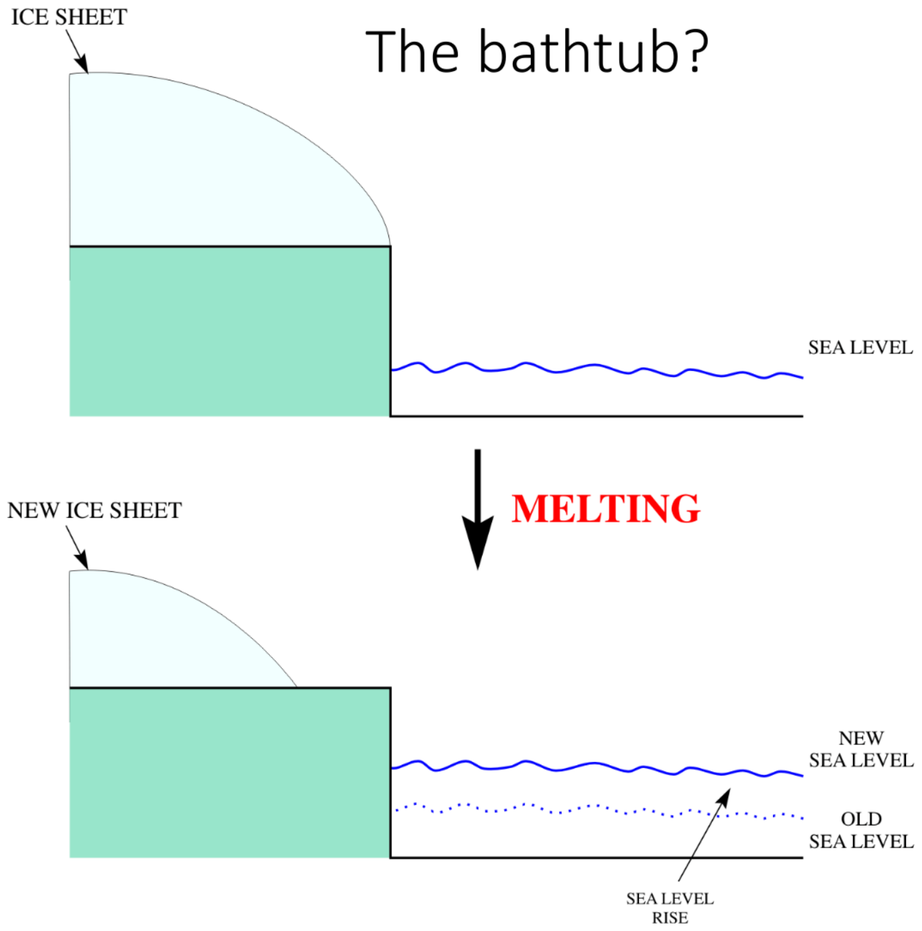
Earth as a viscoelastic solid

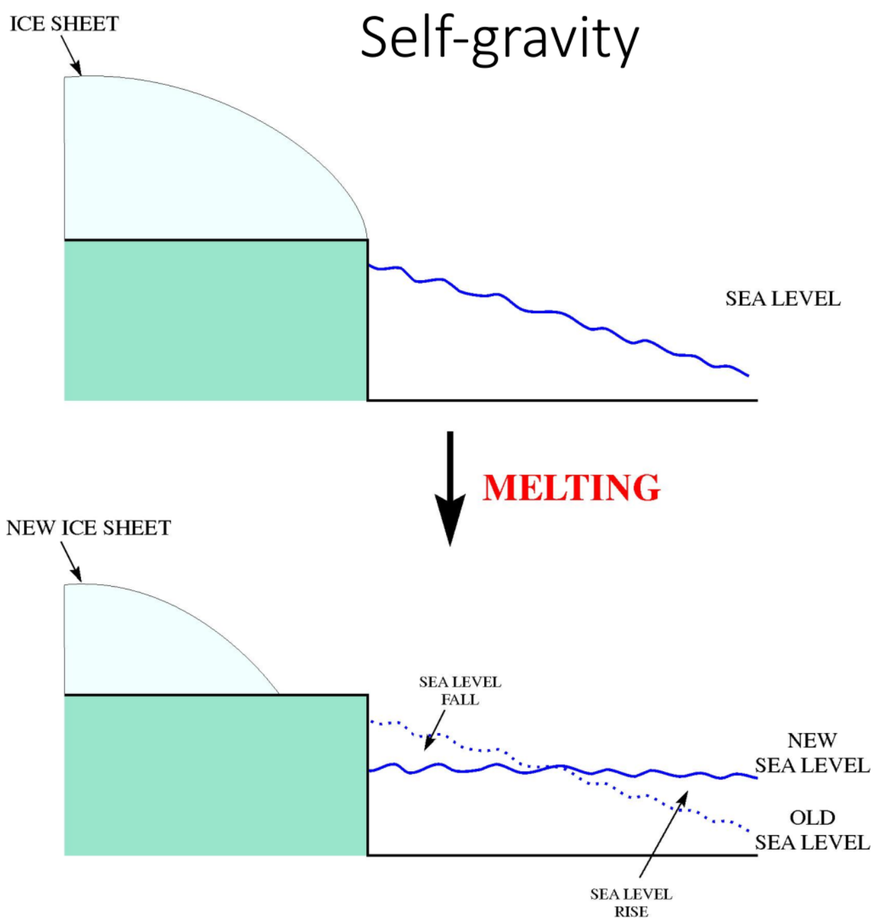


- Load change at the top (a change in stress)
- instantaneous elastic response
- time-dependant viscous response

Elastic response

Sea level response to rapid melting of ice sheets and glaciers:





Elastic response

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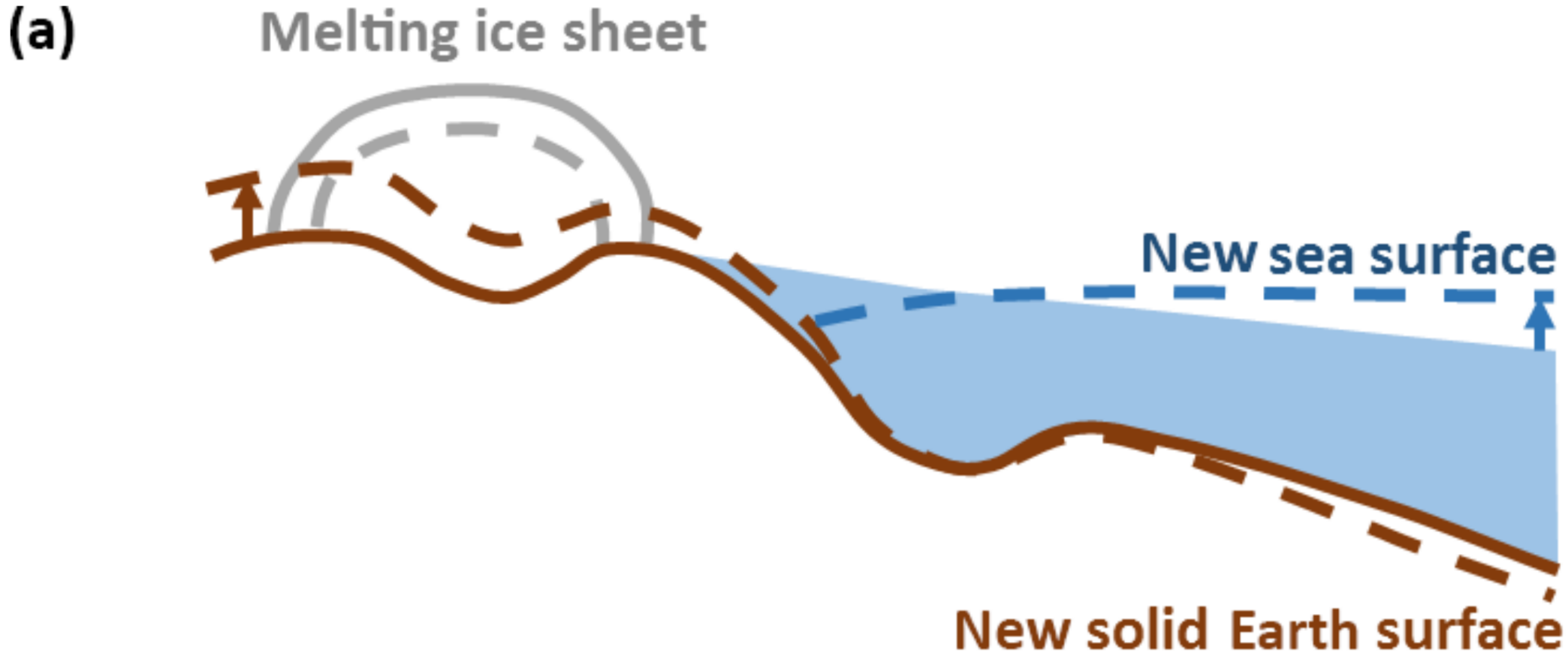
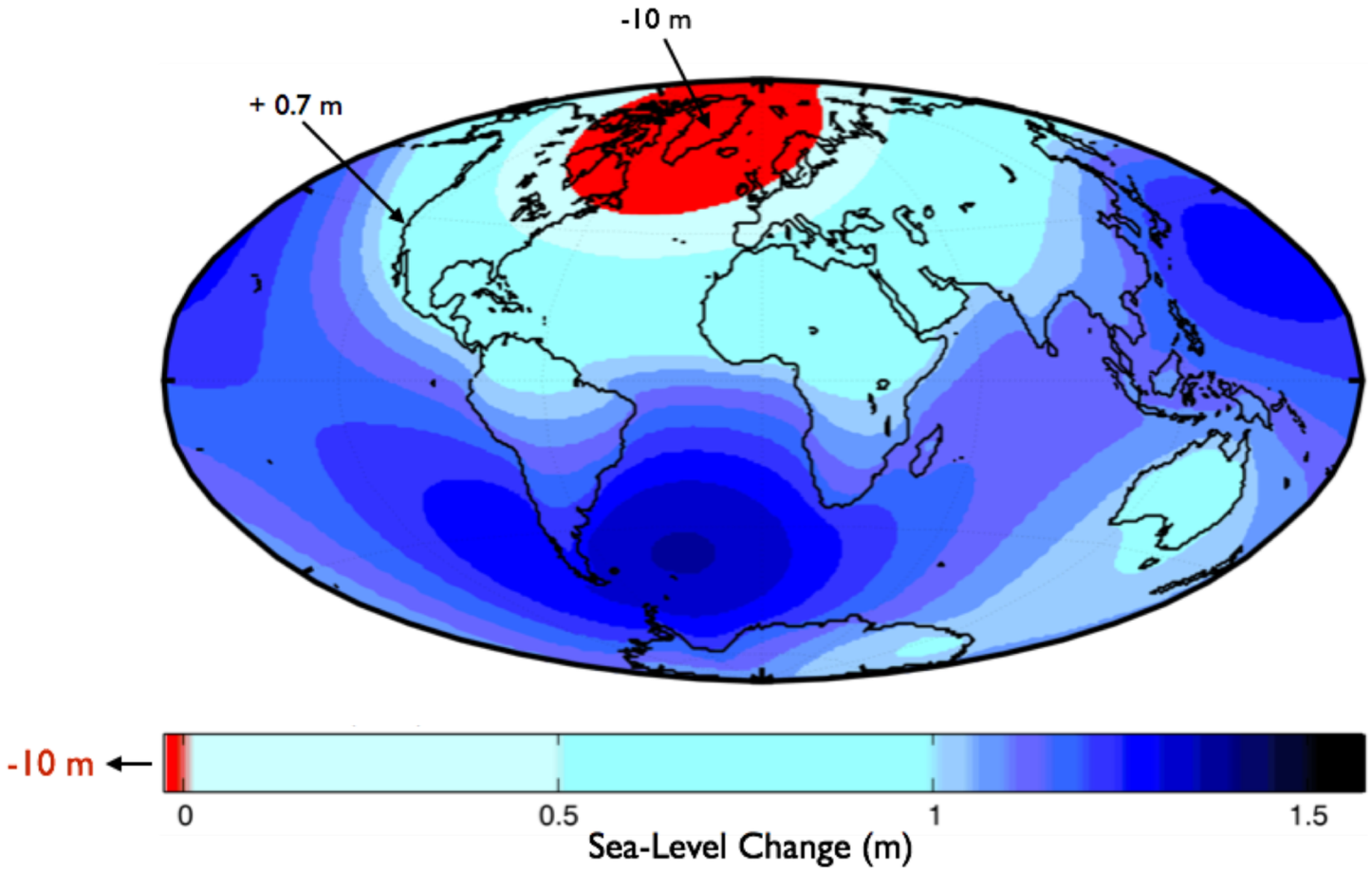


Sea level fingerprints

The instantaneous spatial pattern of sea level rise will be different depending on which ice sheet is melting



