Sorry about the Orange Roughy, why you should care about the bottom of the ocean, and other adventures in satellite oceanography

2018 Science on a Sphere
Users Collaborative Network Workshop
29 November 2018

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
NOAA

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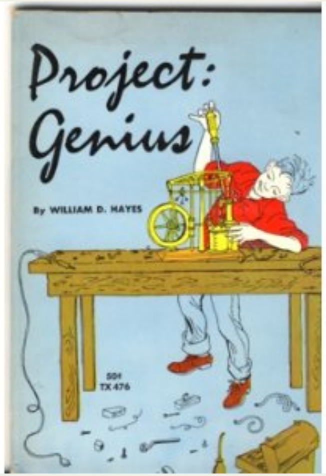
I was born at a young age…

I loved to take things apart, to see what was inside that made them go.

I loved to be the navigator on family trips, and I drew maps of imaginary places with crayons



I loved Chicago's museums, particularly Sci & Ind

I learned that I could repair things and even make them better

A dropout, loving things mechanical

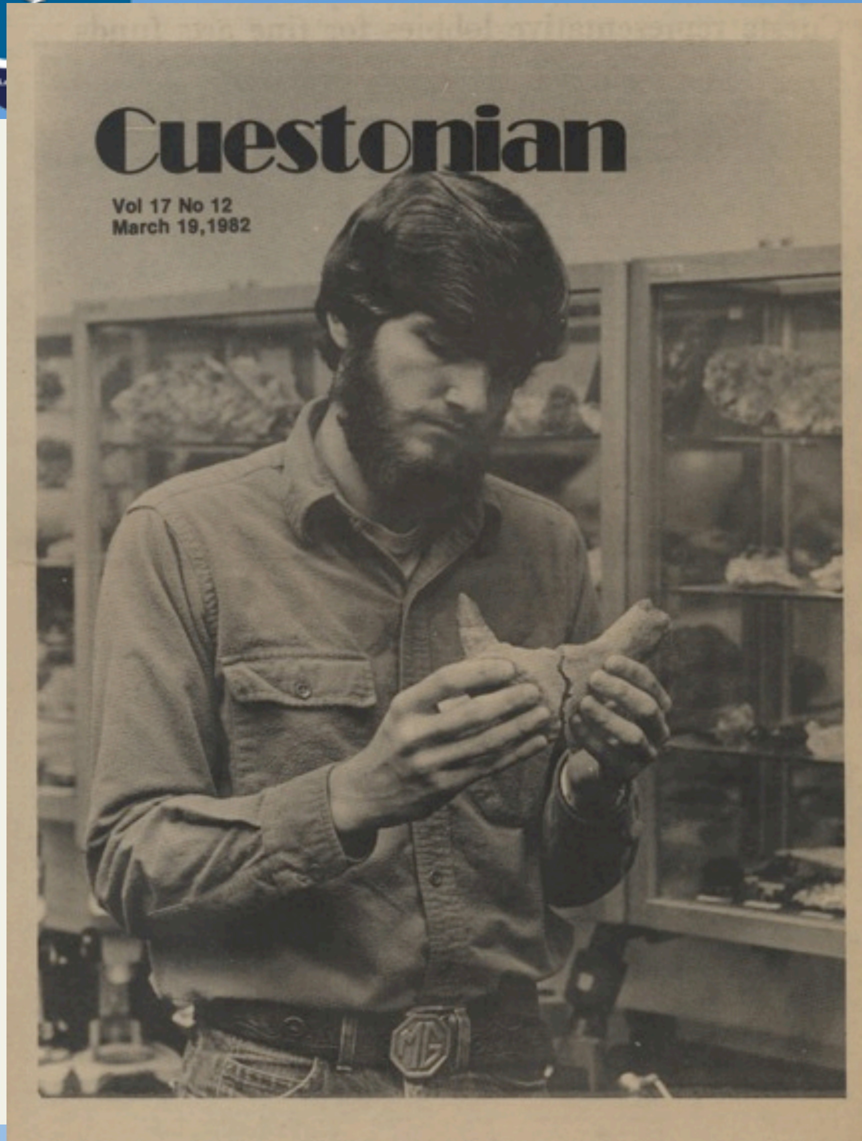
I was on the pit crew for Stormin' Norman David, who drove in a very minor league of NASCAR. I sold fluid power components to agricultural industry customers.

A journey of self-discovery

When in doubt, go for a walk.

A planned 4-week, 400+mile solo backpacking trip was cut short by a bear, but I emerged wanting to know where mountains came from, so I took a geology class at Cuesta Community College.

Community College, age 20



Learning to study, learning geology,
loving field trips, finding my voice.

I was always drawn to active tectonics

I nearly killed myself taking this picture of Stromboli.

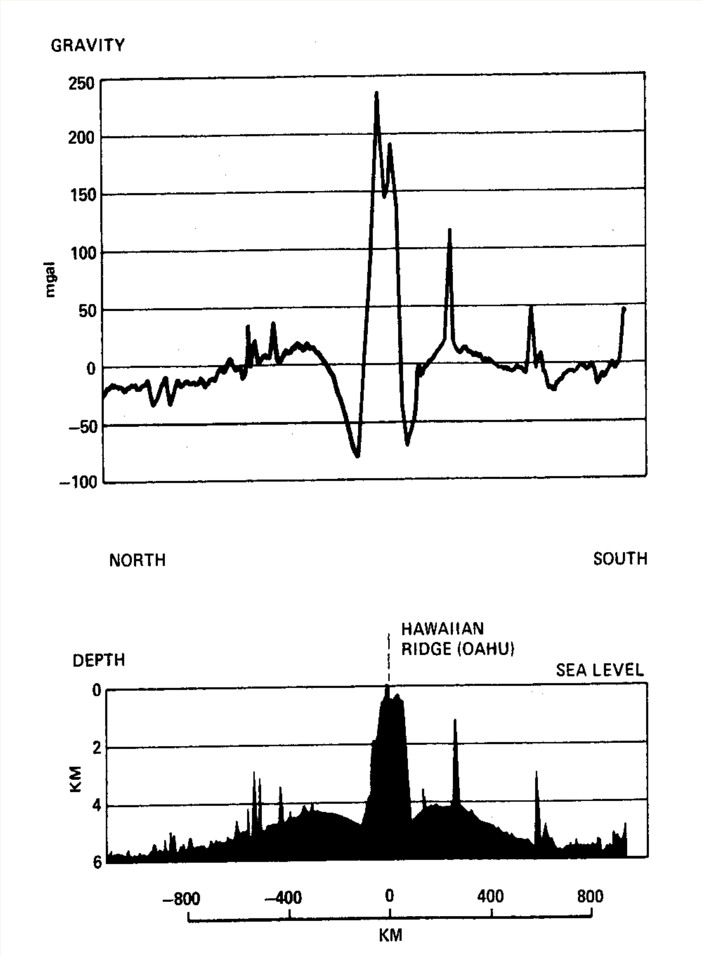
Mister Fixit Strikes Again !

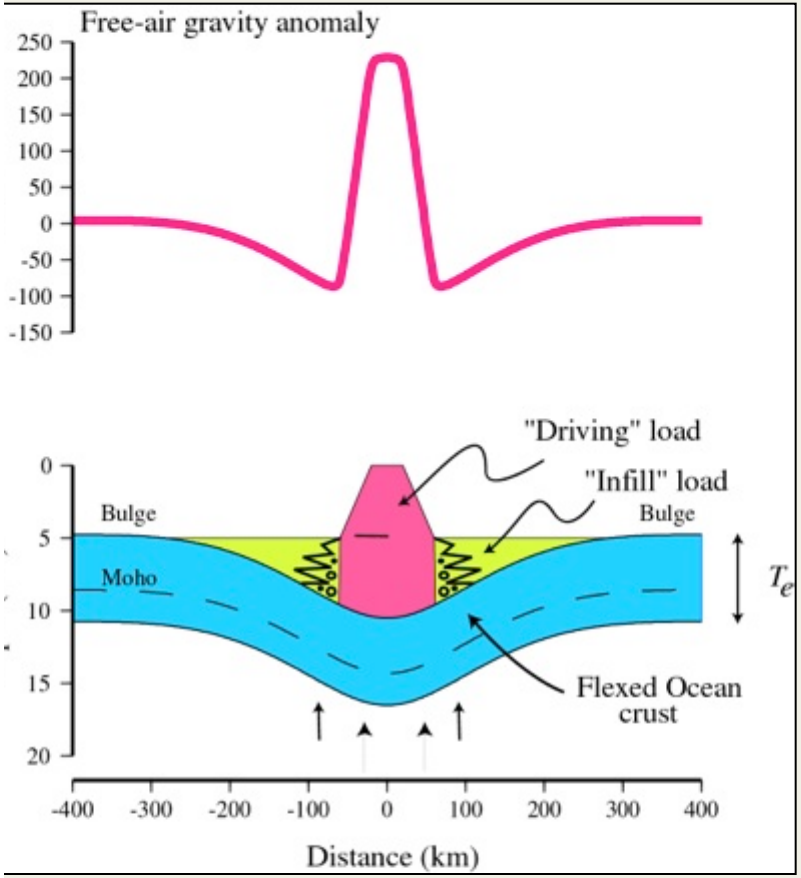
Prof. A. B. Watts led the Gravity Department at Columbia University's Lamont Geological Observatory.
He always bought the cheapest coffee-maker for his lab, and it would soon break, to be replaced by another.

