

Are Tides Controlled by Latitude?*

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Abstract

A common belief about tidal sedimentation, based on equilibrium-tide theory that predicts the existence of two ocean-surface bulges centered at low latitudes, is that tides are always larger near the equator and negligible at high latitudes. This is a misconception, because the real-world tide is not explained well by equilibrium-tide theory. Instead, the tide behaves as a shallow-water wave that is guided around the world by the continents. Tidal ranges (and tidal-current speeds) increase as the tidal wave propagates onto and across continental shelves; especially large ranges and fast currents can occur in coastal embayments and in straits that join two larger bodies of water. Tide models demonstrate that tides in shallow water (< 100 m) have amplitude peaks at 50°-70°N and 50°S that are associated with especially wide continental shelves and coastal embayments in which the tidal wave is close to resonance. The small tides characterizing most polar areas today are the result of local geomorphic features: the Arctic Ocean is too small to have its own tide and has only a small connection to the Atlantic Ocean that prevents effective northward propagation of the tidal wave; and Antarctica has narrow and deep continental shelves that do not accentuate the tide. Nevertheless, there are local areas in both the Arctic and Antarctic with favorable geomorphology that have macrotidal ranges. Thus, the latitudinal distribution of large tides is contingent on the plate-tectonic and sea-level history of the Earth, and changes over geologic time as the configuration of the ocean basins changes. Because coastal sedimentation is controlled by the relative importance of tidal currents and waves, the abundance of tide-dominated deposits might not reflect perfectly the latitudinal distribution of large tides. Thus, the small size of waves in the equatorial zone might cause preferential development of tidal deposits near the equator.

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Are Tides Controlled by Latitude?

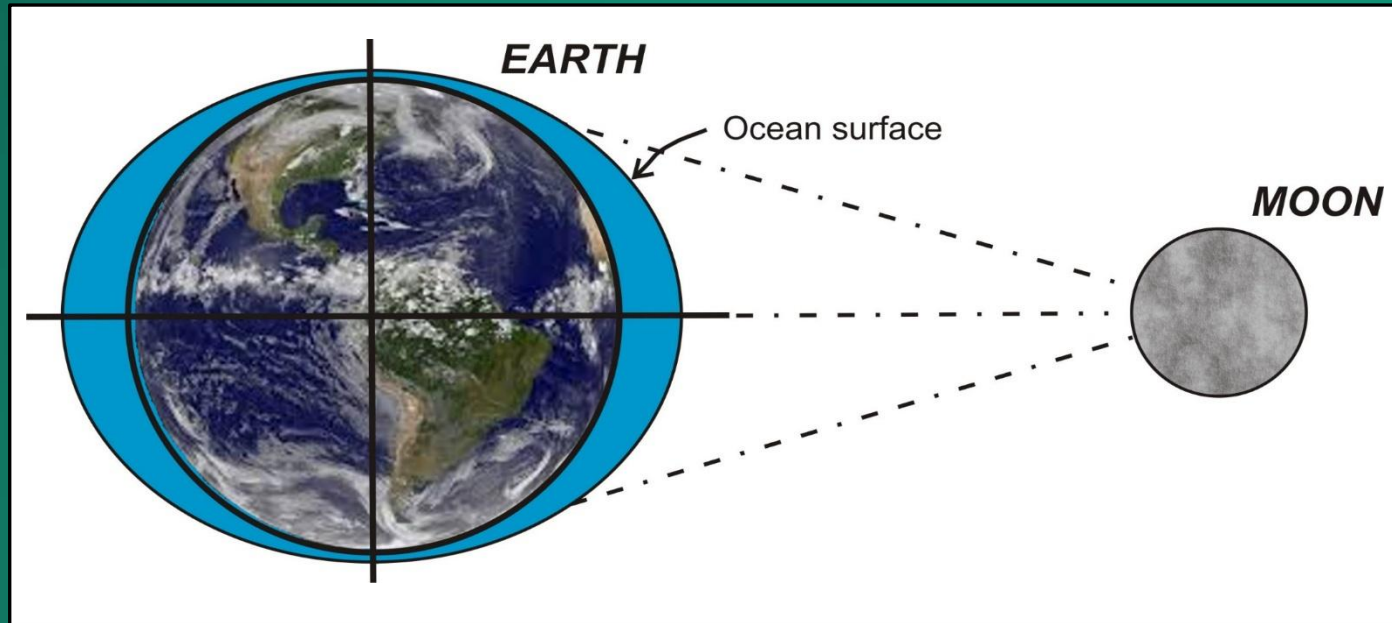
Bob Dalrymple¹ and Laurie Padman²

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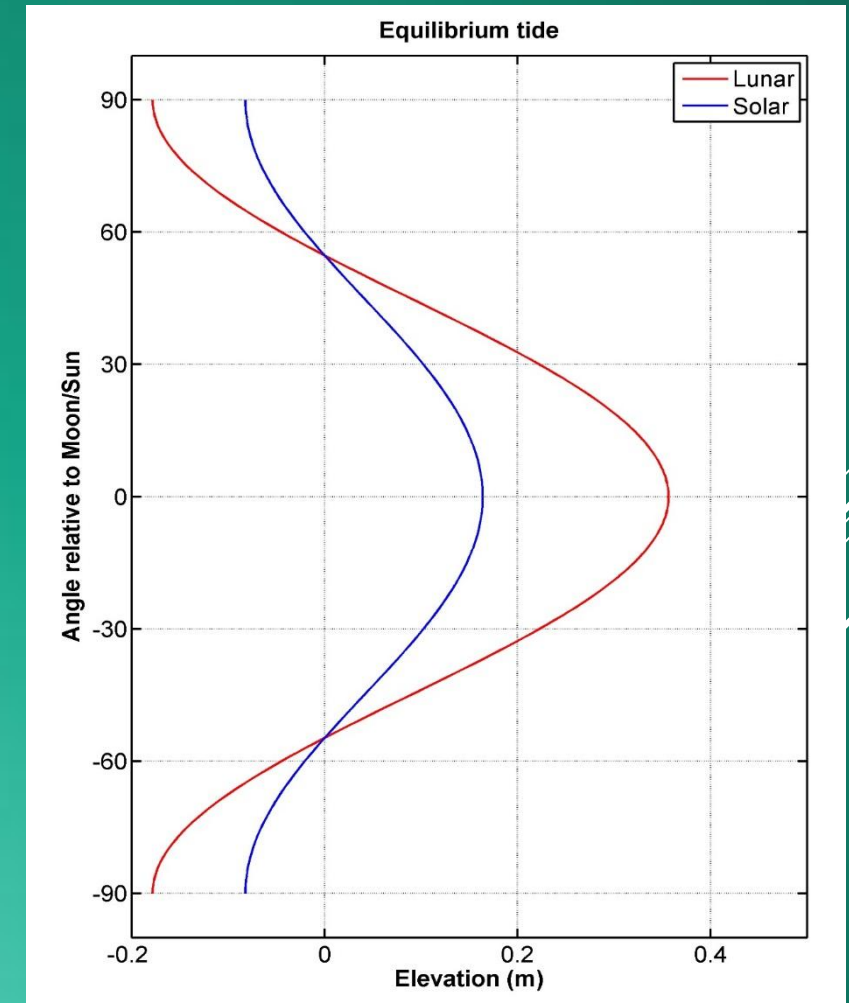
²*Earth & Space Research, Corvallis, Oregon, USA*



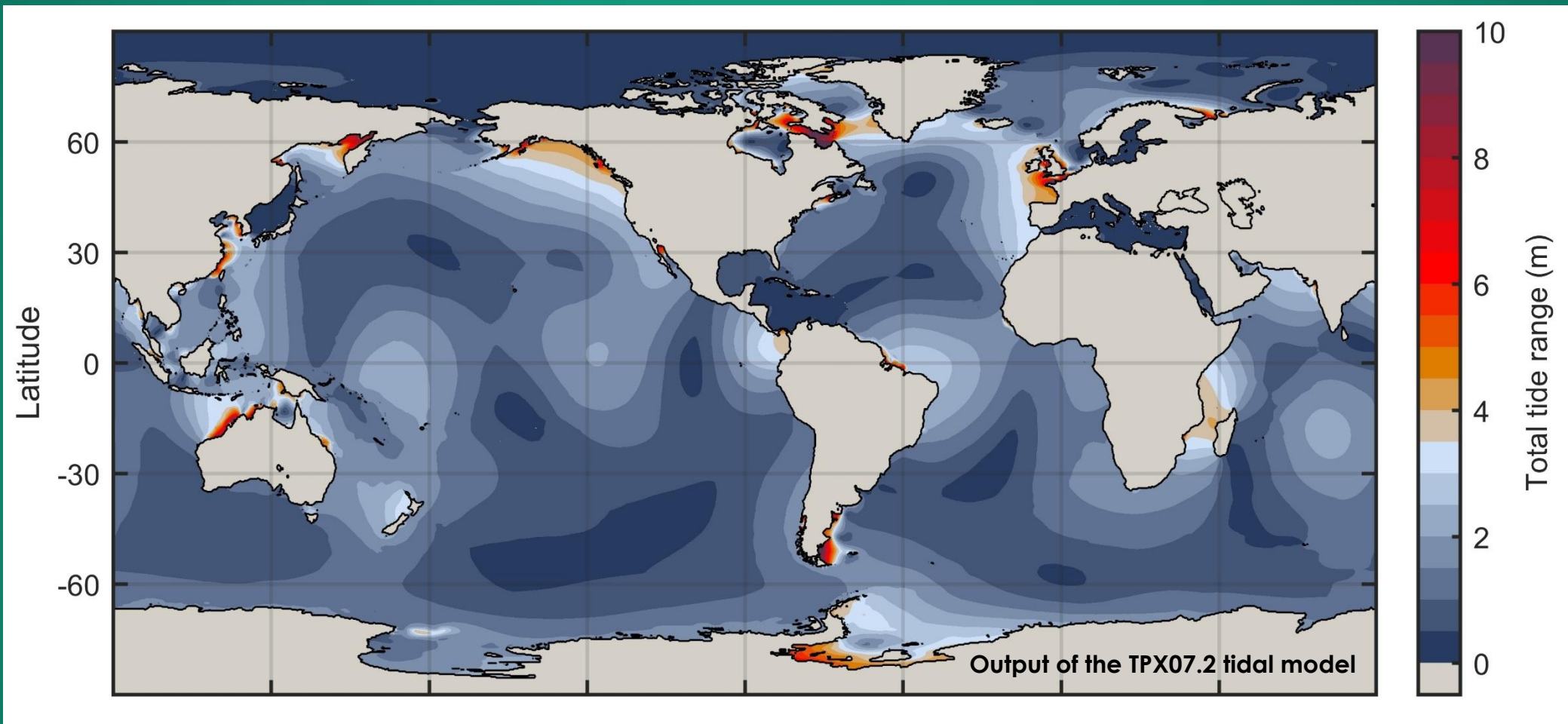
One of the myths about tides is the idea that tides should, on average, be largest near the equator, because that is where the tidal bulges created by the Moon and Sun are largest. Conversely, tides are thought to be small at high latitudes.