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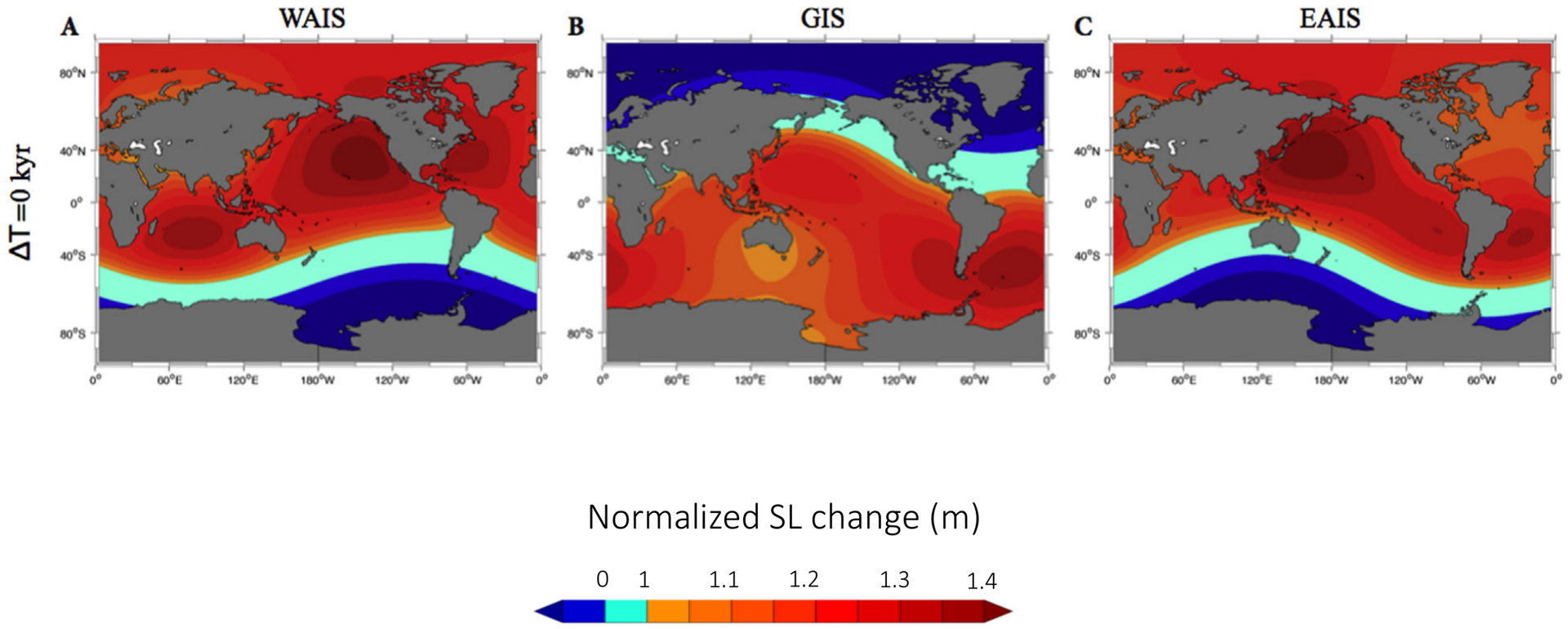
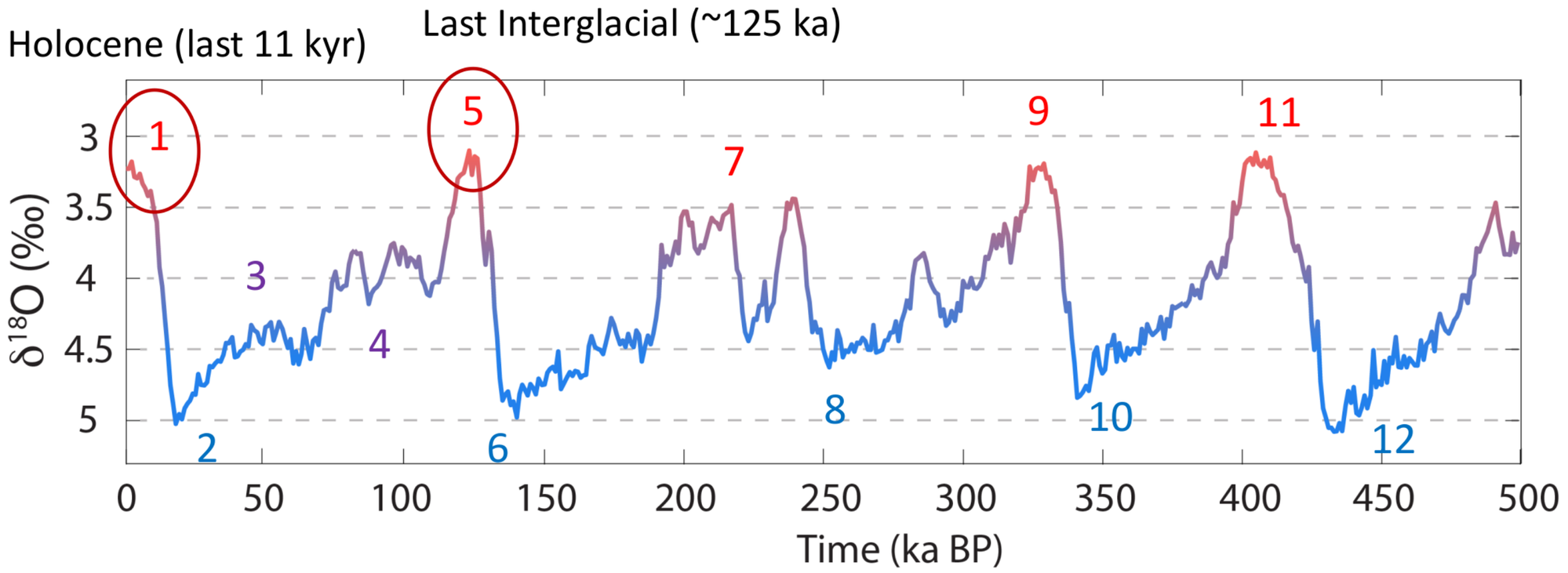


Viscous response

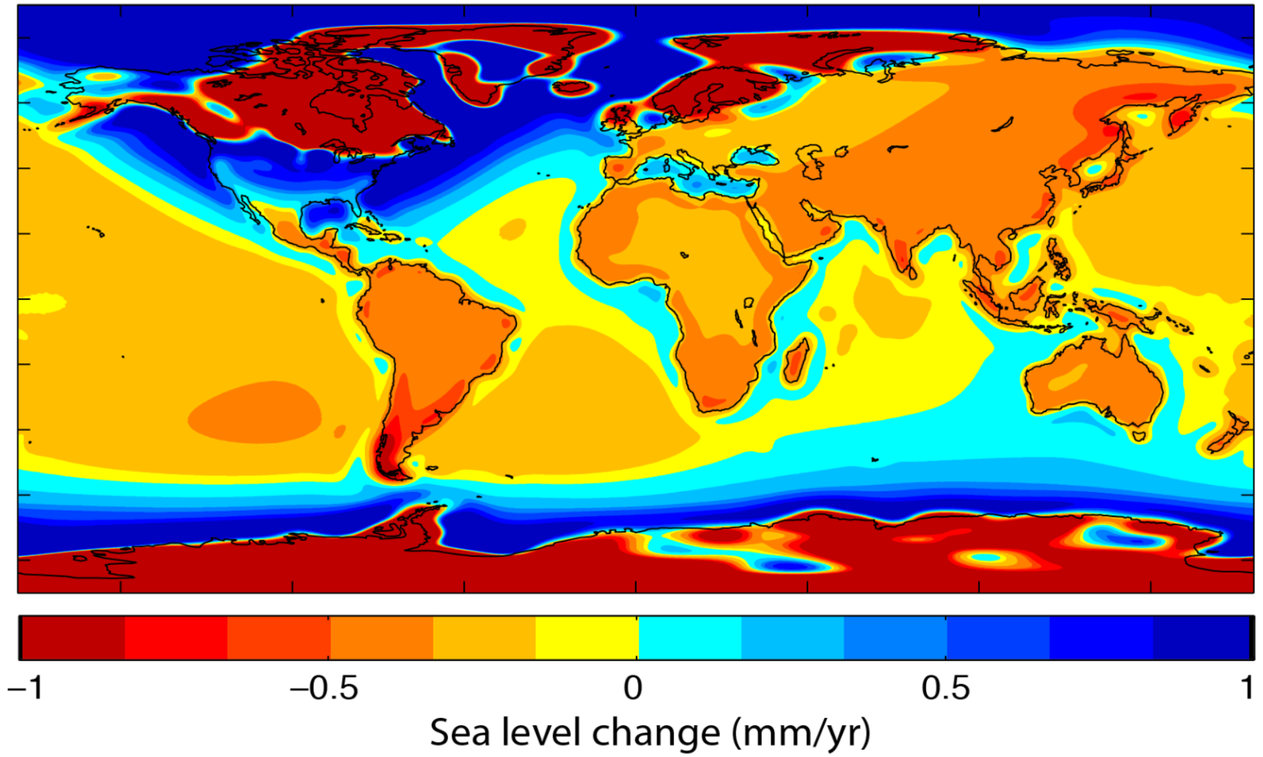
What is the ongoing viscous response during an interglacial (after most ice melting is complete)?



Interglacial = warm period between glacial maxima.