While I was an undergrad at USC I had a summer internship in his lab, and I fixed the coffee pots.

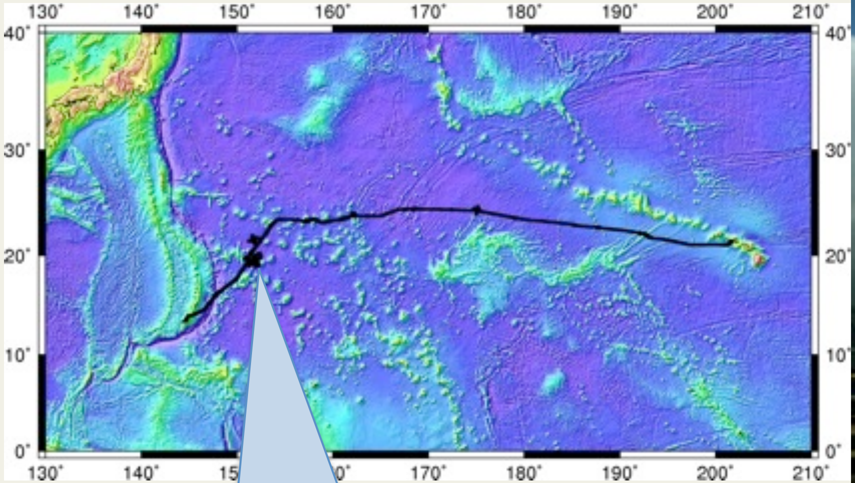
This is probably what got me admitted there as a PhD student.

What is a plate? How strong is it? What happens when a heavy volcano grows on it? Does it bend or sag?





My first cruise across the Pacific



I measured depth, gravity, magnetism, and collected rocks from these two seamounts

R/V Robert Conrad, 29 August – 26 September 1985,
Honolulu – Guam

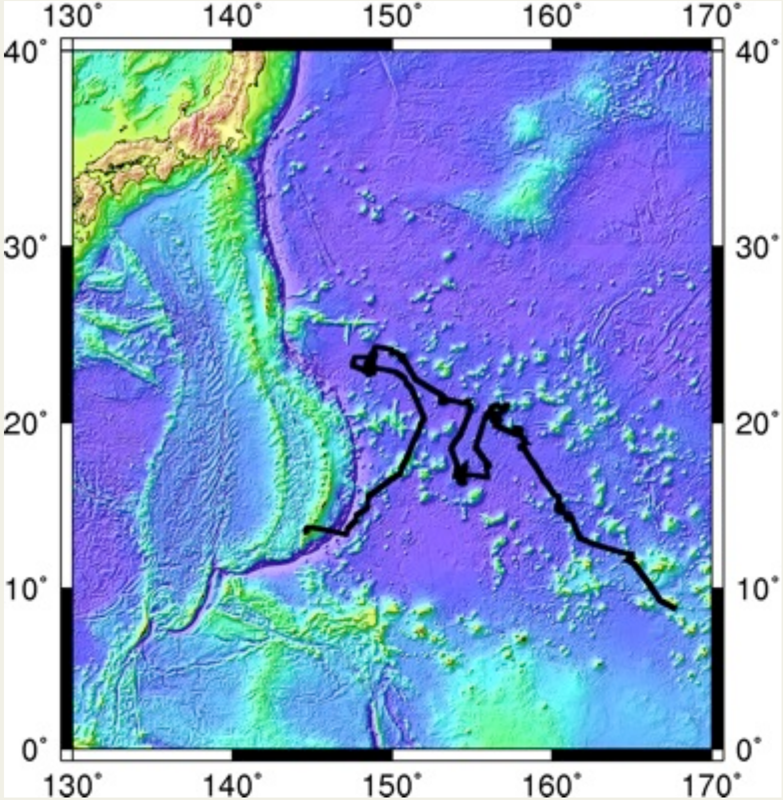
Never work in a latitude exceeding your IQ

My first community college geology instructor advised me to find a project necessitating field work in beautiful tropical islands, and as it happened, I did.

At my PhD thesis defense I related the story of this advice. A wise-acre in the audience piped up:
"And as a result, Smith has never worked in a latitude higher than his IQ."

After decades of quiet, the Big Island had just begun erupting when I got there for the first time in 1985.

My last cruise



Infamous 1991 Western Pacific Typhoon Season:

Super Typhoon Seth: 150 MPH winds

Tropical Storm Thelma (Uring): killed 6,000 people

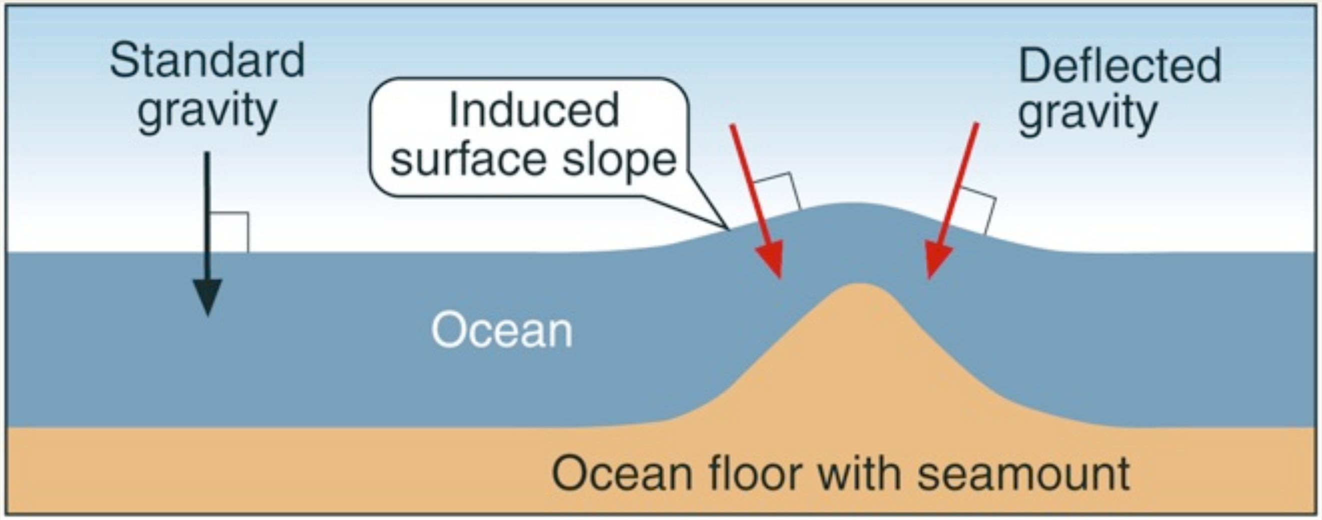
Tropical Storm Verne: 65 MPH winds

Tropical Storm Wilda: 45 MPH winds

Super Typhoon Yuri: 180 MPH winds, 3rd most intense tropical storm of all time up to that point, $33M (1991 USD) damage, 350 buildings destroyed on Guam.