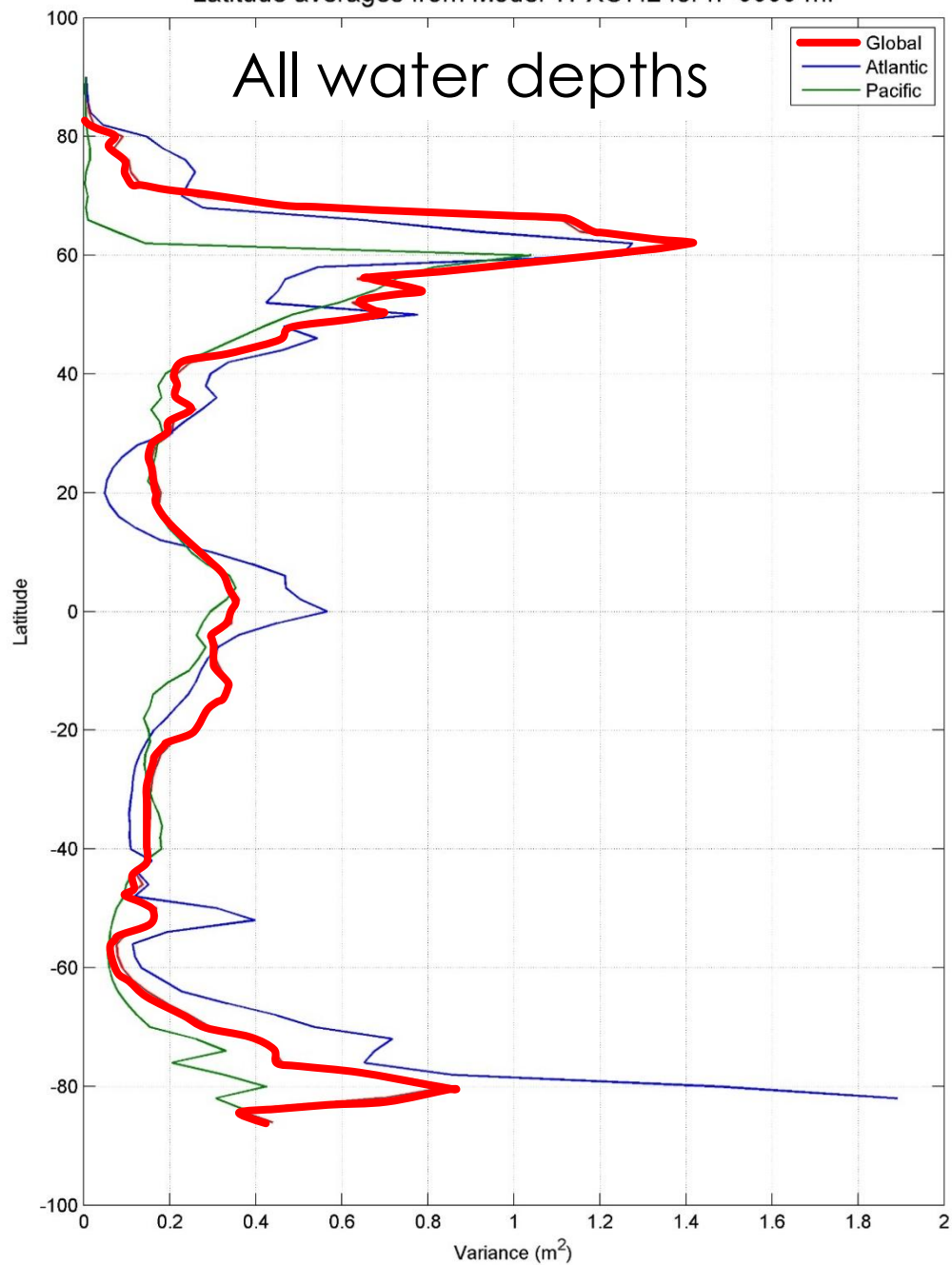
HOWEVER: “Equilibrium tidal theory is unfit to explain the actual tides of the oceans” (Defant, 1961, p. 277), because it fails to take into account the presence of the continents and the influence of the Coriolis effect!



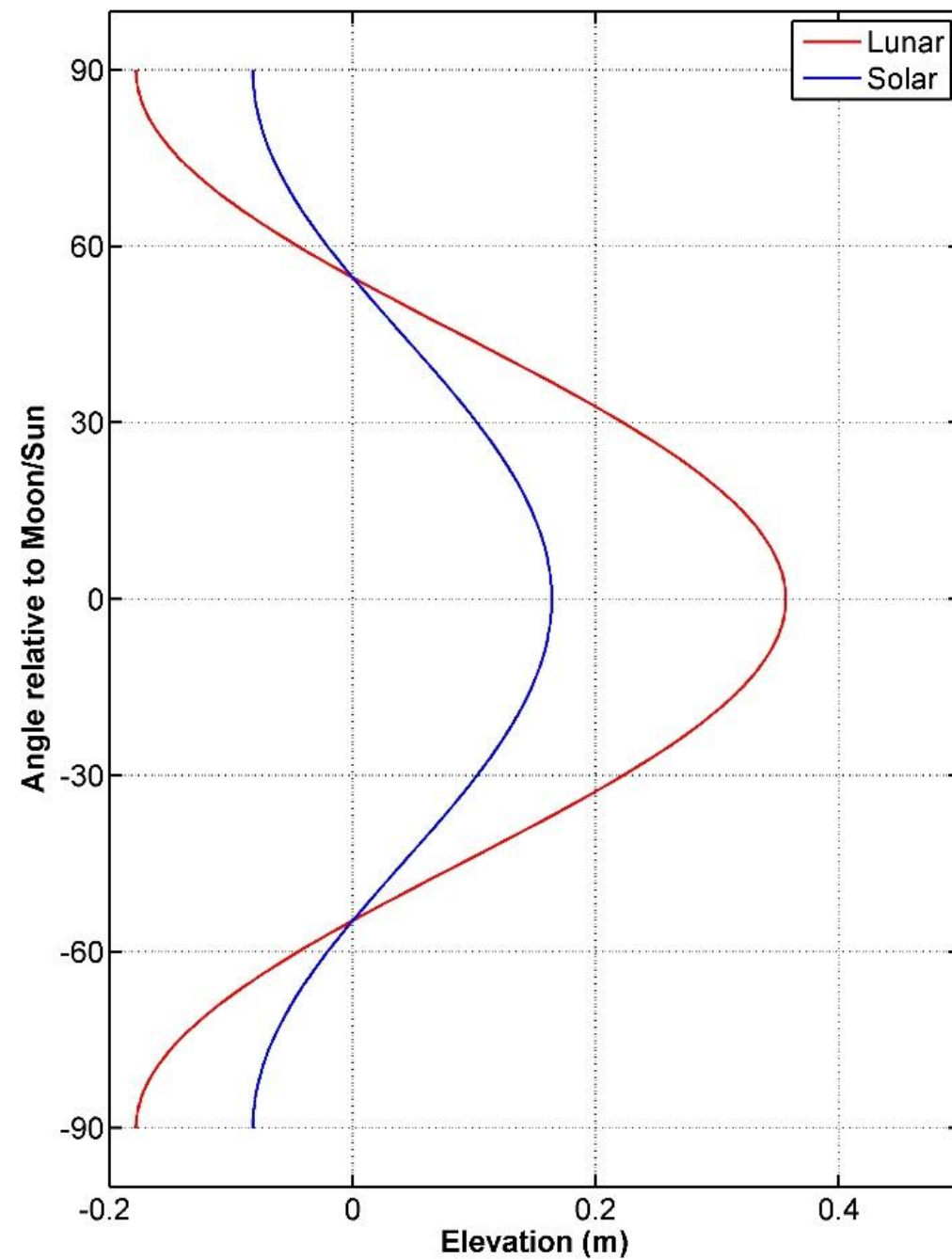
Dynamic tidal theory takes these factors into account, but is too complex to explain simply in textbooks, and the equations can only be solved by numerical approximation. The real tide tends to be largest (but still only ~ 2 m) in the equatorial belt of the open ocean, but the tidal wave's motion is deflected by the Coriolis effect and travels away from the equator toward the poles. It also interacts with the bathymetry and coastal morphology, becoming larger as it propagates across continental shelves and into embayments.



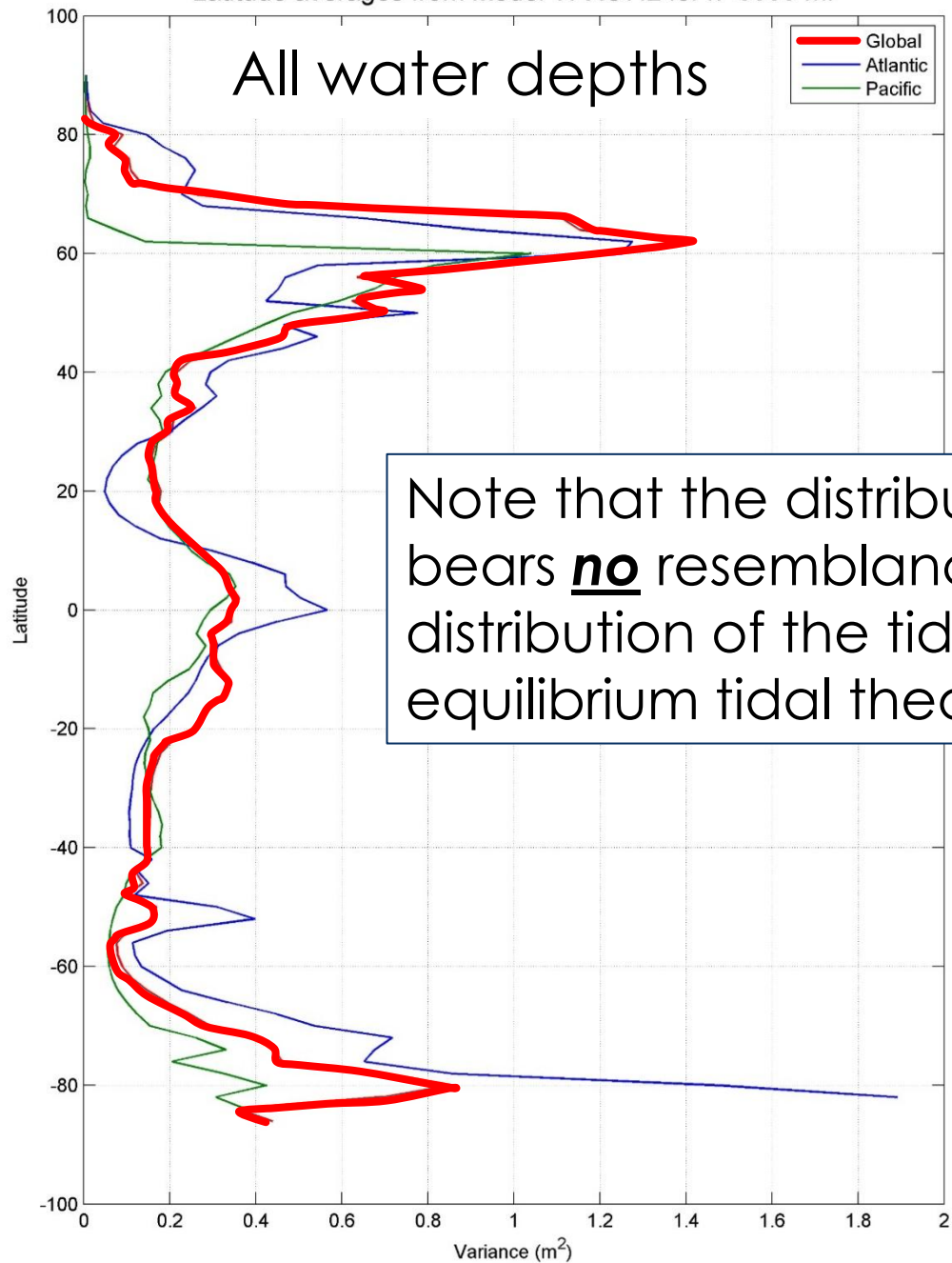
Latitude averages from Model TPXO7.2 for $h < 9999$ m.