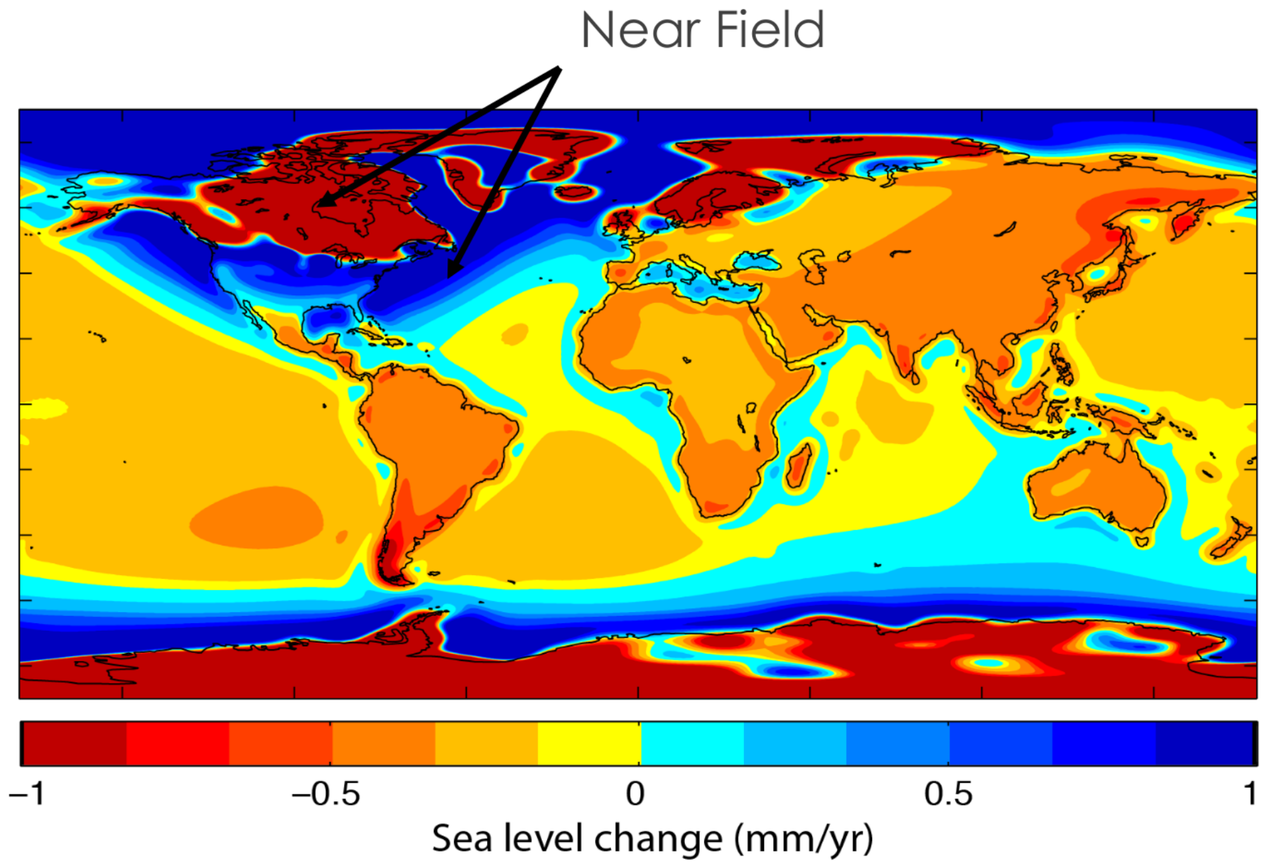
Viscous response

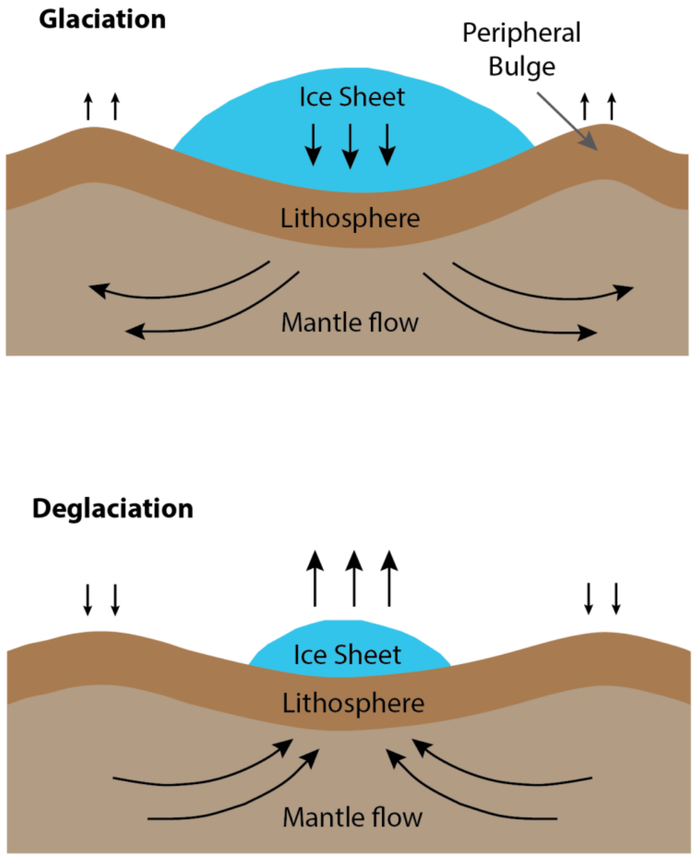
Numerical prediction of present-day rate of local sea-level change due to ongoing glacial isostatic adjustment



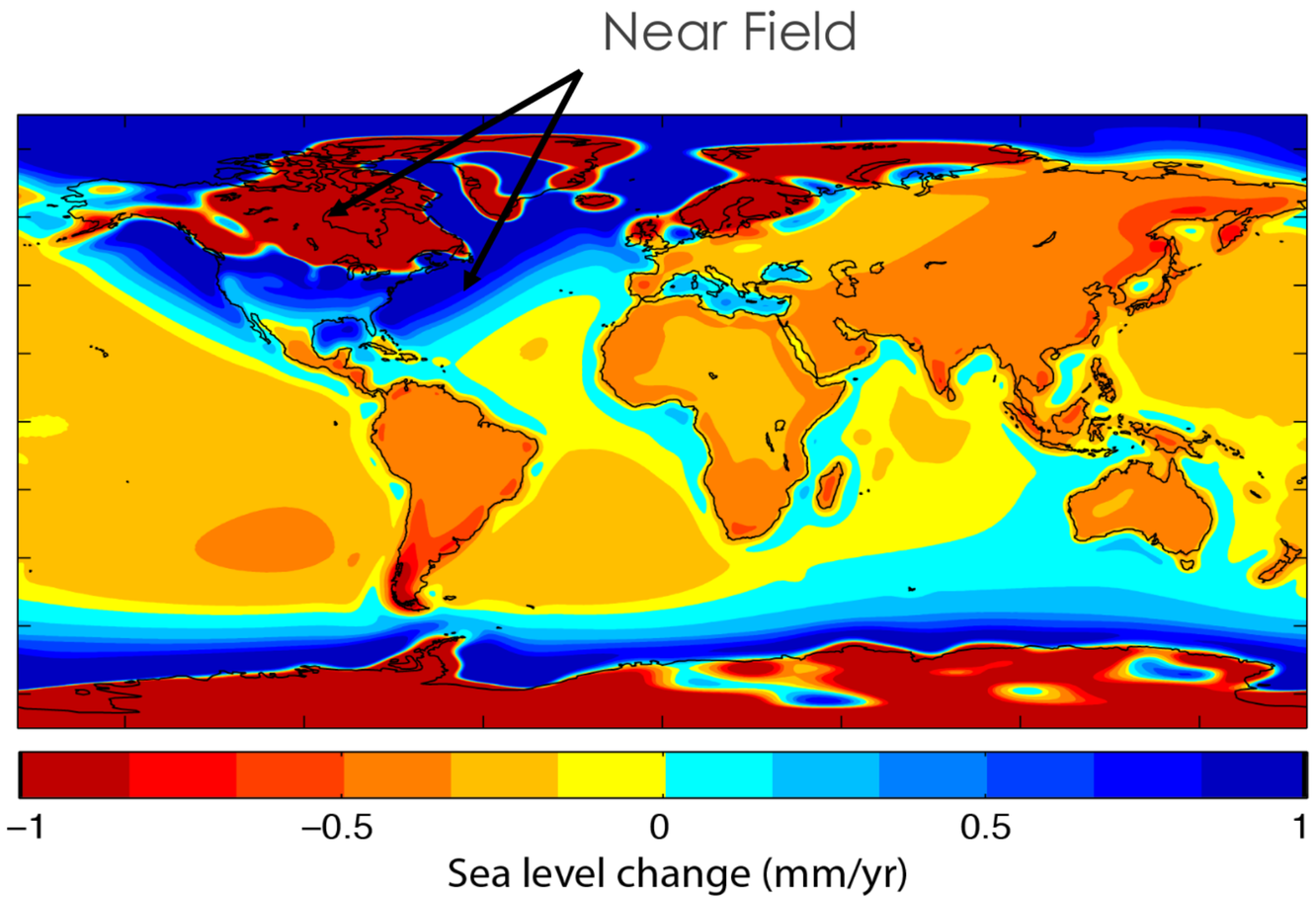
Describe the general pattern you see. What gives rise to this pattern?