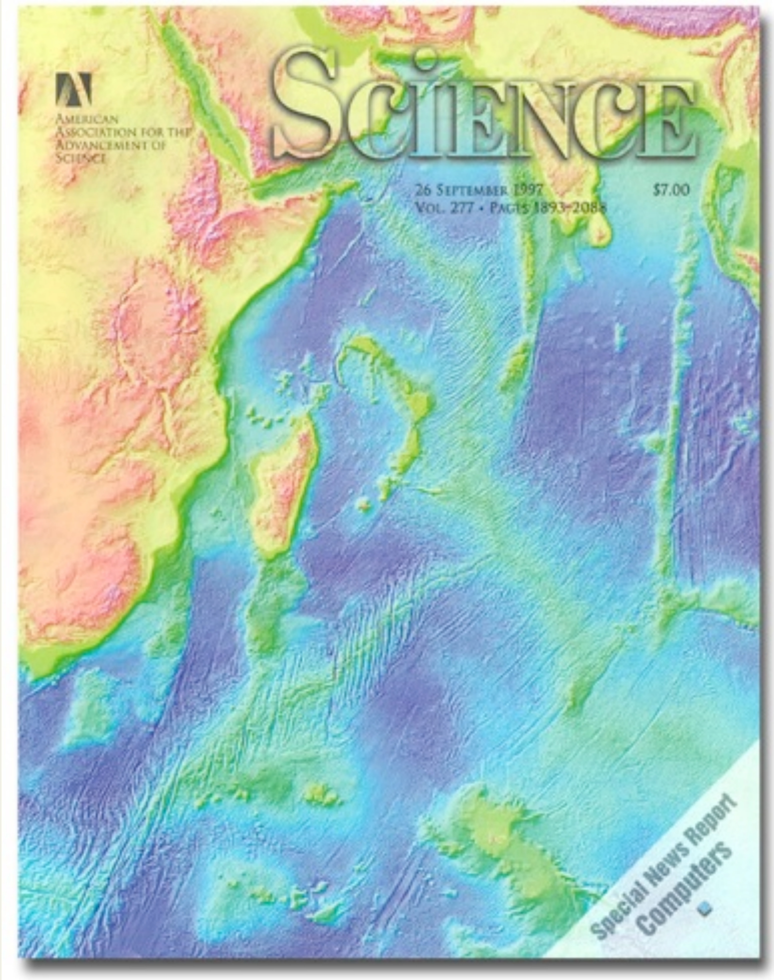
In 32 days at sea we got 8 days work done. There must be a better way. I settled on utilizing satellites.

Mapping the ocean by satellite

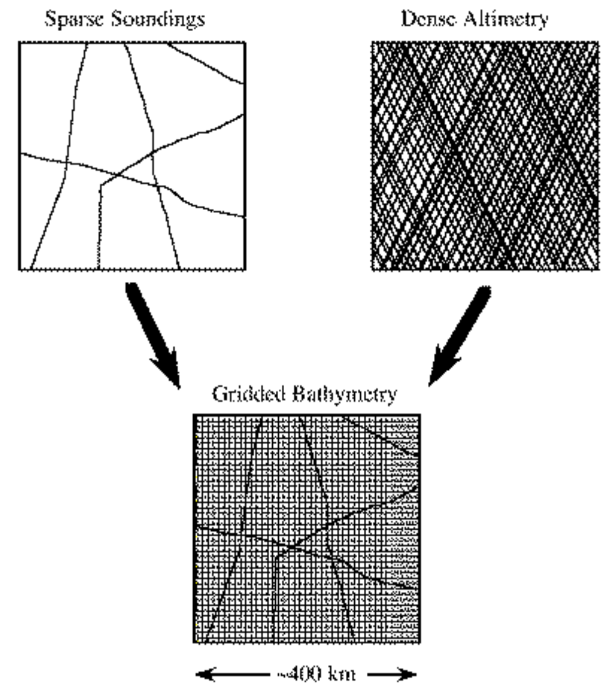


Satellites do not "see" through deep water. We use radar to measure the sea surface height. Where the height profiles show tilts, we infer that a mountain exists below.

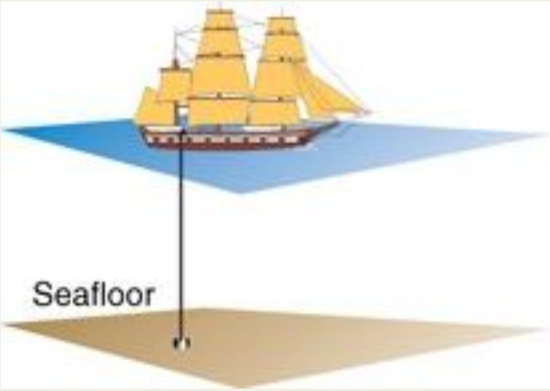
Bathymetry from Space

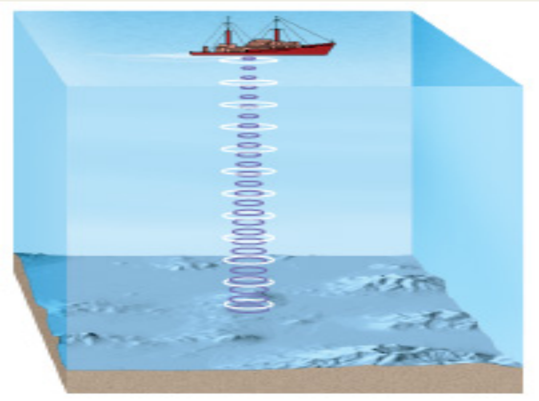


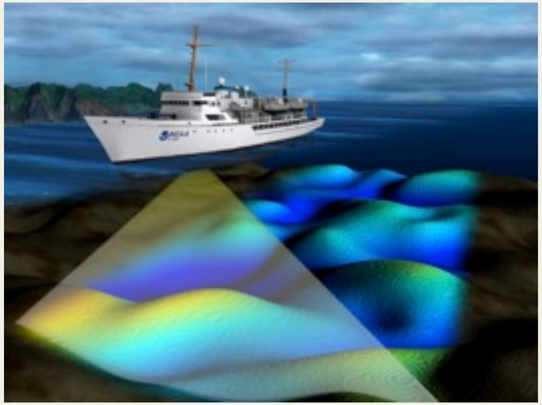
Use the dense network of satellite profiles to guide the interpolation between ship surveys.



Depth measurement requires "sounding"







"Sounding" once meant probing for where things were "sound", i.e. firm. [Mark Twain]

In deep water it was a slow process. *Challenger* took 492 soundings during a 4-year expedition in 1872-6.

Since WW-II, single-beam echo-sounders record depth profiles on analog scrolls of paper, continuously along a ship's path. These are digitized and combined with (often poor) navigation to give us most of the data we have about the ocean floor.