Equilibrium tide

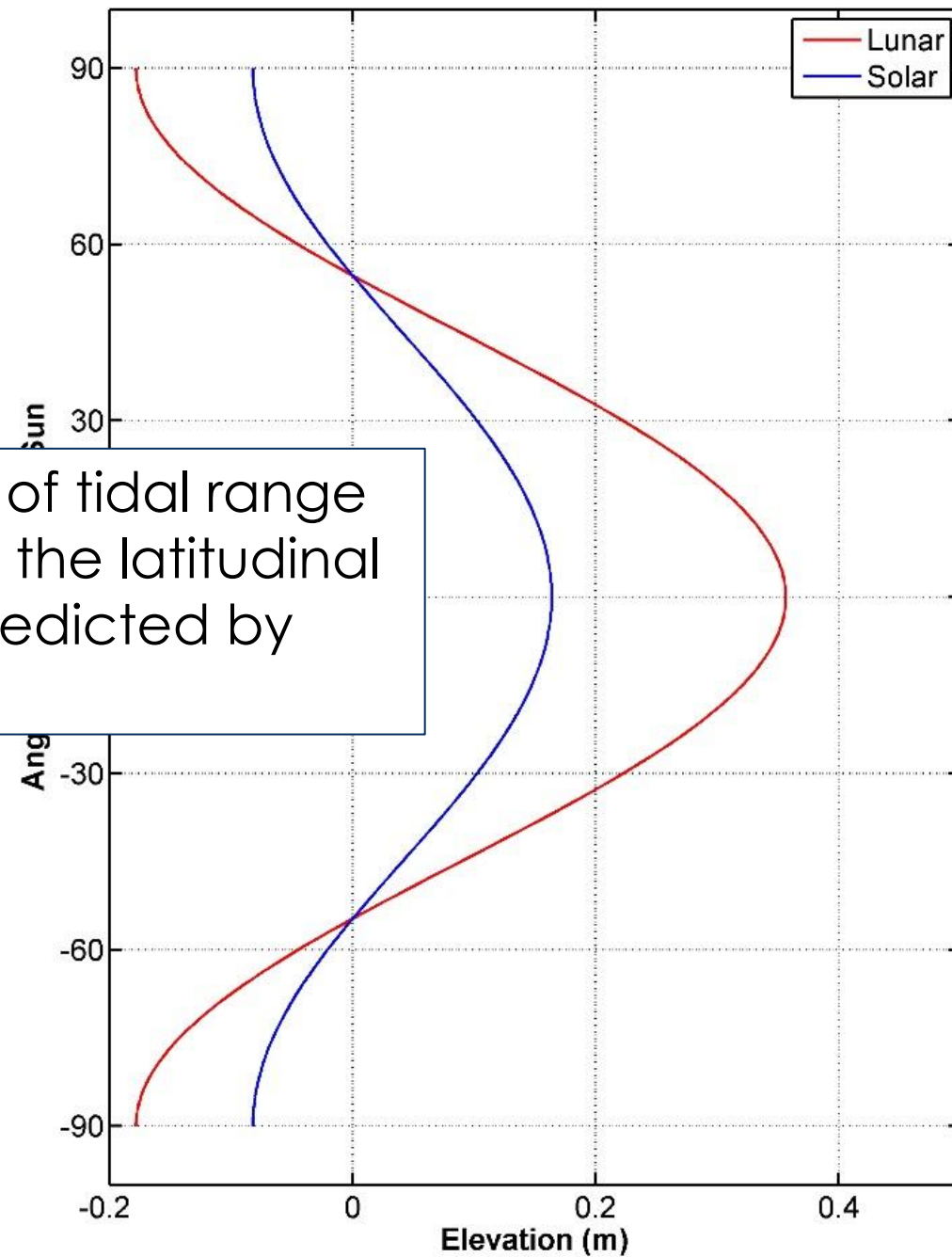


Latitude averages from Model TPXO7.2 for $h < 9999$ m.

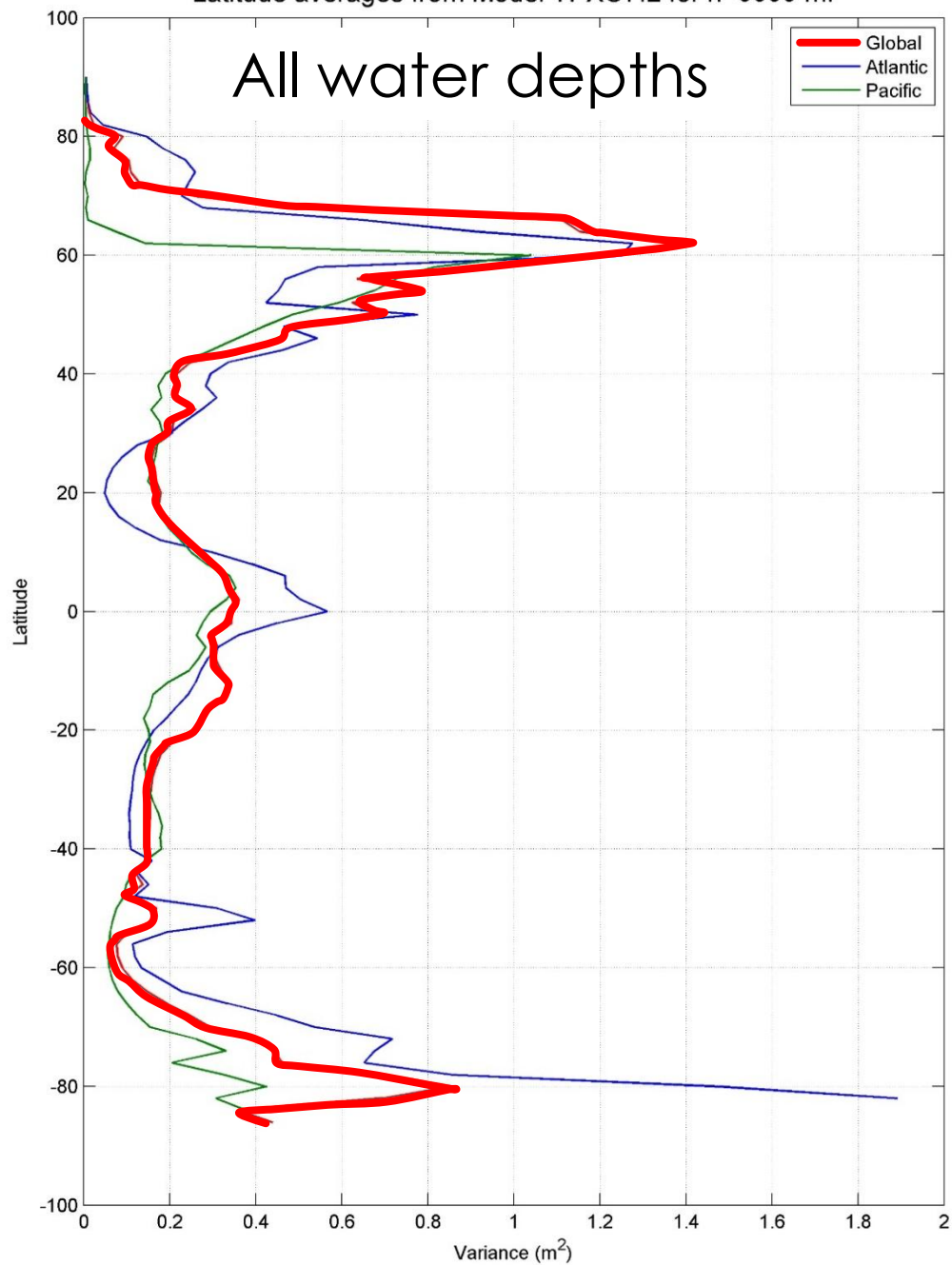


Note that the distribution of tidal range bears **no** resemblance to the latitudinal distribution of the tides predicted by equilibrium tidal theory!