Viscous response





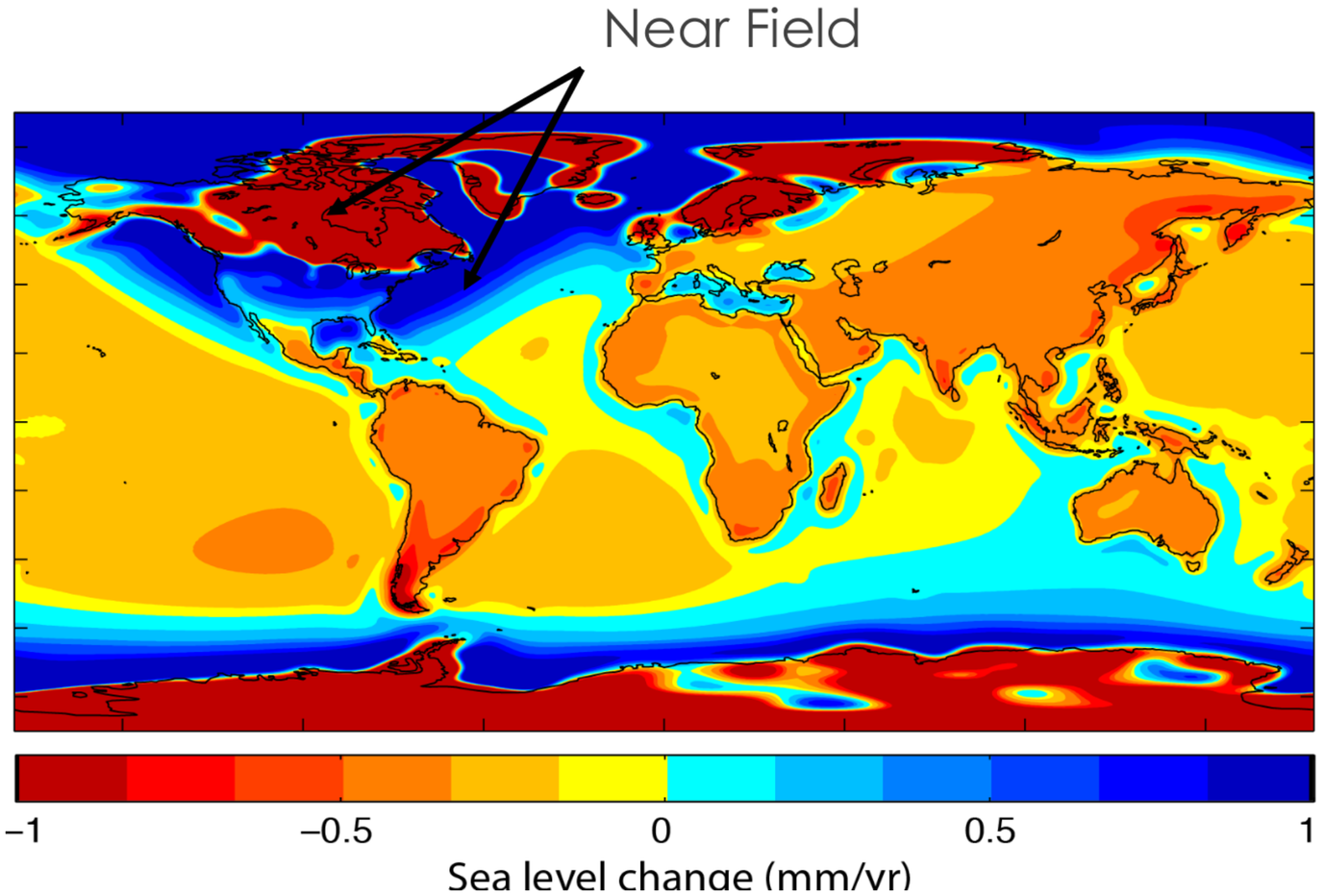
Viscous response

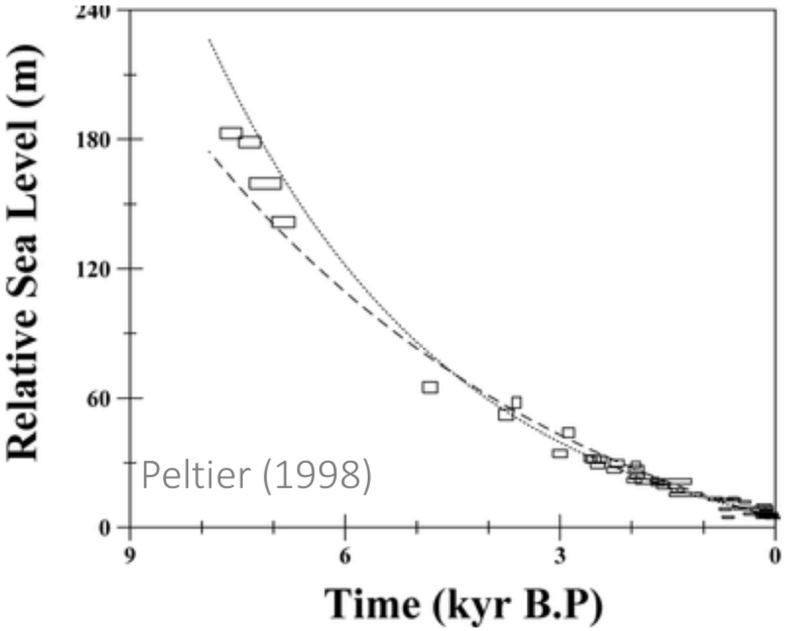


Nunavut - Canadian Arctic

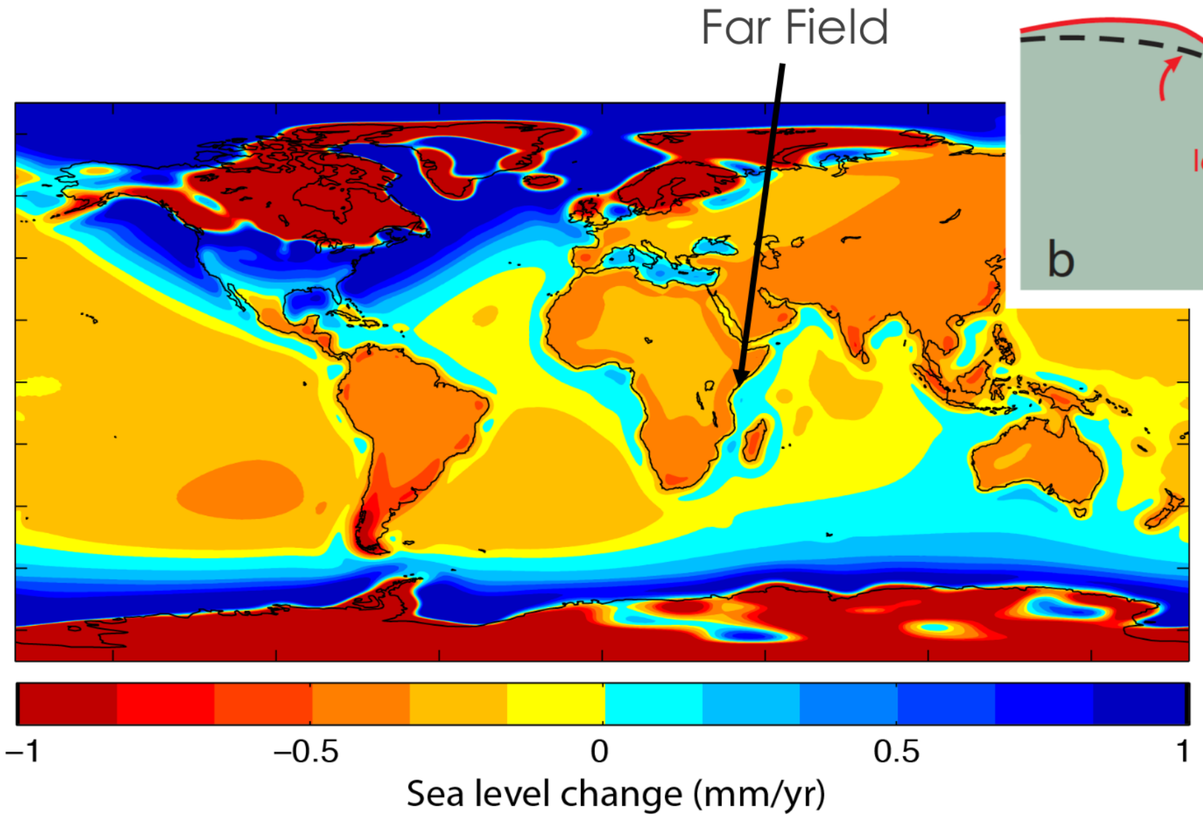
Image credit: Mike Beauregard

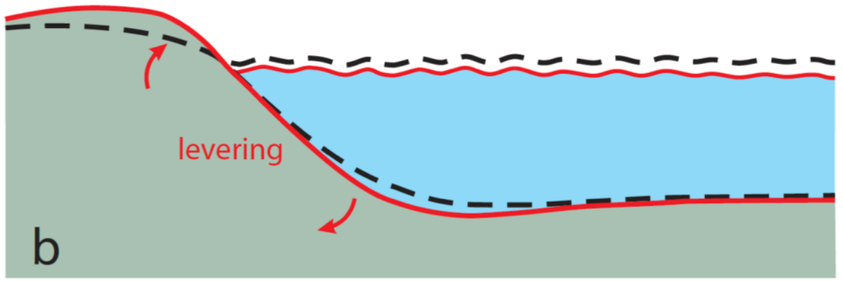
Viscous response