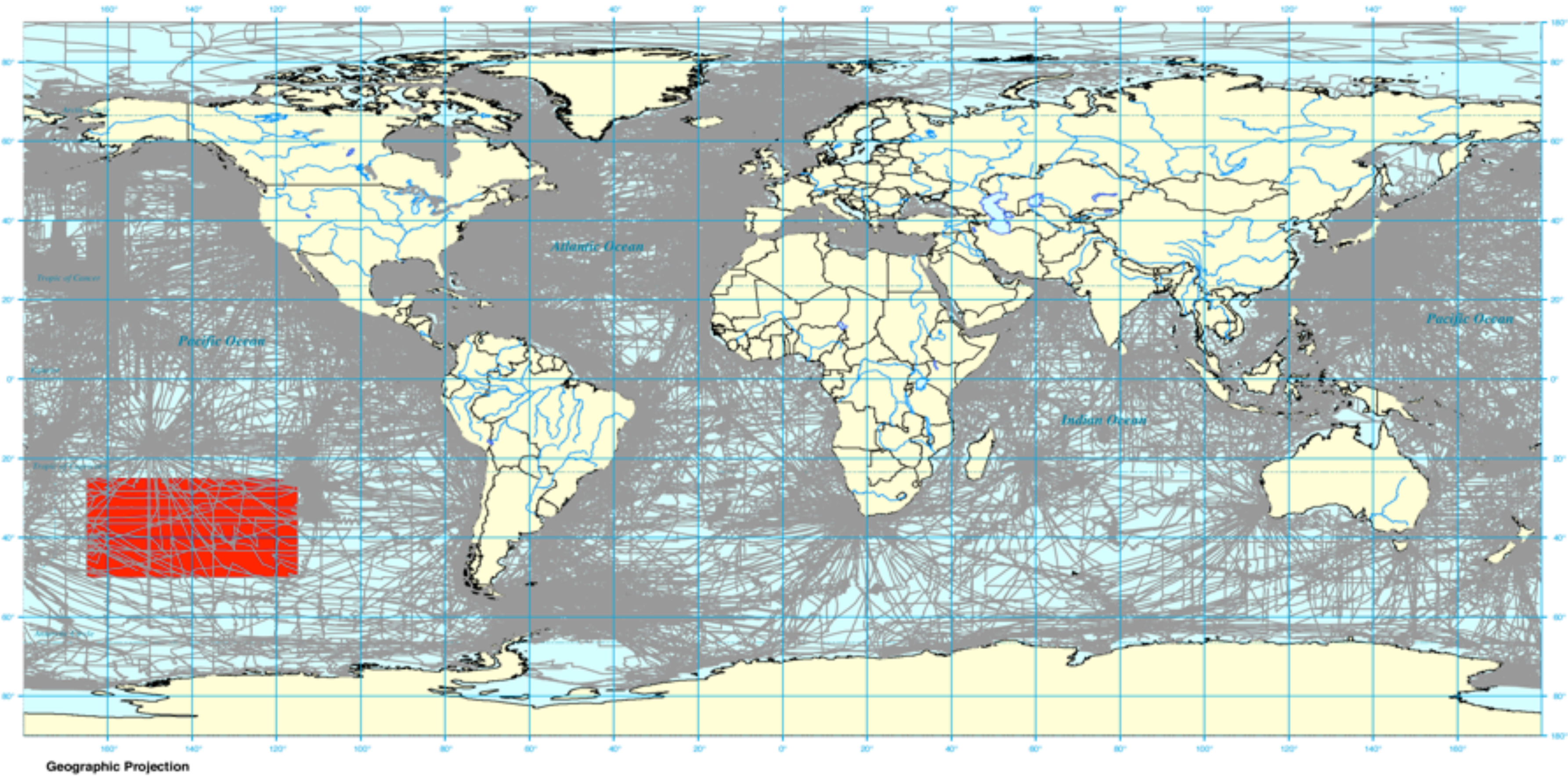
Since the 1980s, some ships are equipped with multi-beam echo sounders. These measure a swath of data as the ship moves, and record it digitally. But in the deep ocean the vast majority of data are old & low-tech. [200 ship-years, Carron et al., Int'l Hydr. Rev., 2001.]