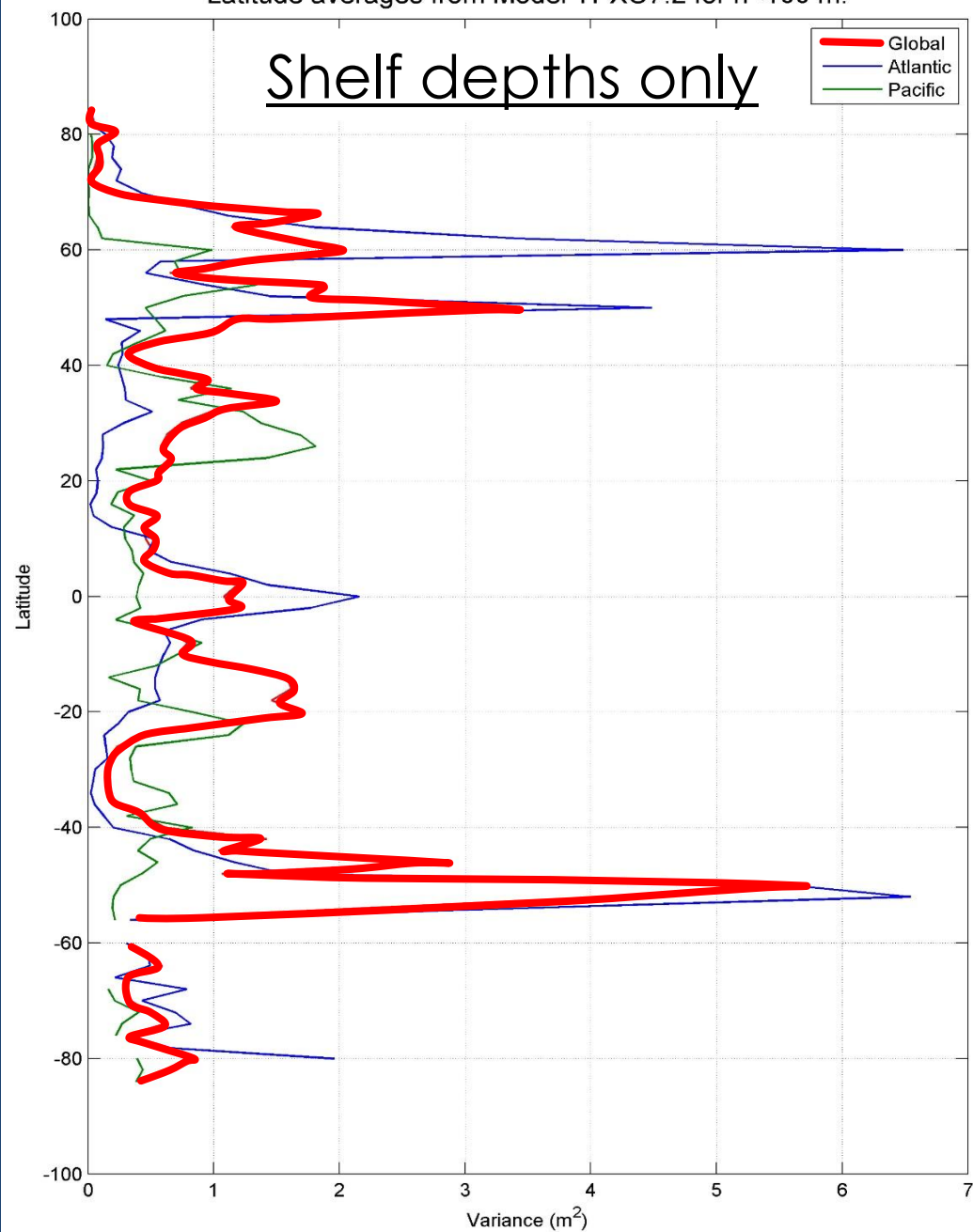
Equilibrium tide



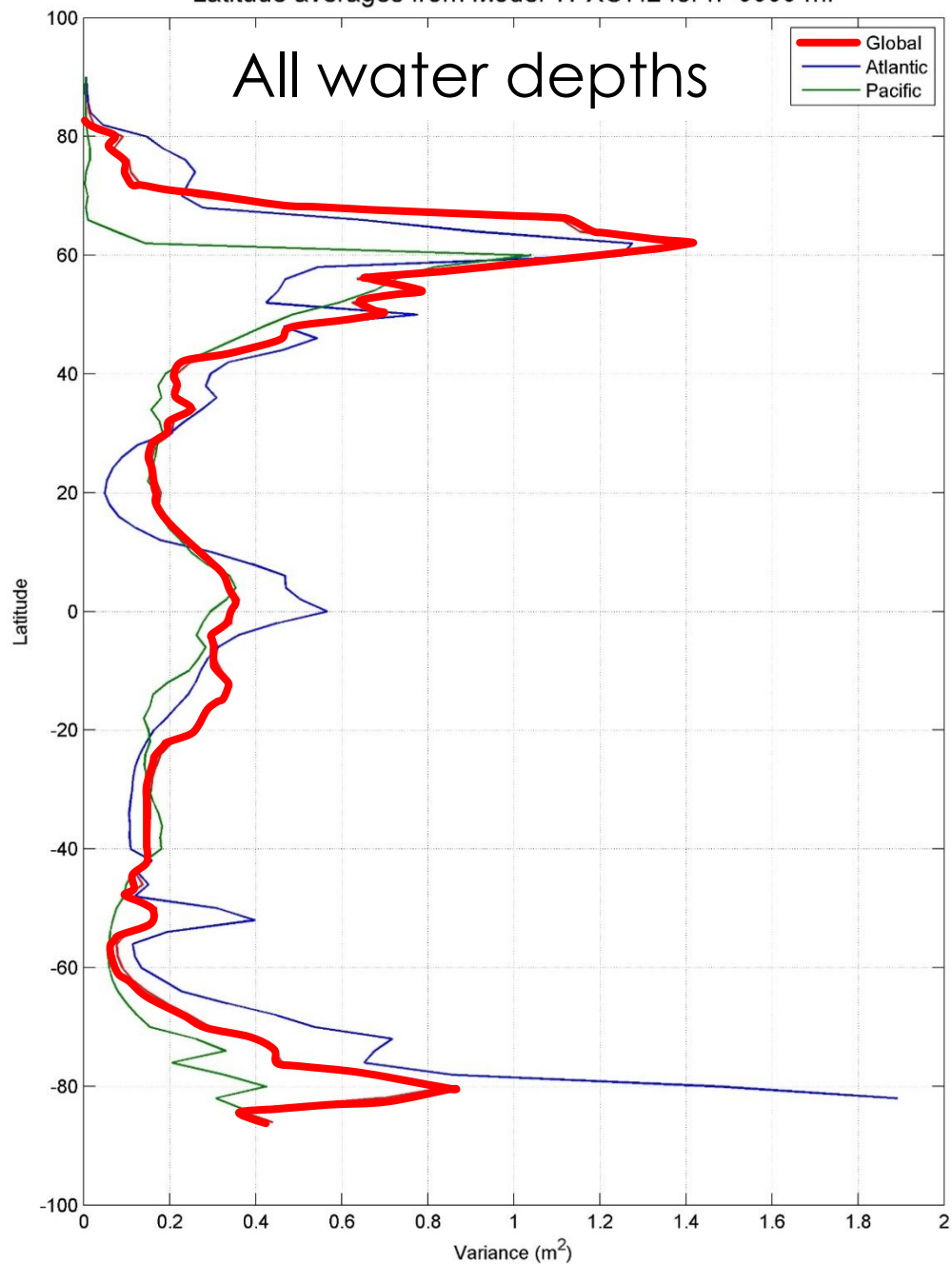
Latitude averages from Model TPXO7.2 for $h < 9999$ m.



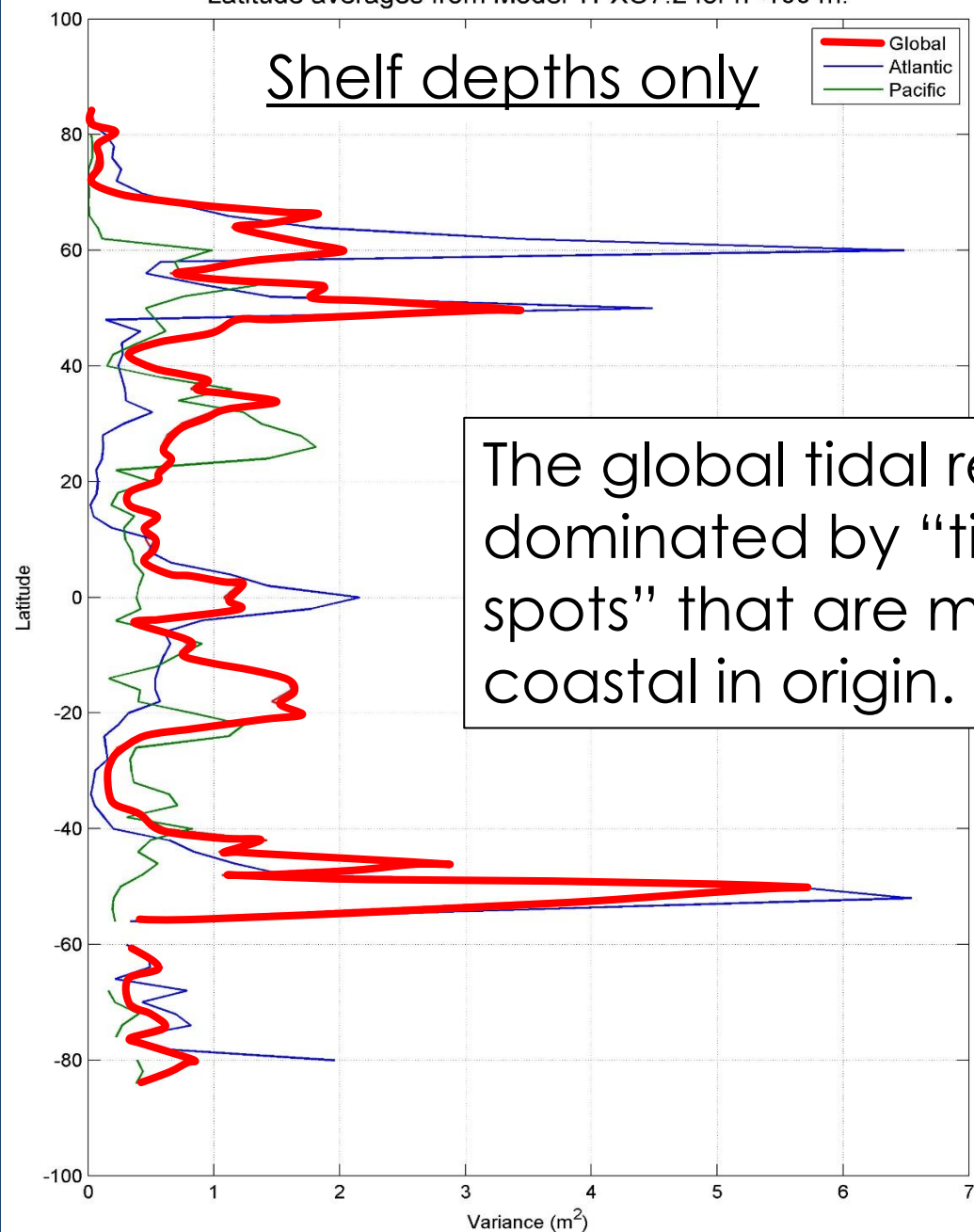
Latitude averages from Model TPXO7.2 for $h < 100$ m.



Latitude averages from Model TPXO7.2 for $h < 9999$ m.



Latitude averages from Model TPXO7.2 for $h < 100$ m.



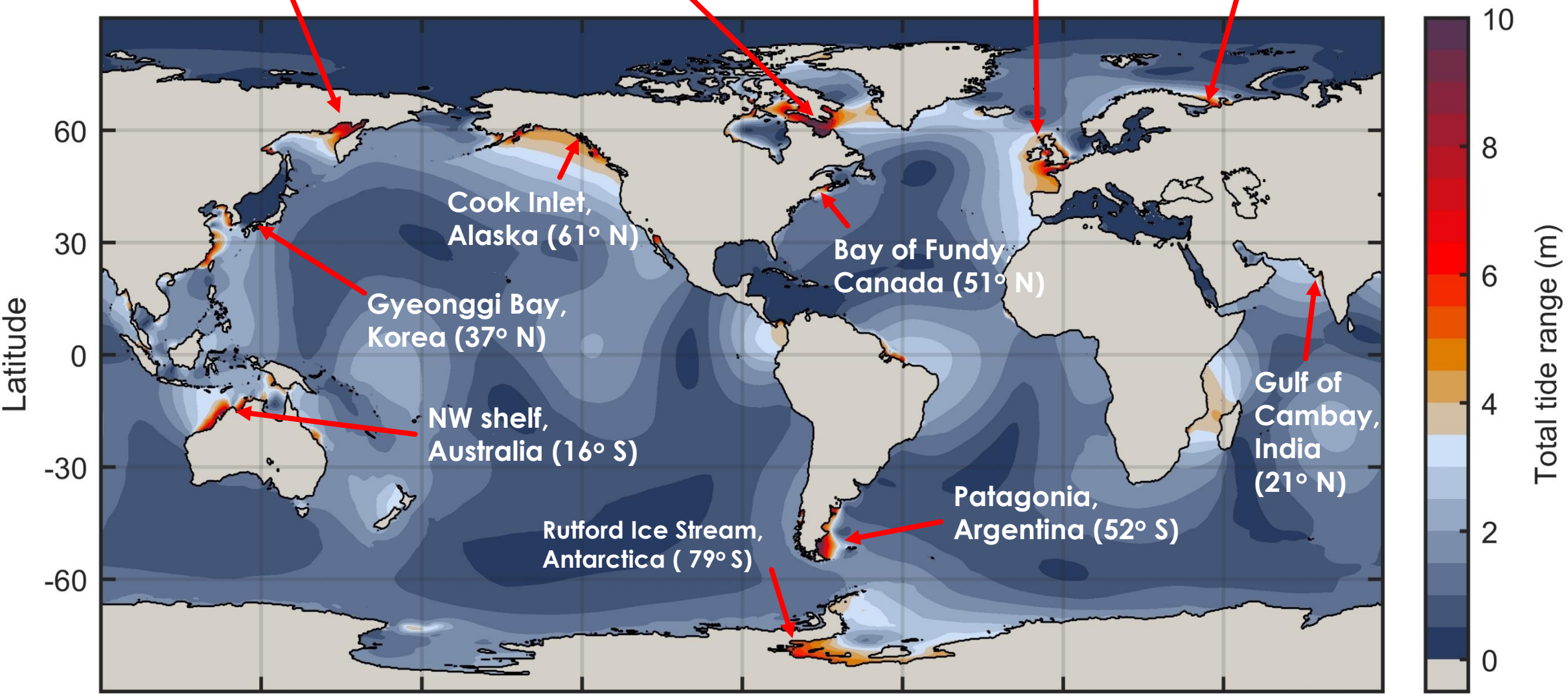
Areas with tidal ranges > 8 m

Sea of Okhotsk, Russia (62° N)

Ungava Bay, Canada (59° N)

Liverpool Bay, Severn River
English Channel, Mont
Saint Michel Bay (49-53° N)

Gulf of Mezan, Russia (65° N)



Cook Inlet,
Alaska (61° N)

Gyeonggi Bay,
Korea (37° N)

NW shelf,
Australia (16° S)

Rufford Ice Stream,
Antarctica (79° S)

Bay of Fundy,
Canada (51° N)

Patagonia,
Argentina (52° S)

Gulf of Cambay,
India (21° N)