Viscous response

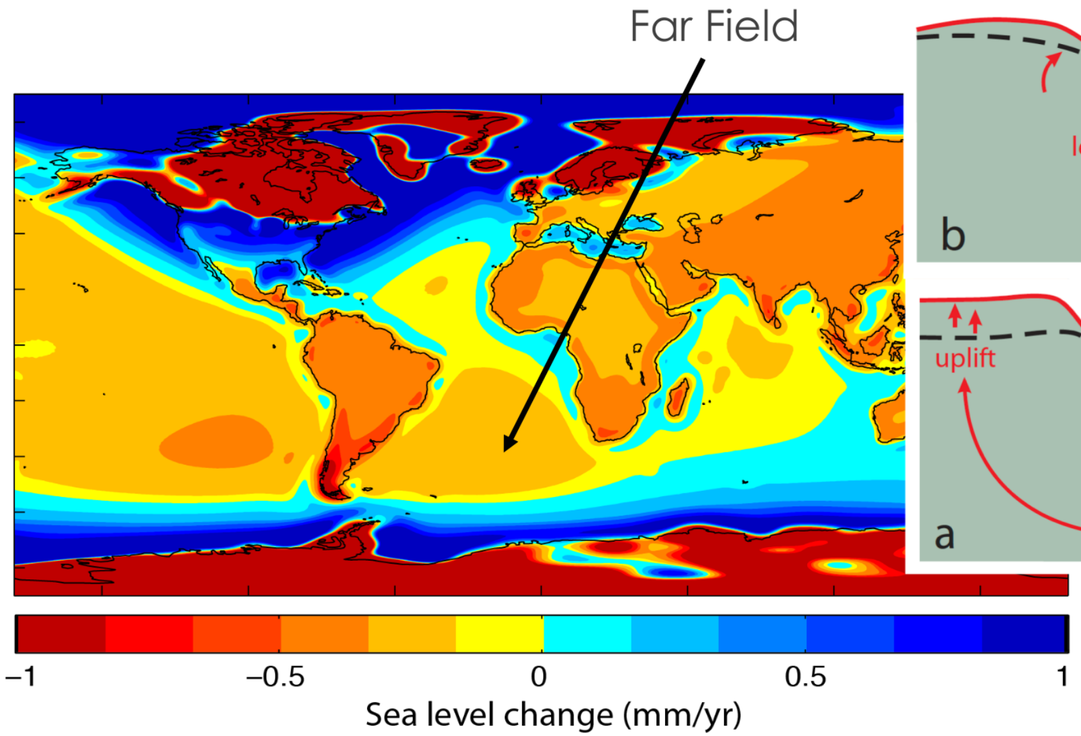




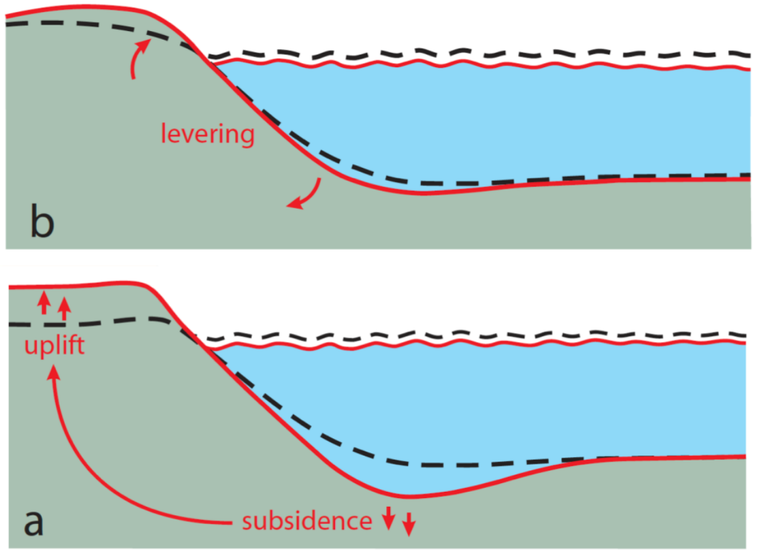
Water is added to the oceans during the deglaciation. Forces mantle to flow from oceans to continents (in the subsurface).

Does the sign of sea level change make sense?