Why I Love the Sphere

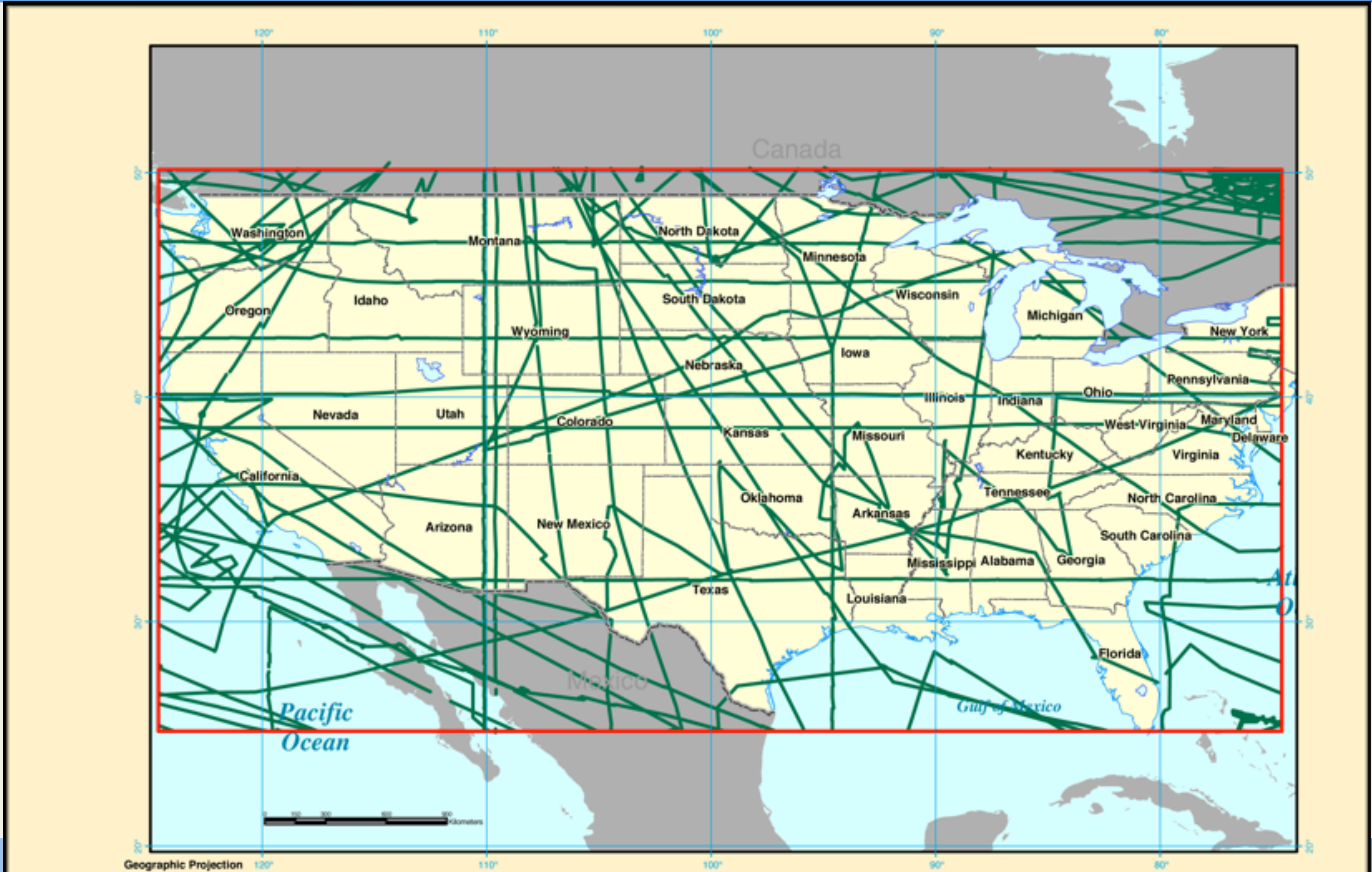
Modern data

All data

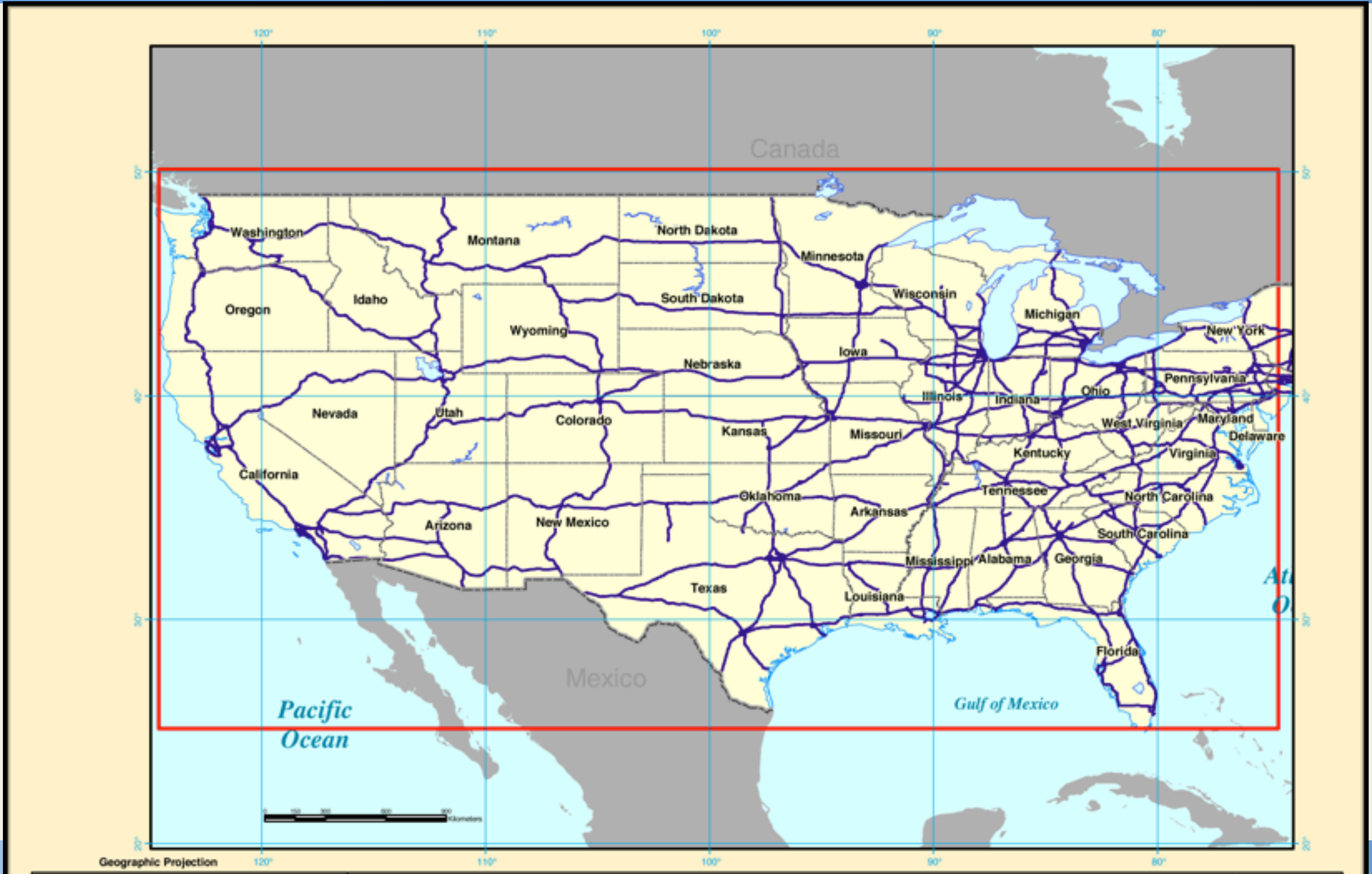
All (good and bad) depth measurements



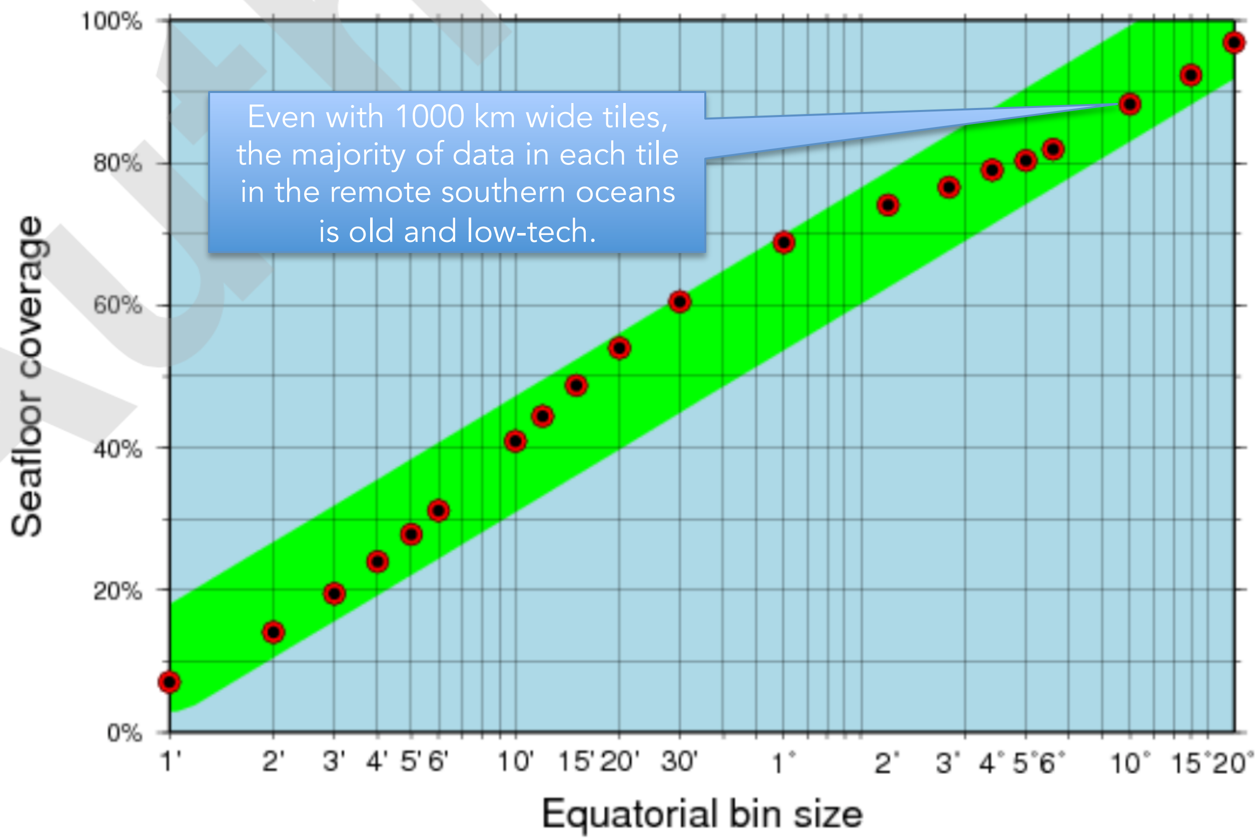
South Pacific ship tracks with depth data



U.S. Interstate Highway System



Why we say the ocean is only 10% mapped



If we "tile" the global seafloor with square tiles one n.m. (1.85 km) wide, more than 90% of the tiles have NO measurements of depth in them!

[2200 km is nearly the distance from Washington DC to Denver CO]

Figure from Wessel & Chandler, 2011, doi:10.2478/s11600-010-0038-1

Even if we use tiles 2200 km by 2200 km, there are still some empty ones!

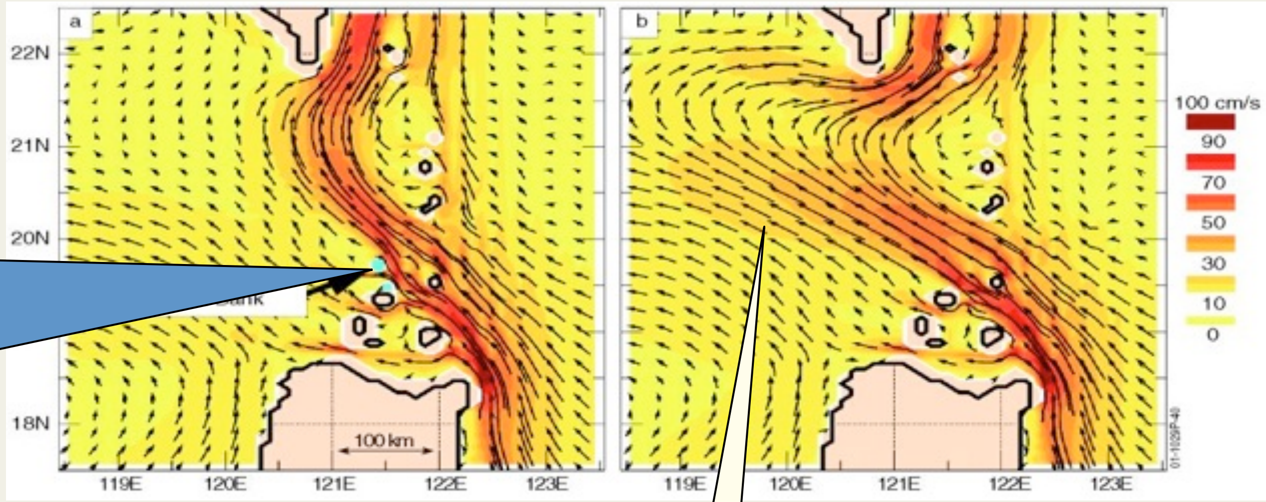
Why should you care?

"I don't know why I don't care about the bottom of the ocean, but I don't."