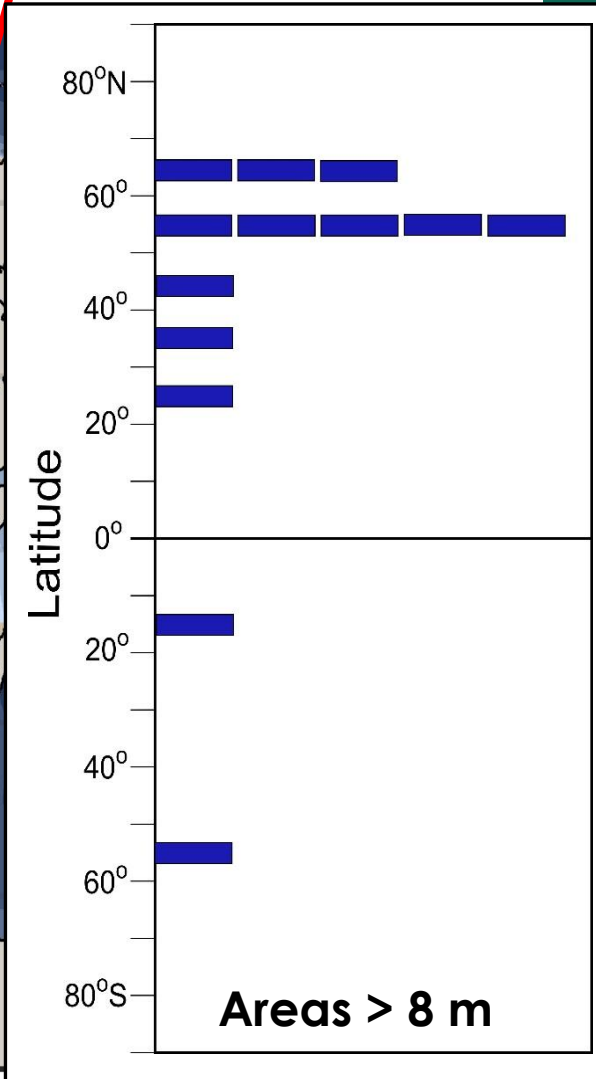
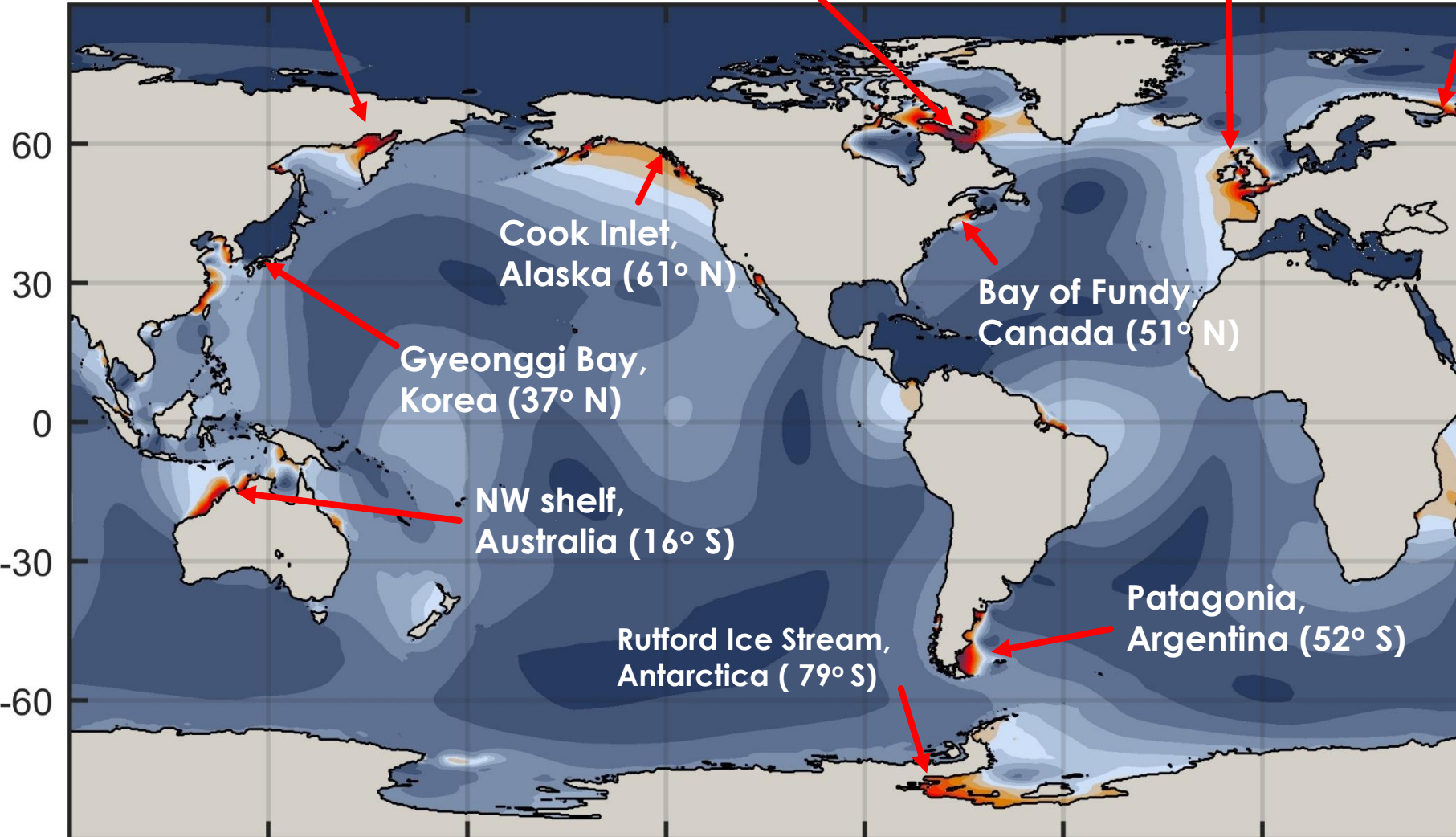
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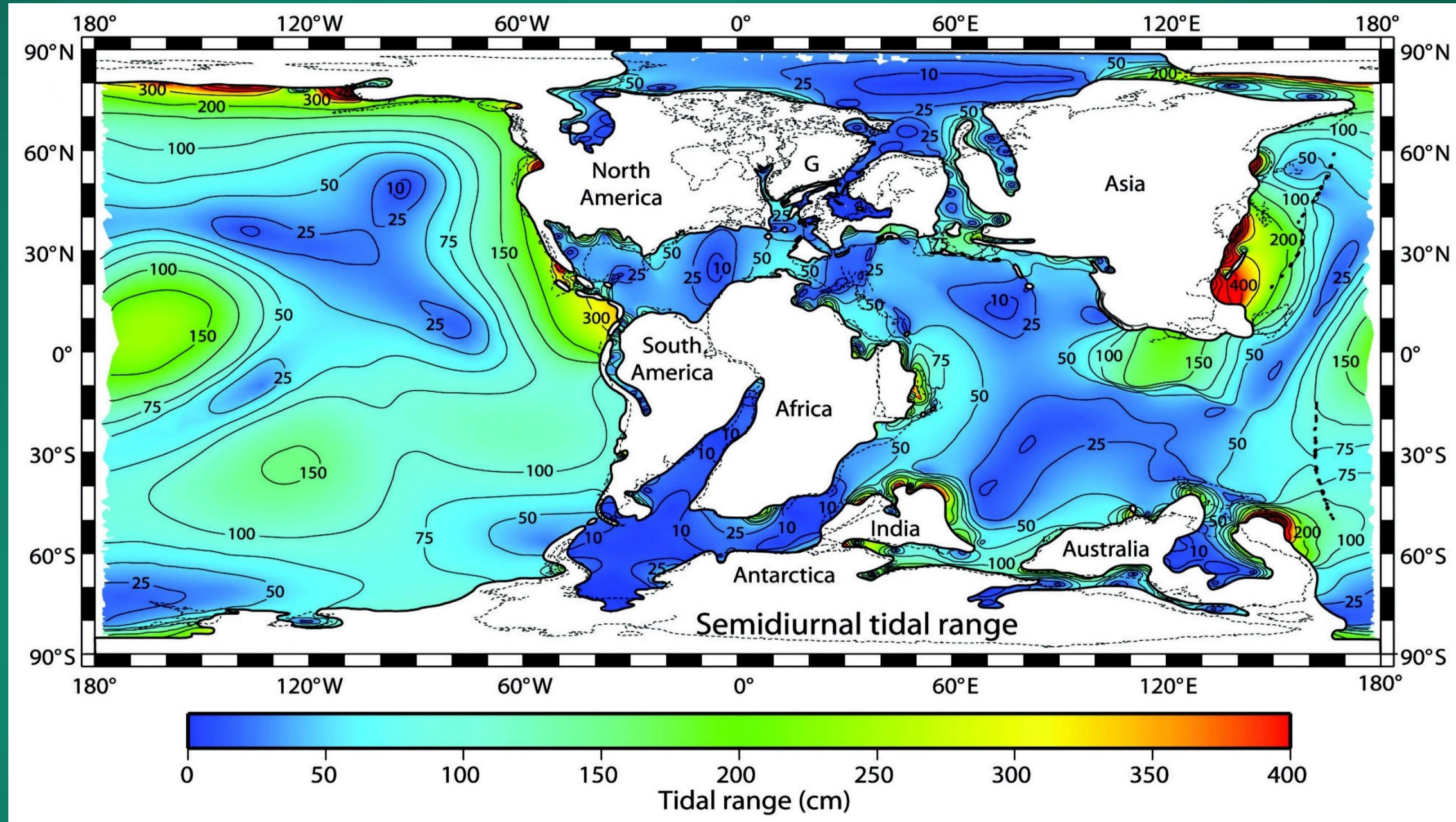
Ungava Bay, Canada (59° N)

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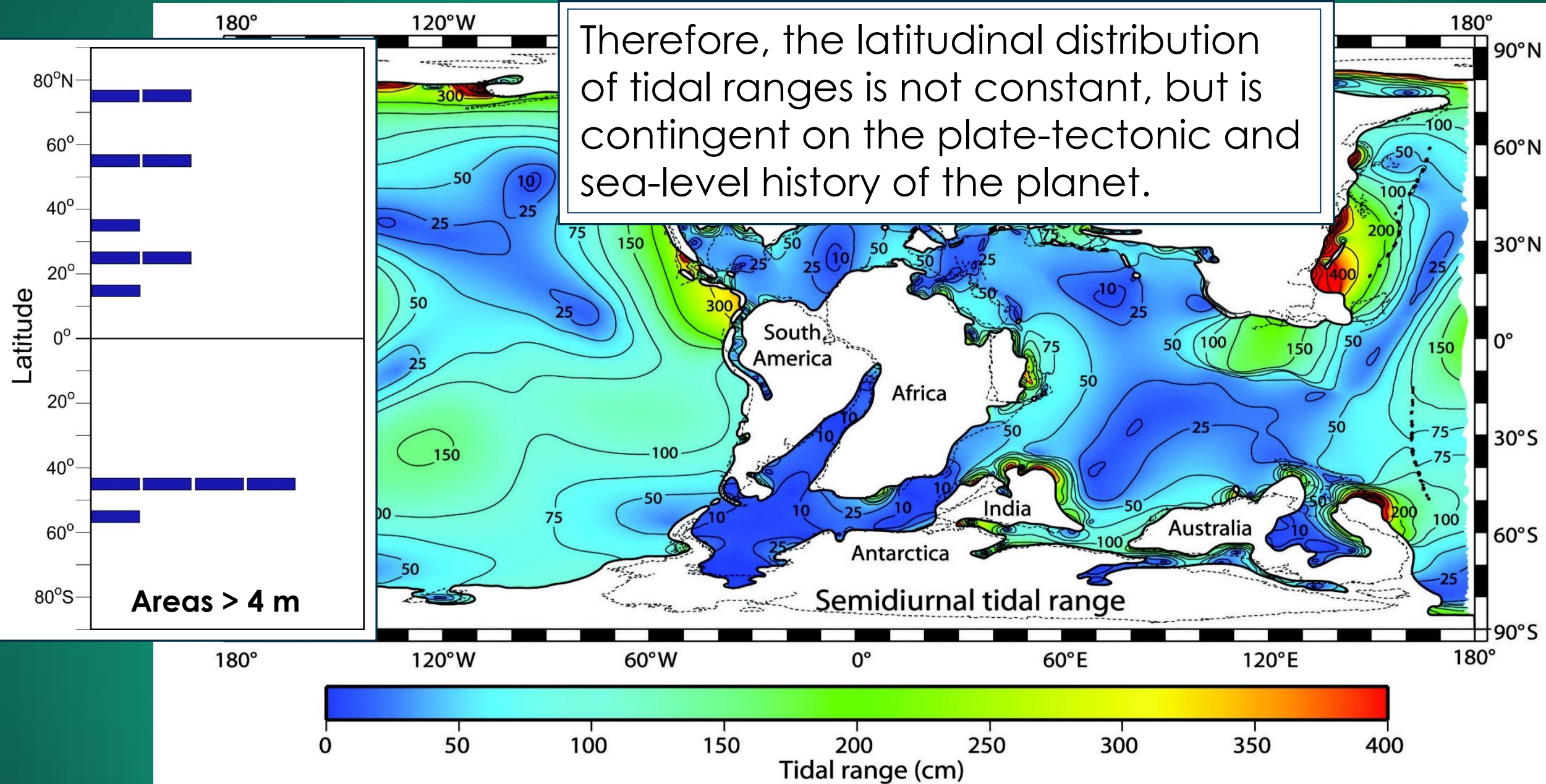


Late Cretaceous (Albian) paleotides (from Wells et al., 2010)



Late Cretaceous (Albian) paleotides (from Wells et al., 2010)

Therefore, the latitudinal distribution of tidal ranges is not constant, but is contingent on the plate-tectonic and sea-level history of the planet.