Viscous response

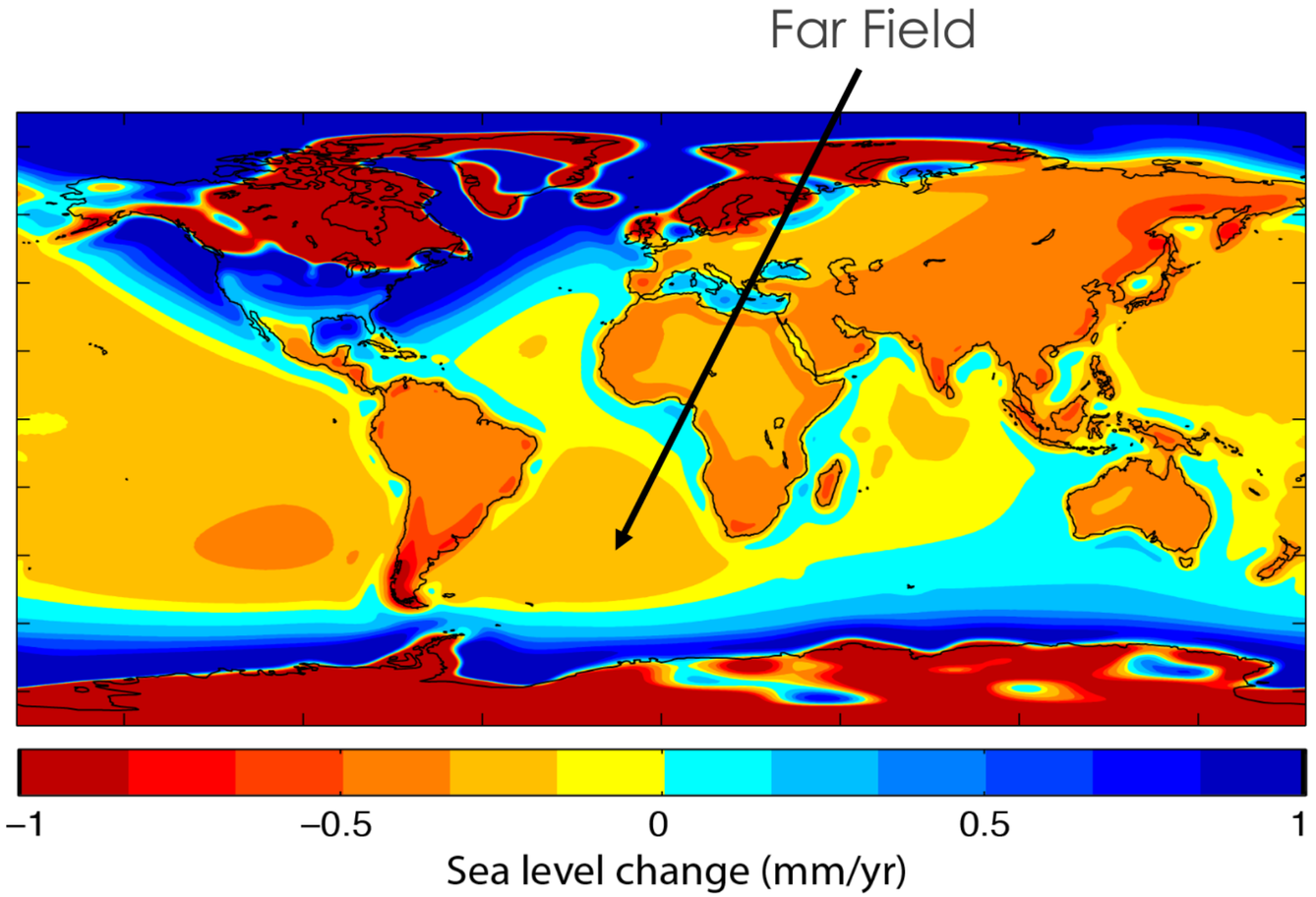


Numerical Prediction of present-day rate of global sea-level change due to ongoing GIA

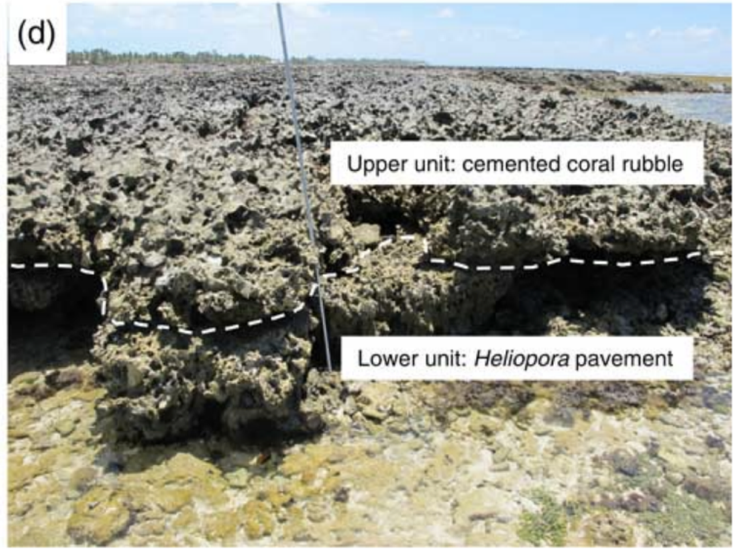


Water flows back into subsiding peripheral bulge and continental levering areas, leading to overall sea level fall.

Viscous response

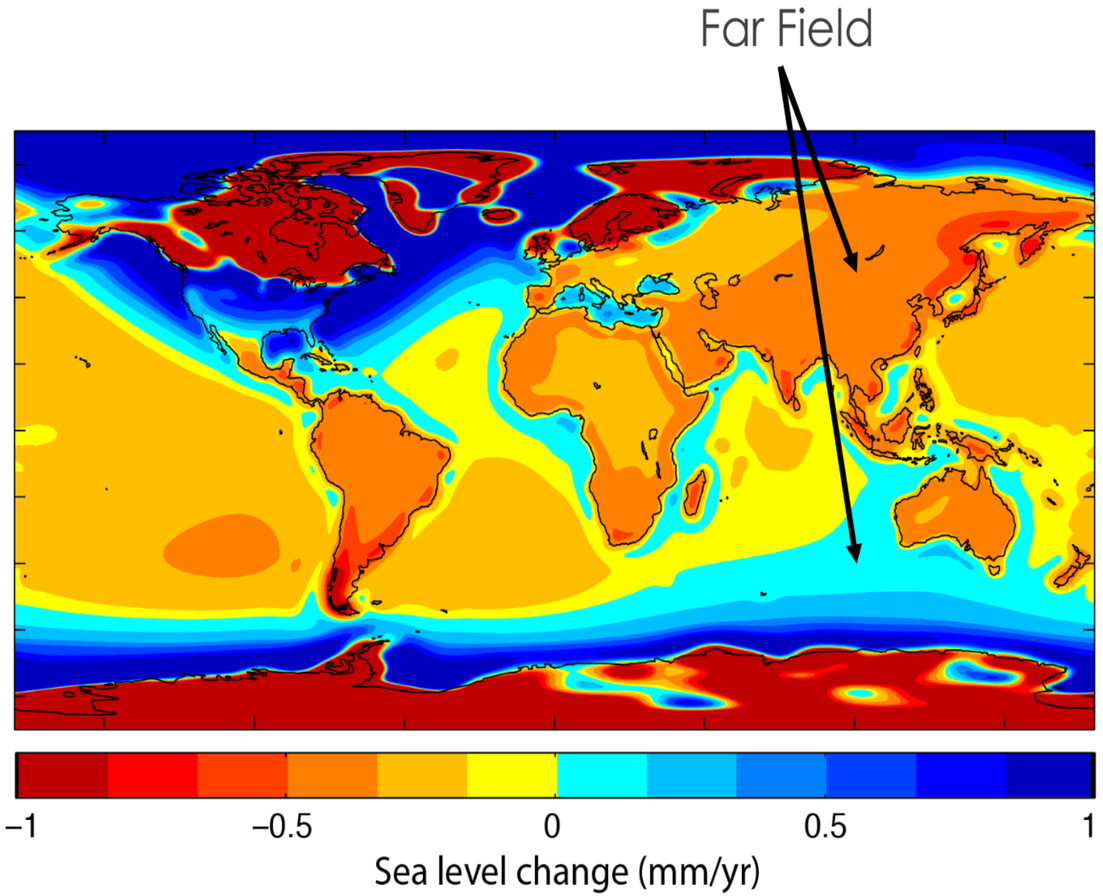


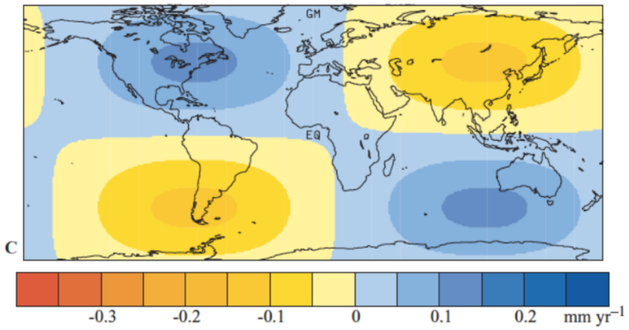
Exposed Holocene corals on Kiribati, west-central Pacific Ocean