Consequences of not knowing ocean depths

Bathymetry steers currents

Forecast models require correct global bathymetry



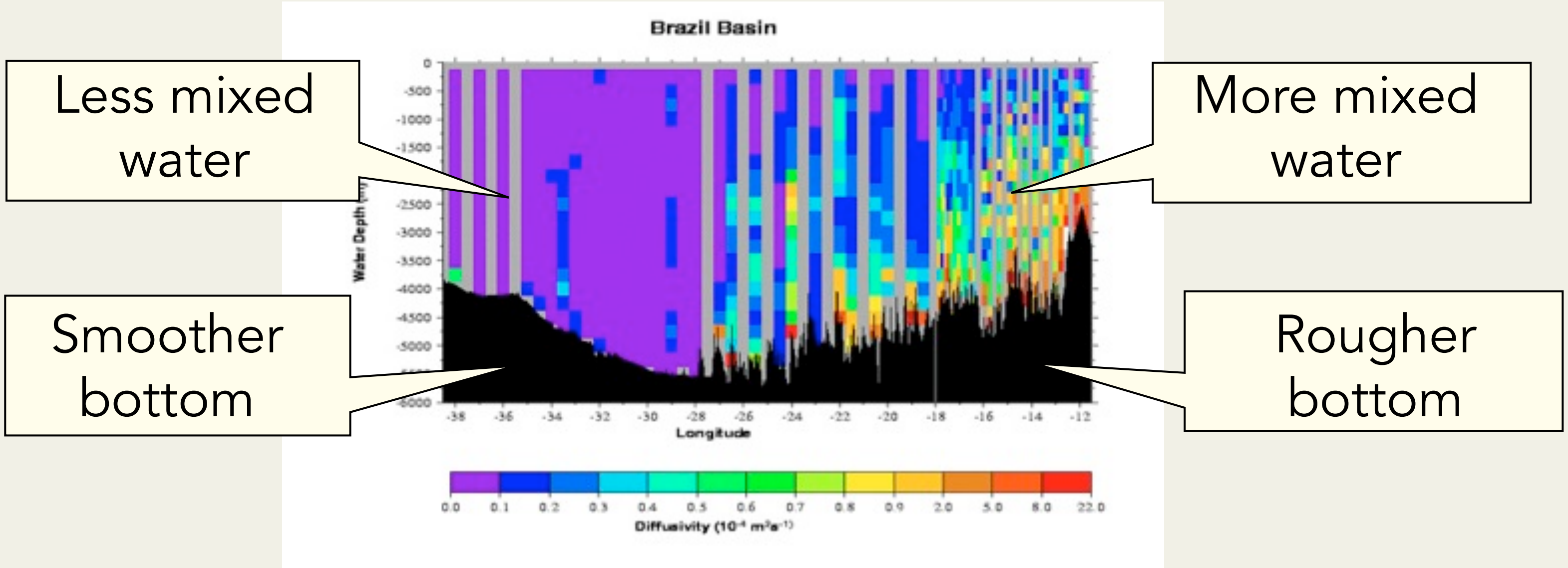
Model Bathymetry Changed Only Here

Approximates nature

Intrudes unnaturally

A single feature as small as 20 km across can steer a major current (Kuroshio mean flow in U.S. Navy model at 1/16°) [Metzger & Hurlburt, 2001]

Bottom Roughness Controls Mixing

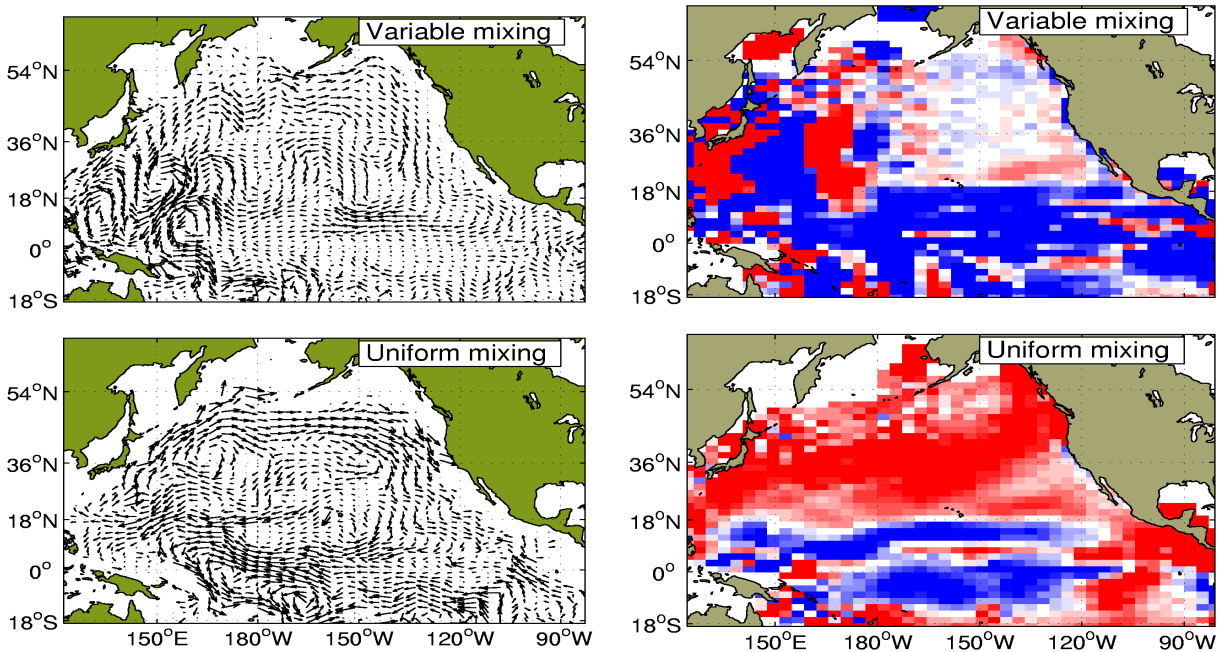


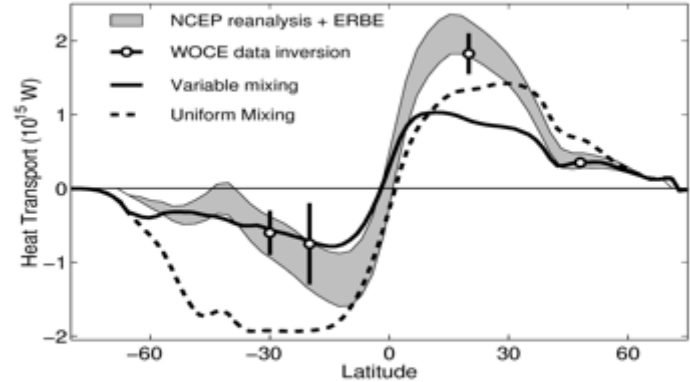
Spatial variations in bottom roughness change mixing rates by more than an order of magnitude (vertical diffusivity < 10^{-5} at left and > 10^{-4} at right; [Polzin et al., *Science*, 1997]).

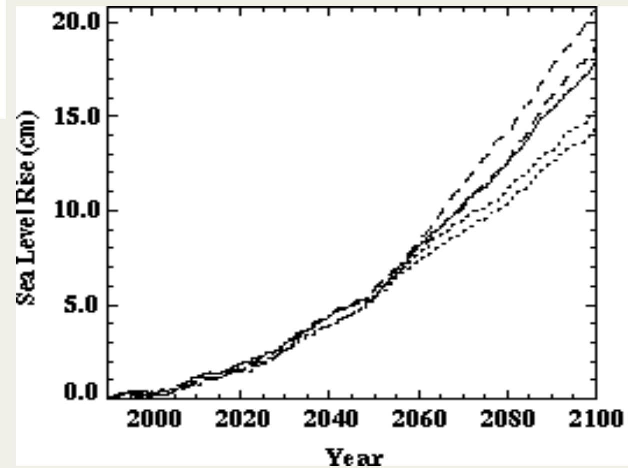
λ< 100 km bathymetry controls mixing.

Seafloor spreading shapes bathymetry at these scales.