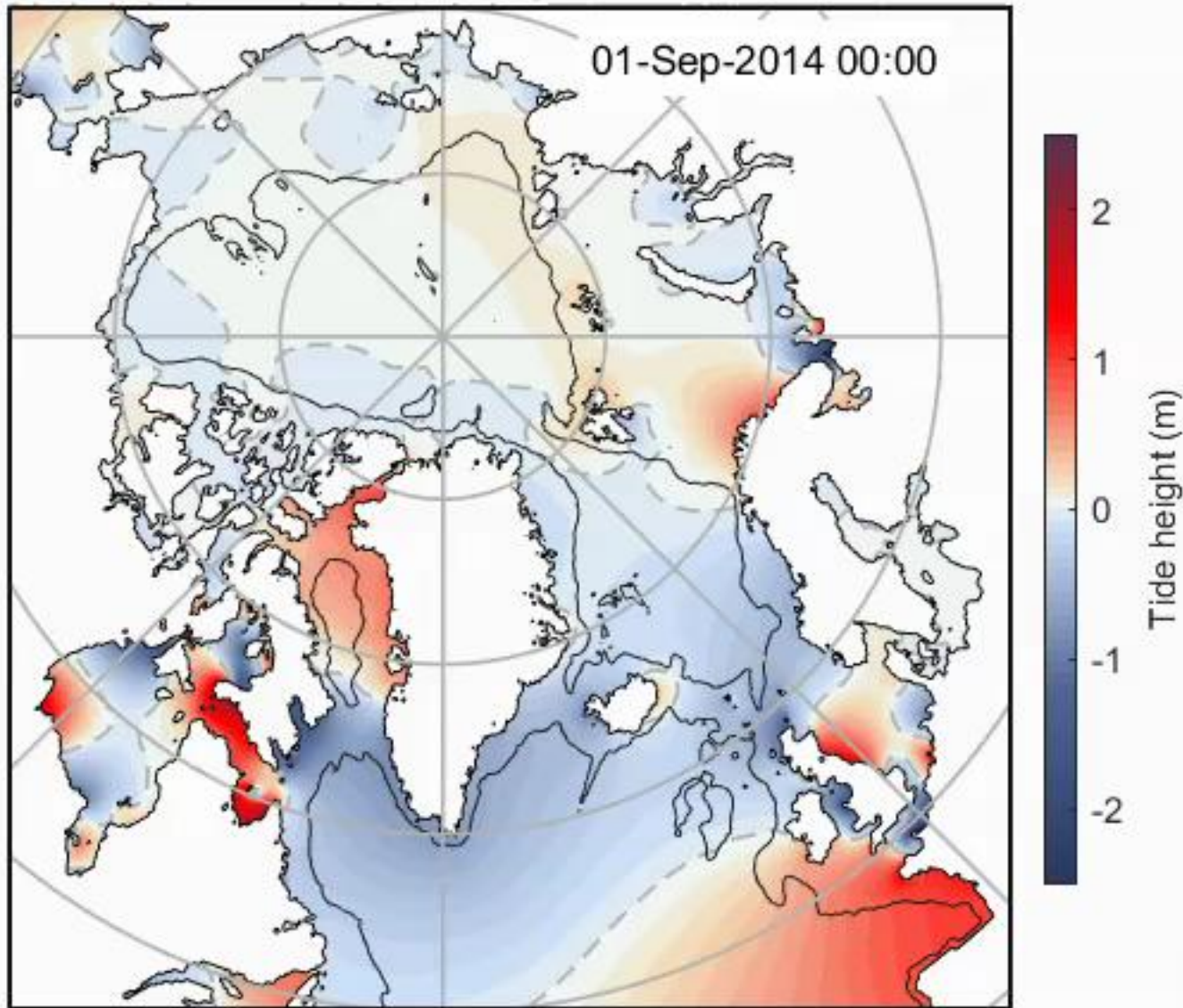


So, why are the tides in the Arctic Ocean and around Antarctica so small?

With regard to the Arctic, the northward-propagating tidal wave is blocked by the narrow and shallow Denmark Strait, and passes over the Iceland-Faroe Ridge with a reduced amplitude.



Arctic Ocean tide height: Model TPXO7.2



L. Padman (ESR)

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Note tide does not pass through Denmark Strait and enters the Arctic Ocean mainly to the east of Iceland, although with an attenuated amplitude. It is further damped by the very broad, shallow continental shelf north of Russia.

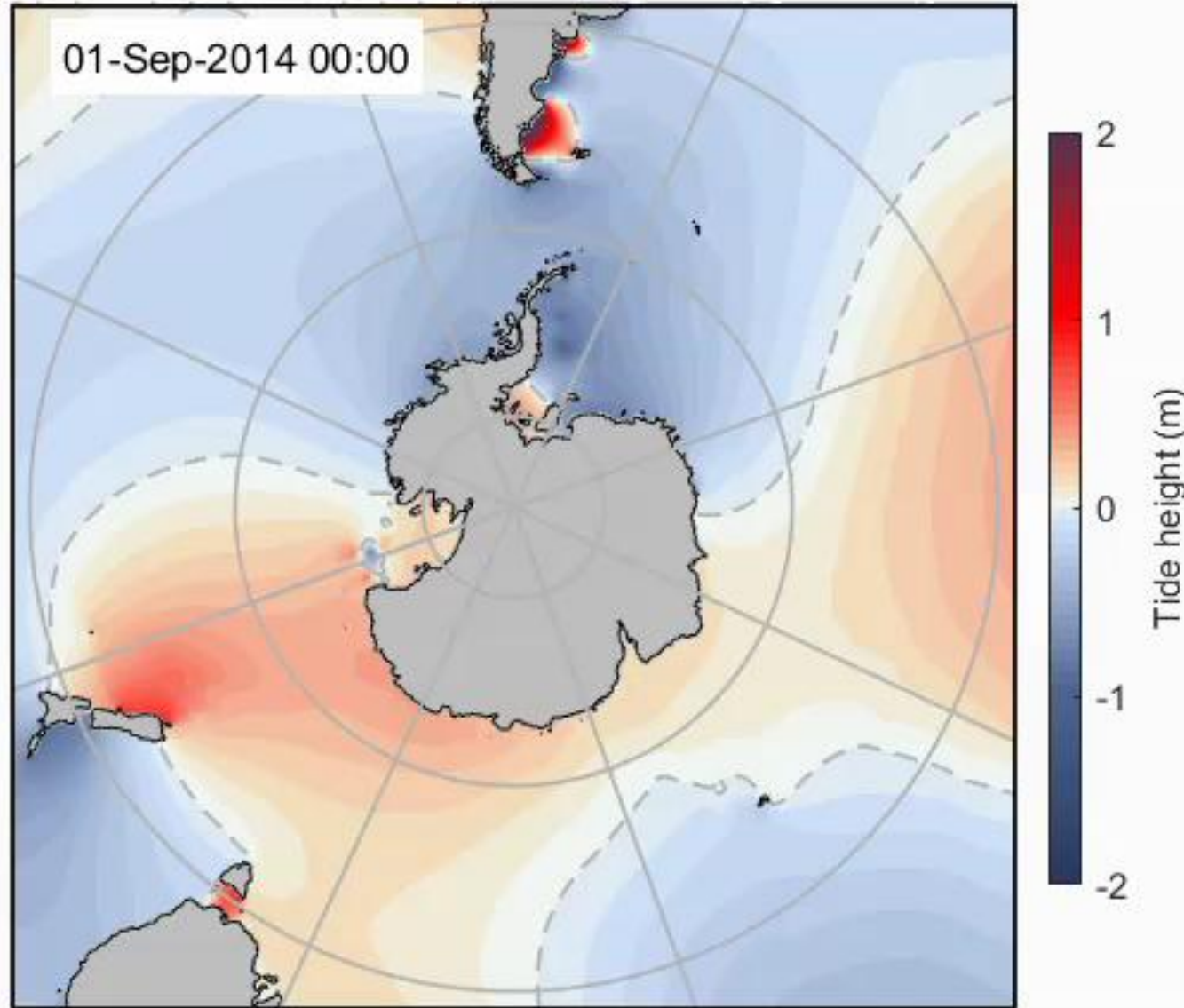
Thus, the small tidal range in the Arctic is due more to the restricted connection with the global ocean than to its polar location. The Arctic behaves like the Mediterranean Sea.

But what about Antarctica?
It is surrounded by ocean but generally has small tidal ranges.

The continental shelves around Antarctica are unusually narrow and deep because of isostatic depression by the ice sheet.



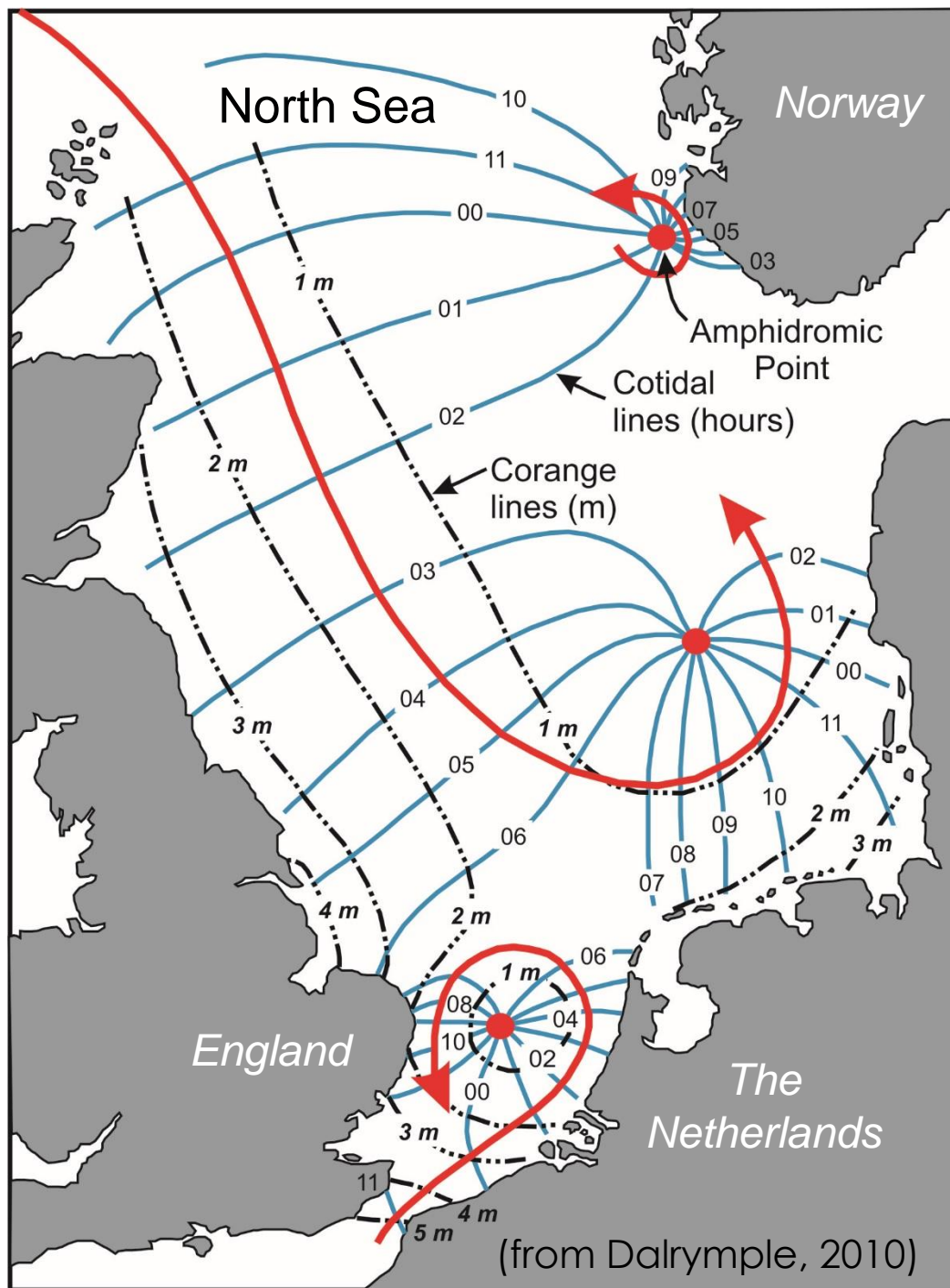
Antarctic Ocean tide height: Model TPXO7.2