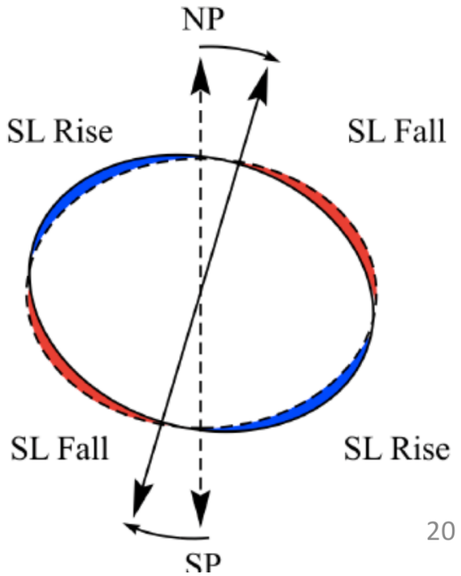


Yamano *et al.*, 2017

Viscous response

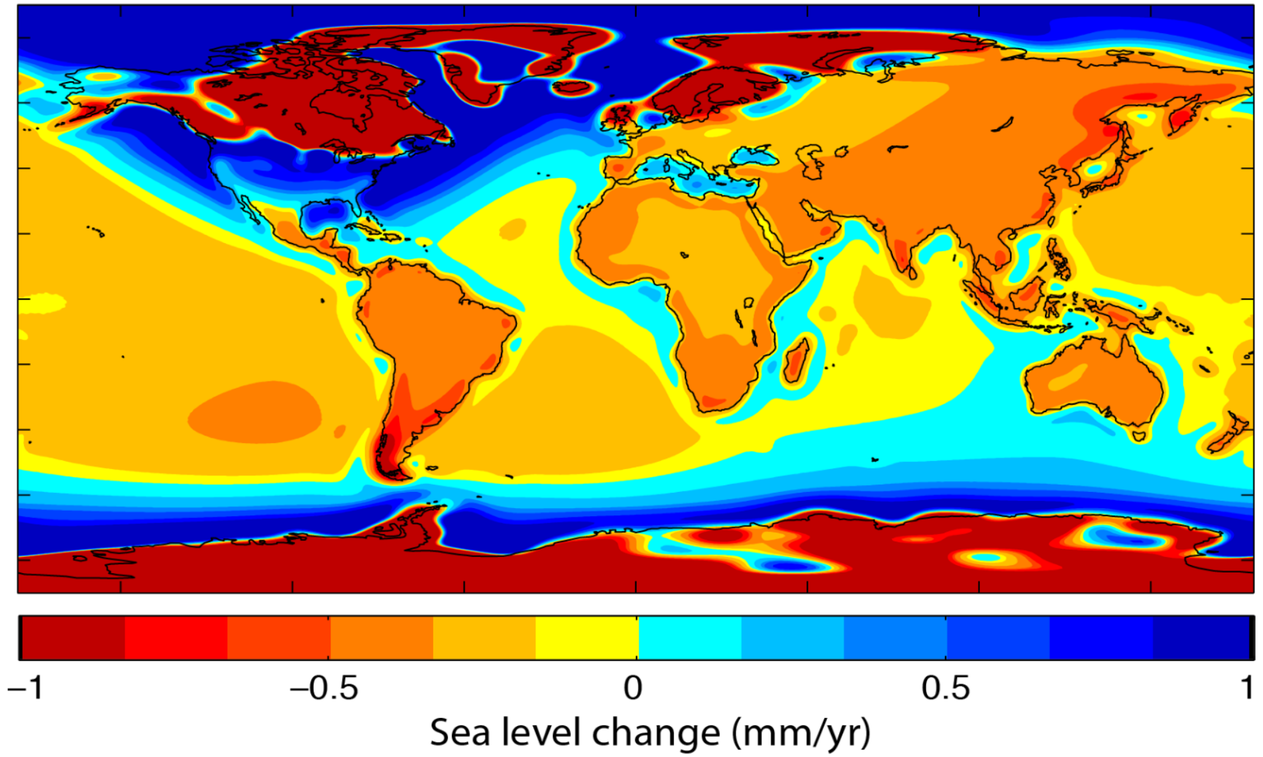




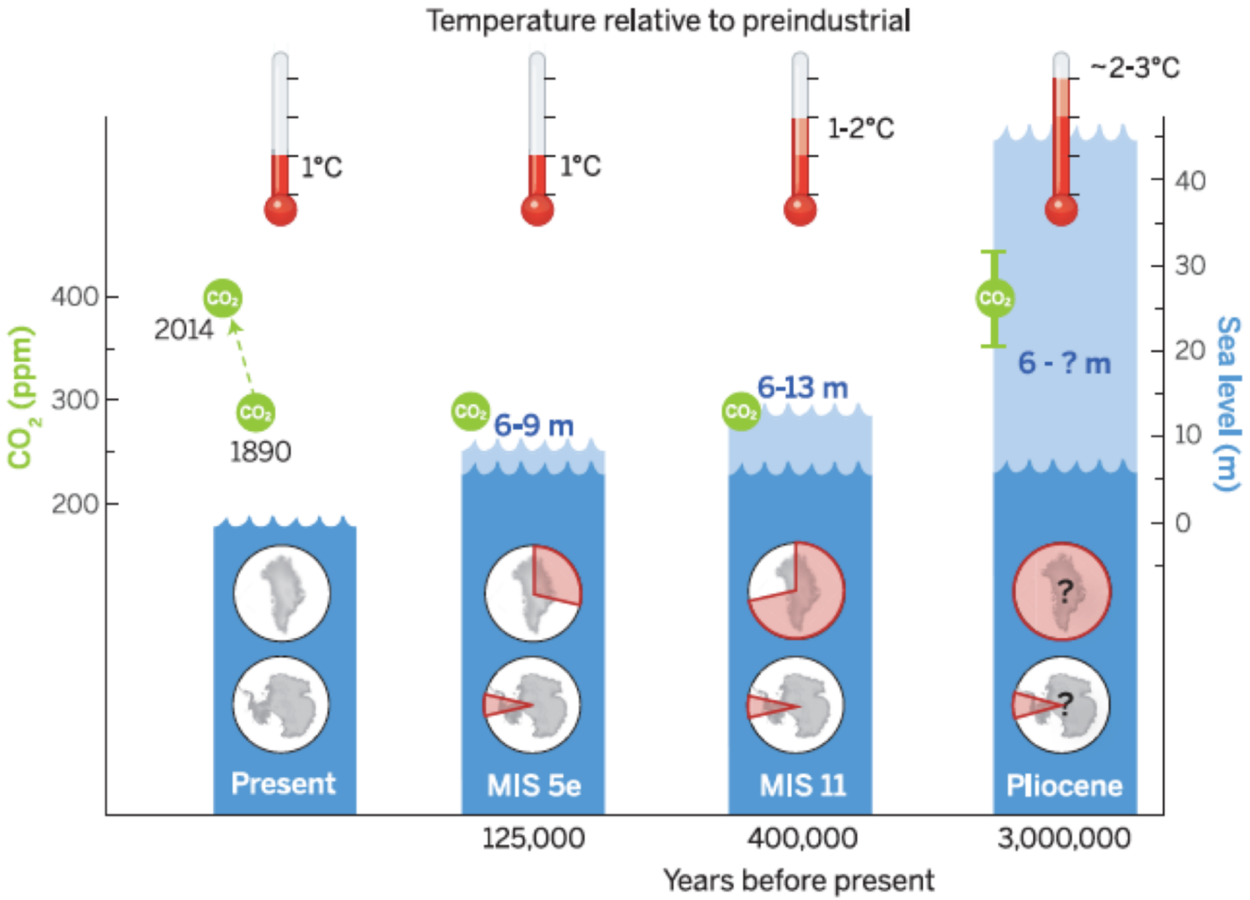


Viscous response

Try to draw the temporal evolution of sea level during an interglacial (with no excess melt) for Hawaii and The Bahamas.



Past warm periods can tell us how sensitive ice sheets are to warming



Past warm periods can tell us how sensitive ice sheets are to warming

Sea level reconstructions are uncertain largely due to uncertainties in GIA, but more data and better inversions can help.