Spatially varying mixing changes everything



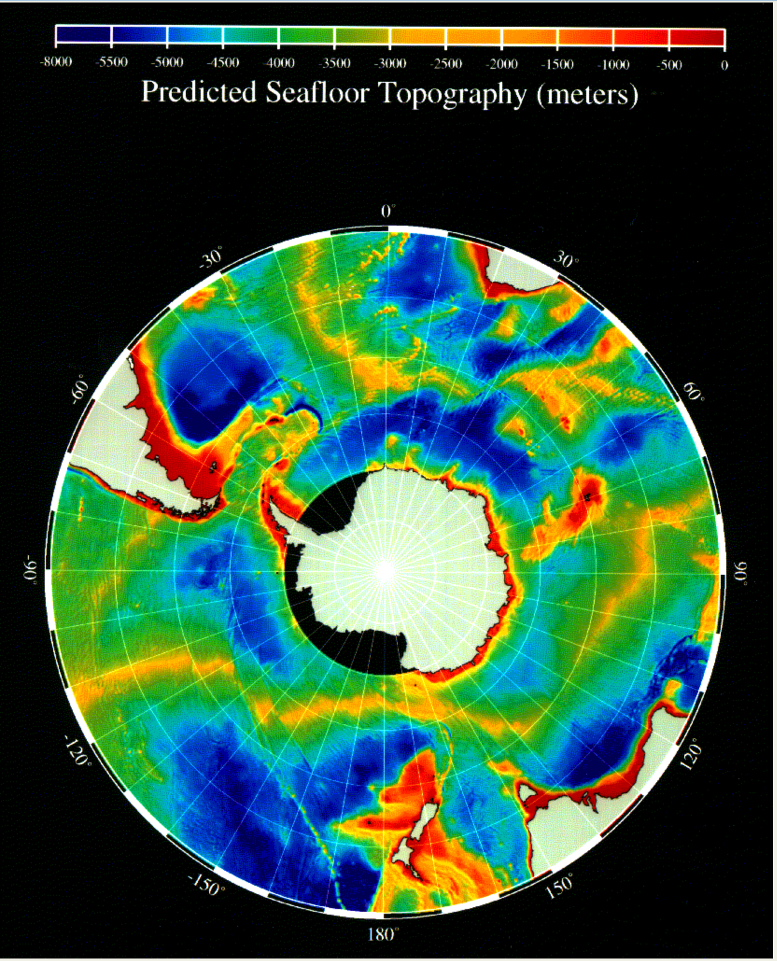




Including spatially variable deep mixing in an ocean model changes its circulation, upwelling, and climatic heat transport. It also changes forecasts of global sea level rise.

[Sokholov, 1997, 1998; Simmons et al., 2004]

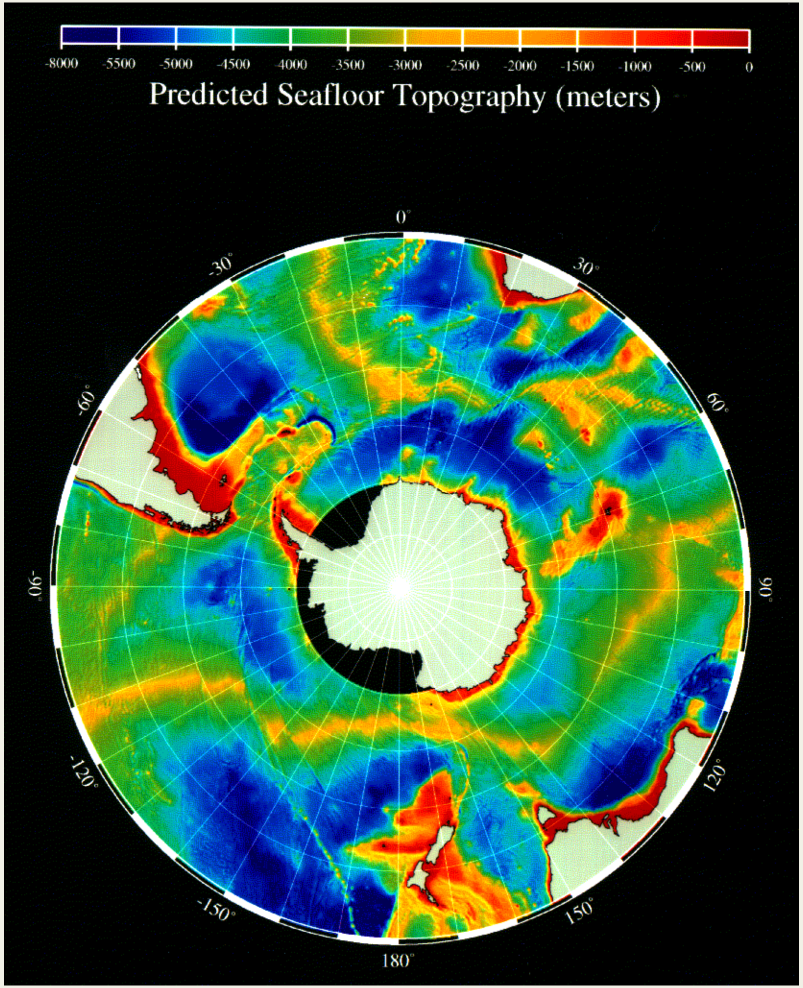
Estimated depth of the Southern Ocean



Geosat data was originally classified Secret and at first (1992) data were released only south of 30°S latitude.

Our first paper (1994) covered that area. doi: 10.1029/94JB00988

Unintended consequences: the Orange Roughy story



The Orange Roughy Story

Scientists call for end to deep-sea fishing

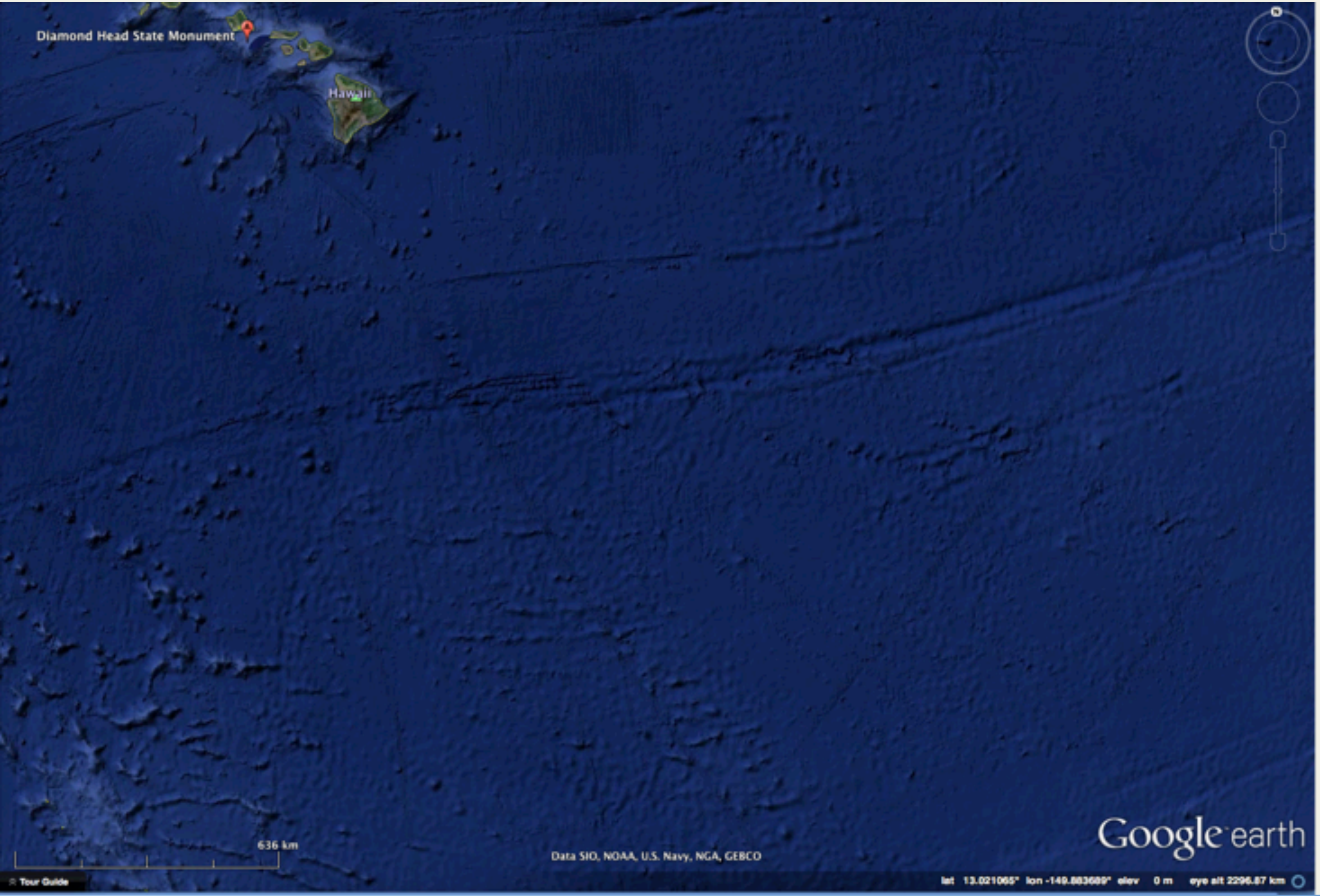
(Claire Nouvian) - Orange roughy is one of the species mentioned in a new report this released this week by an international team of marine scientists that suggests industrial deep-sea fishing should be restricted.