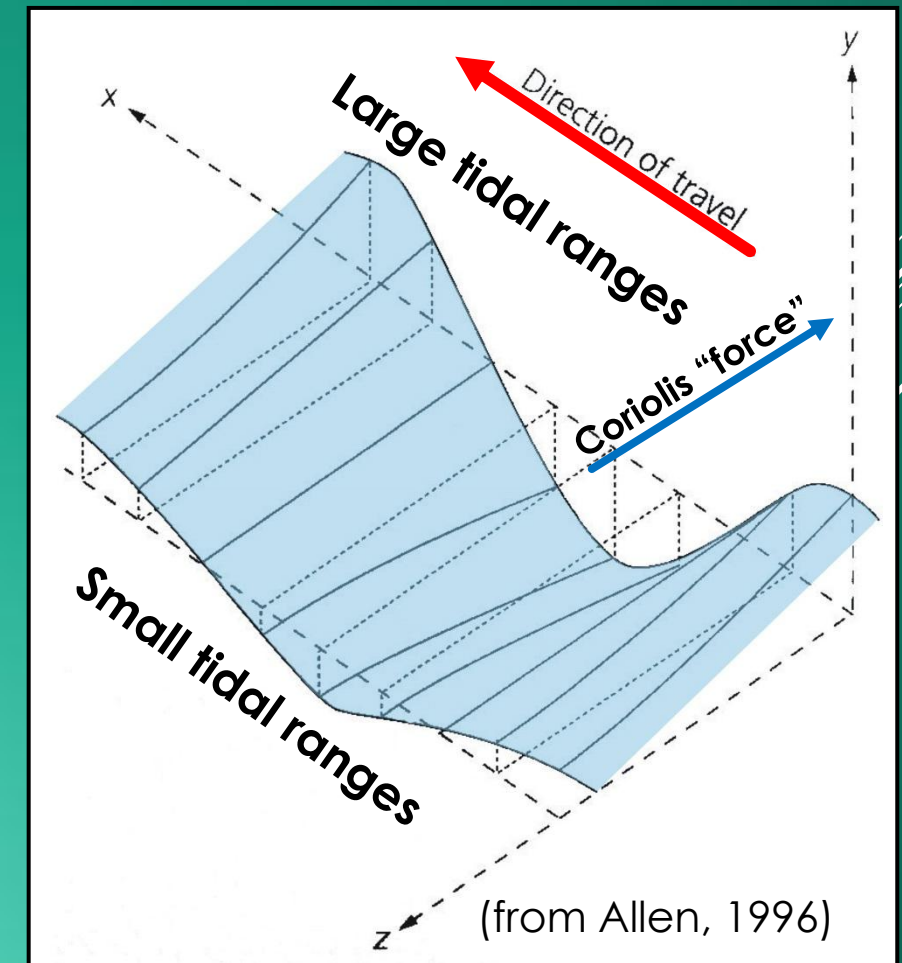
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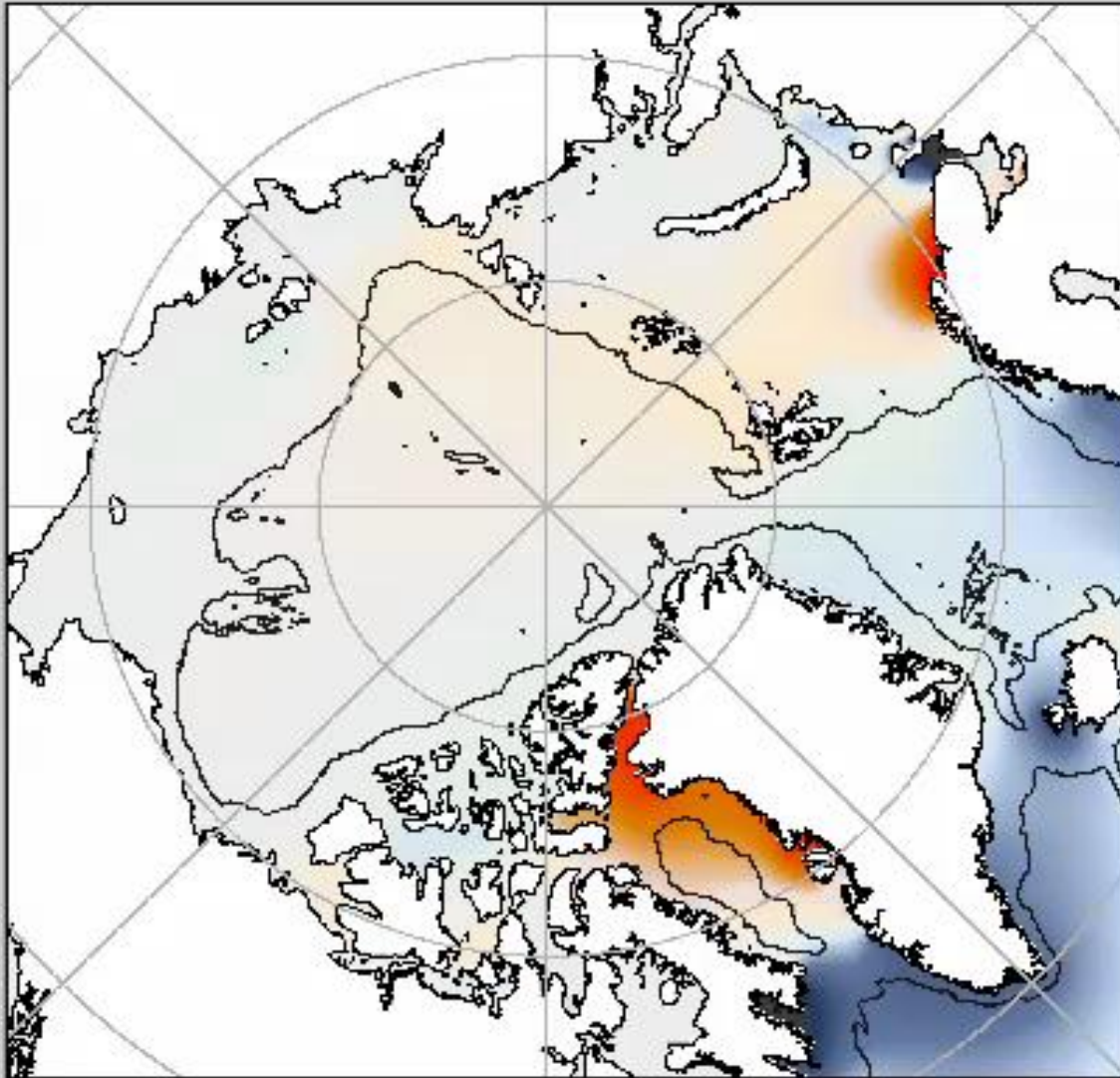
As a result, tidal ranges are not much larger than open-ocean values, with some notable exceptions in large embayments.



There is one aspect where latitude might be very important and that is the influence of the Coriolis effect on the travel of the tidal wave. Note how the tidal banks up against the right-hand side of the basin in the northern hemisphere.

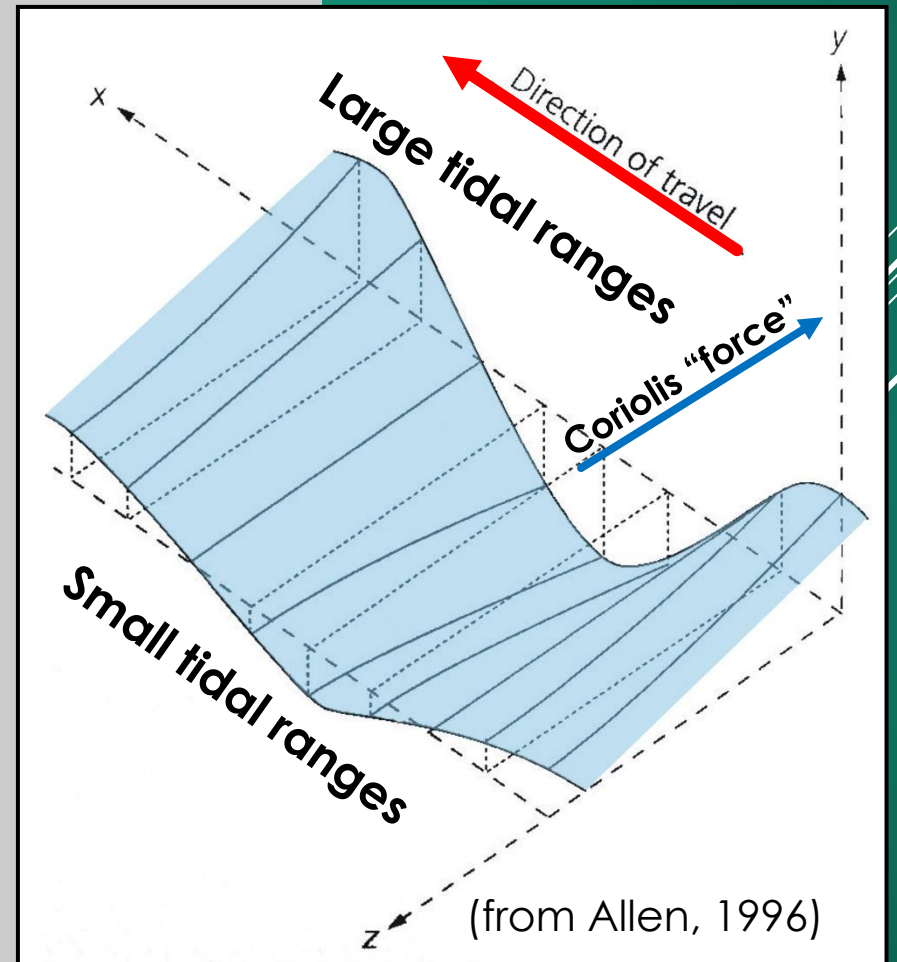


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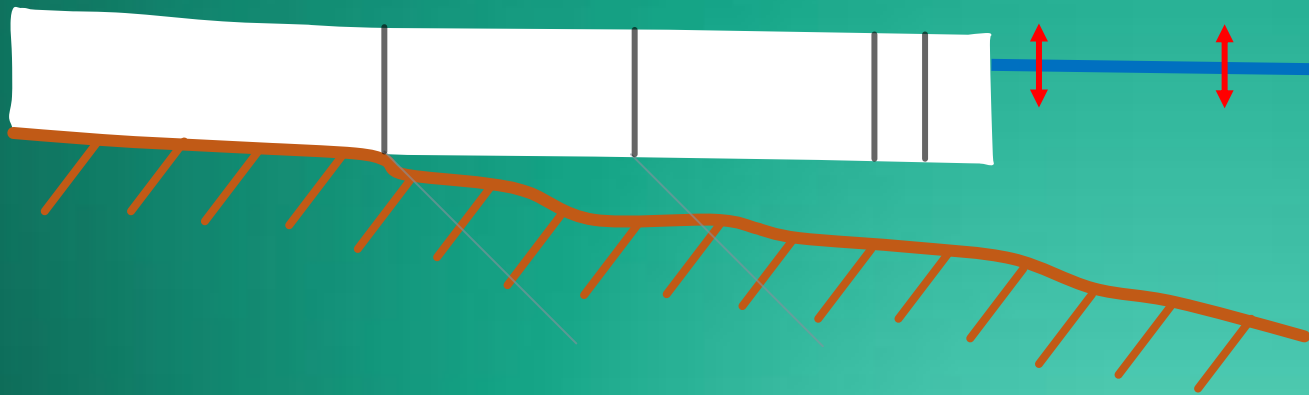
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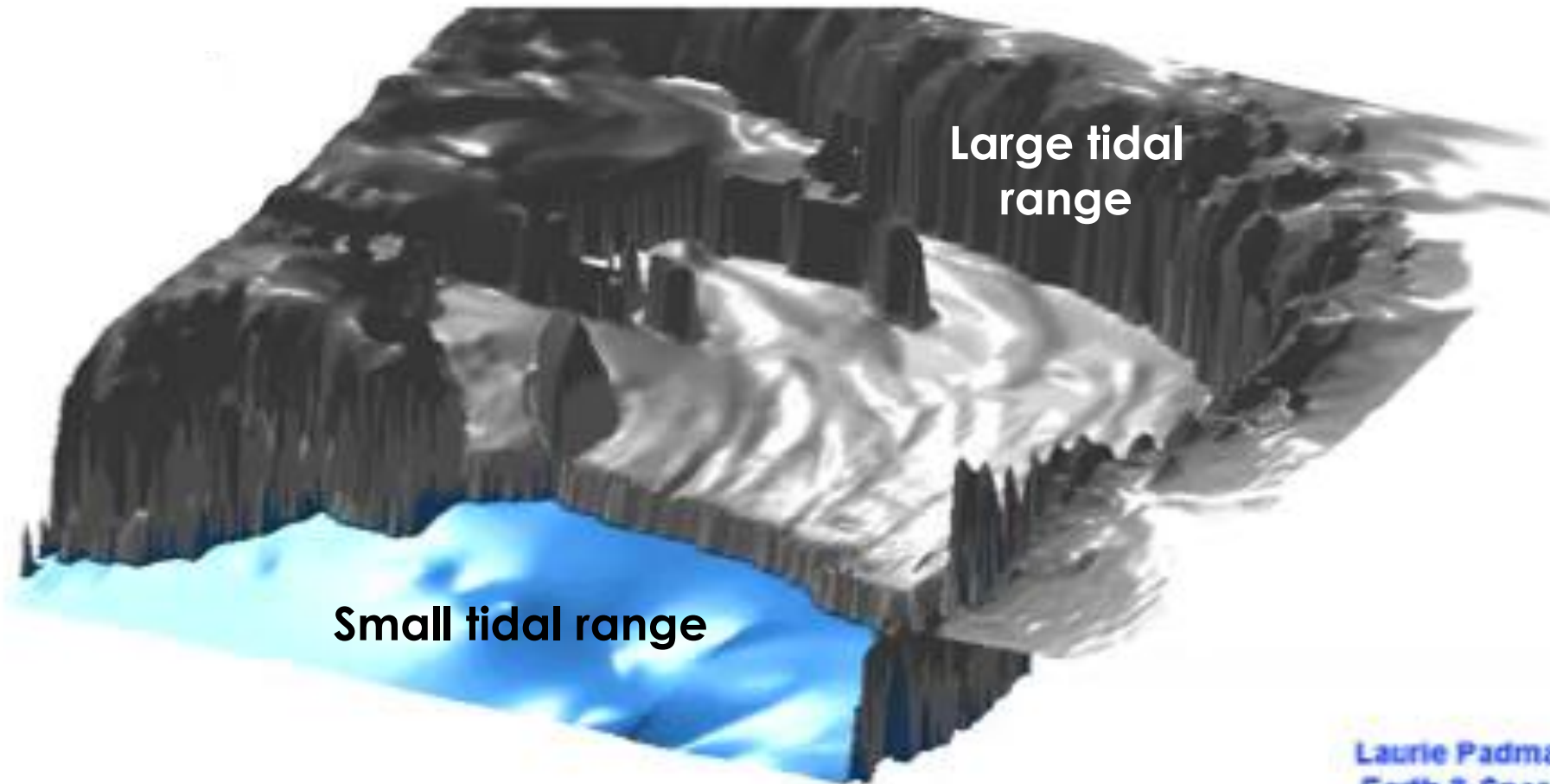
What about the influence of ice on the tide?

Floating ice has only a small affect on the tide. The weight of the ice is the same as the weight of the water that would have been there. However, the friction exerted on the moving water and between the individual bodies of ice are thought to decrease the tide by 5-10%.

On the other hand, the presence of a thick floating ice shelf can greatly increase the tidal range and tidal currents because the tidal wave is compressed into a smaller cross-sectional area.



Simulation of the tidal movement of the Ross ice shelf: note the inward increase in the tidal range.



Small tidal range

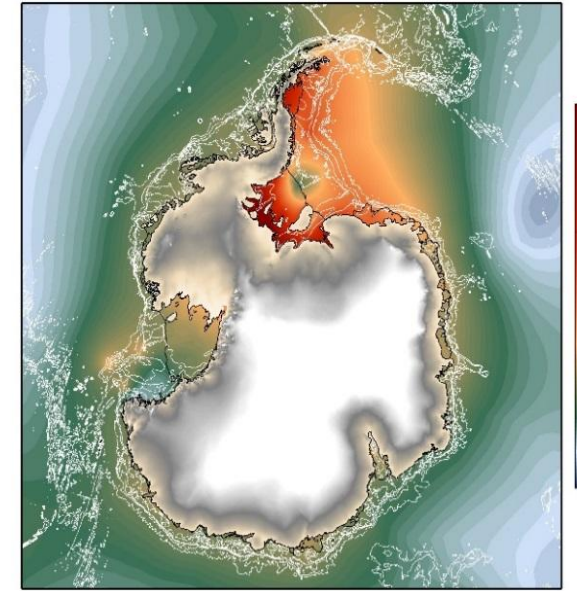
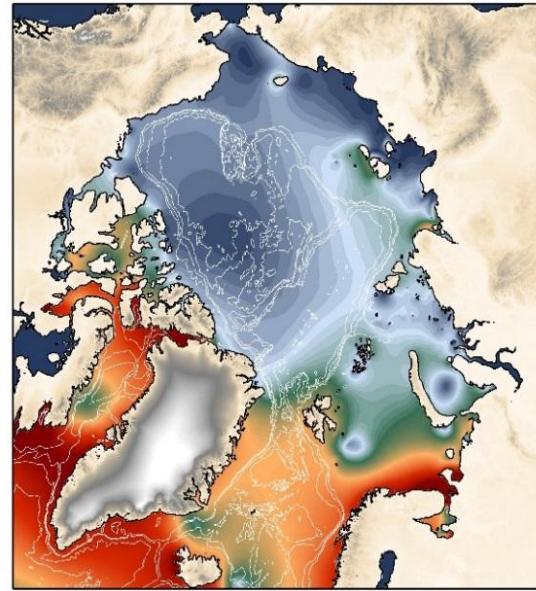
Large tidal range

Laurie Padman
Earth & Space
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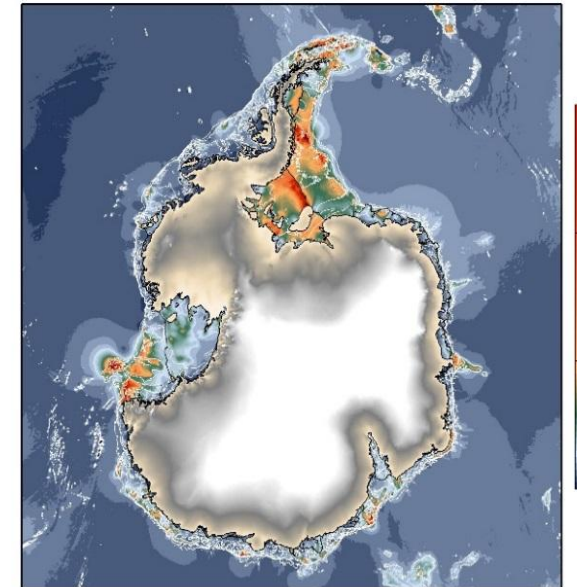
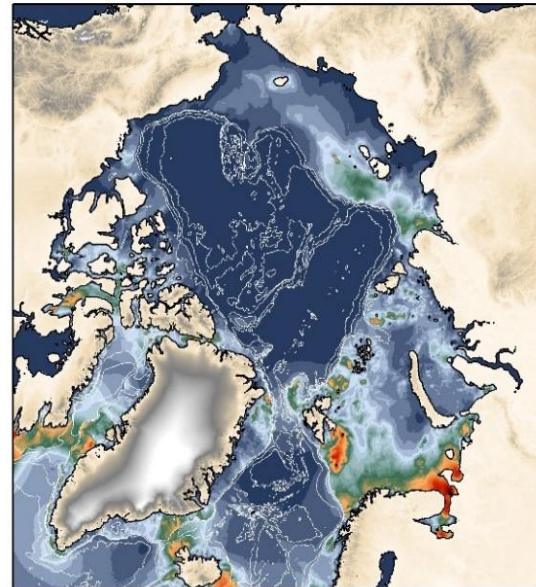
Conclusions

- 1) Even though the equilibrium tide is largest near the equator, large tidal ranges at the coast are not controlled by latitude.
- 2) The primary determinant of tidal range is the local bathymetry or coastal morphology which change over geologic time.
- 3) Environmental asymmetry across a basin should become more pronounced as latitude increases.
- 4) Polar areas can have large tides, and tide-dominated sedimentation can occur at any latitude.

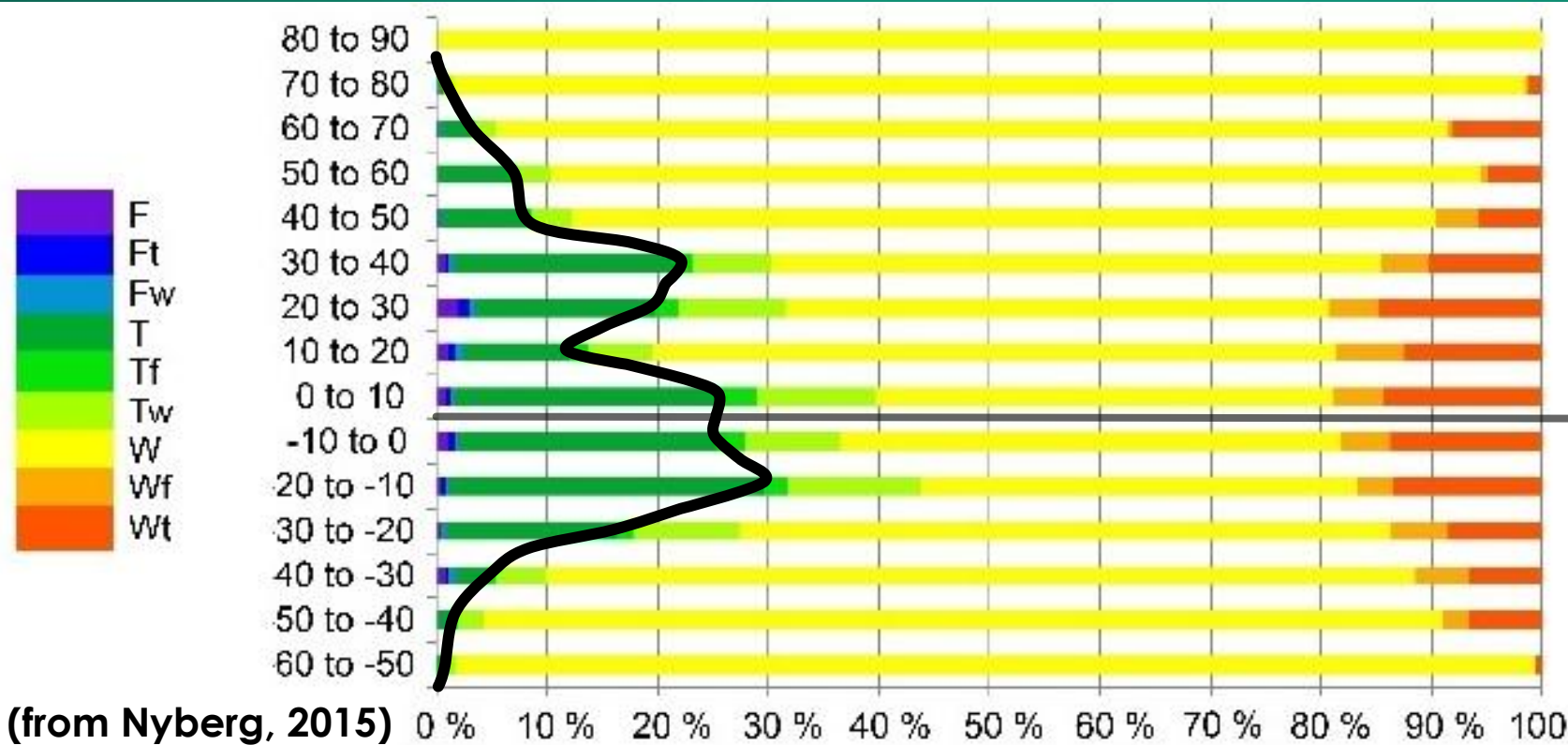


TIDAL RANGE

TIDAL CURRENT SPEED



But how does the latitudinal distribution of tidal ranges translate into the nature of coastal environments? Apparently it doesn't. Why not? ... because the nature of a coastal zone is determined by the relative power of waves and tidal currents.



The distribution of coastal-zone types appears to be more strongly influenced by the latitudinal variation in wind strength and the resulting intensity of waves.