Graphics at left and right from *The Washington Post*, 30 August 2011.

Deep-sea fish living on seamount flanks (orange roughy, oreos, …) soon became more than half the total fish catch landed in Australia and New Zealand [Sokolov, 1997].

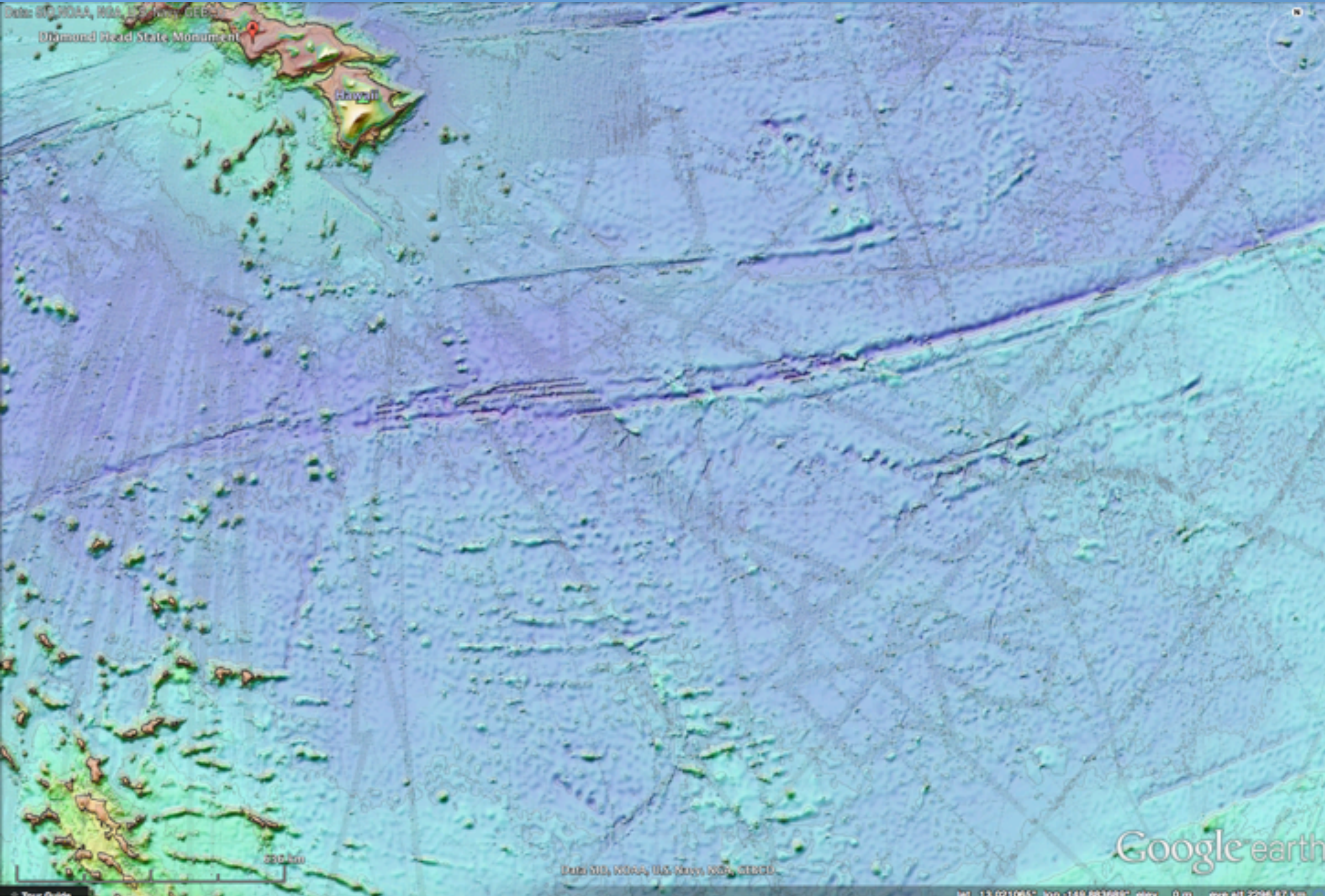
They appeared in U.S. supermarkets and restaurants, and then just as quickly disappeared.

Faking It or Not: The *Google Earth* story



Pacific, with Hawaii in the north west corner.

Same area, different colors



Soundings shown by gray dots. Note high resolution in surveyed areas, lower where not surveyed. Gaps between ship tracks can be as large as the Big Island of Hawaii. But we are in the most densely mapped area of the central Pacific; every vessel in the area makes a port call in Honolulu.

Filling the gaps with satellites reveals the details of plate tectonics on the sea floor.

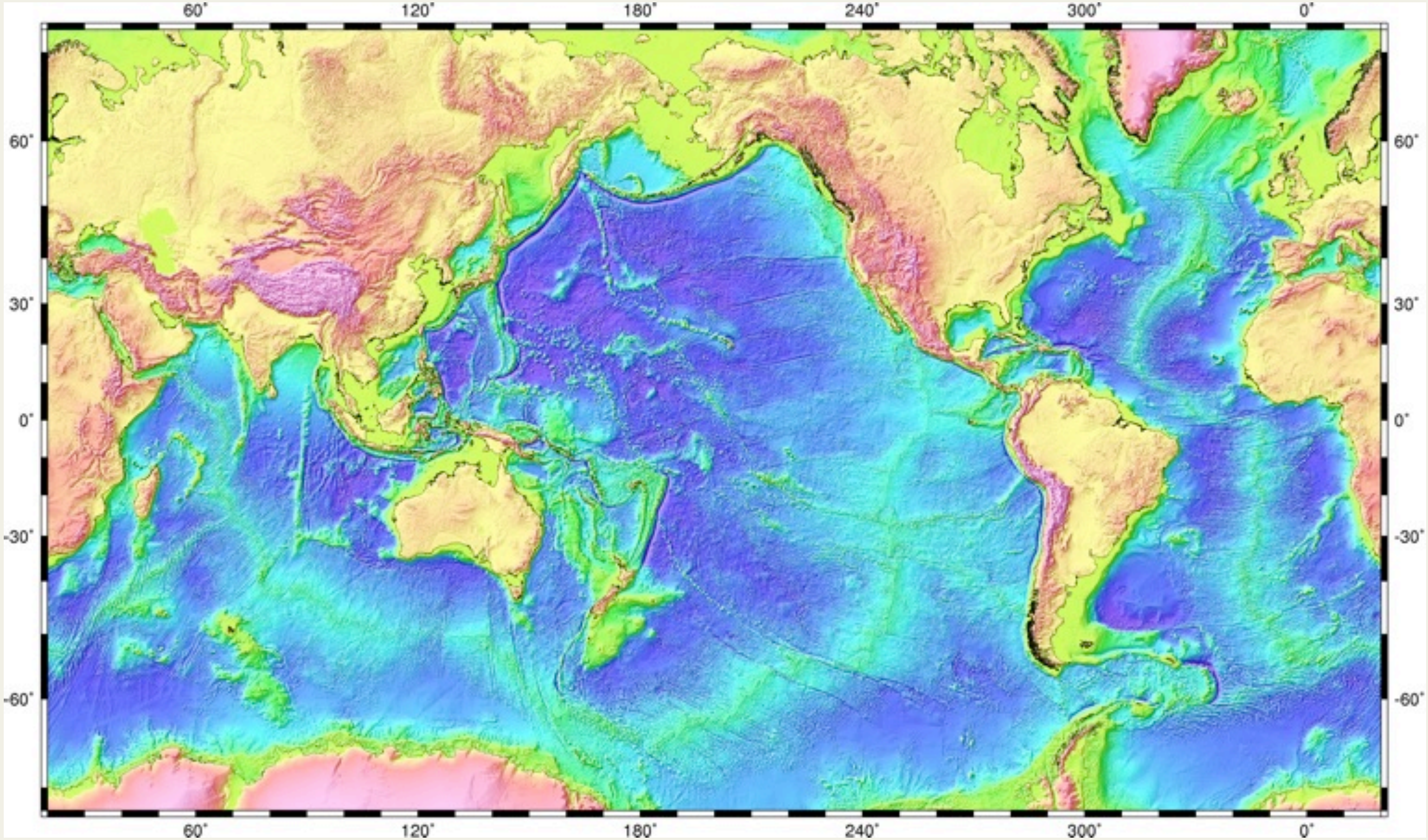
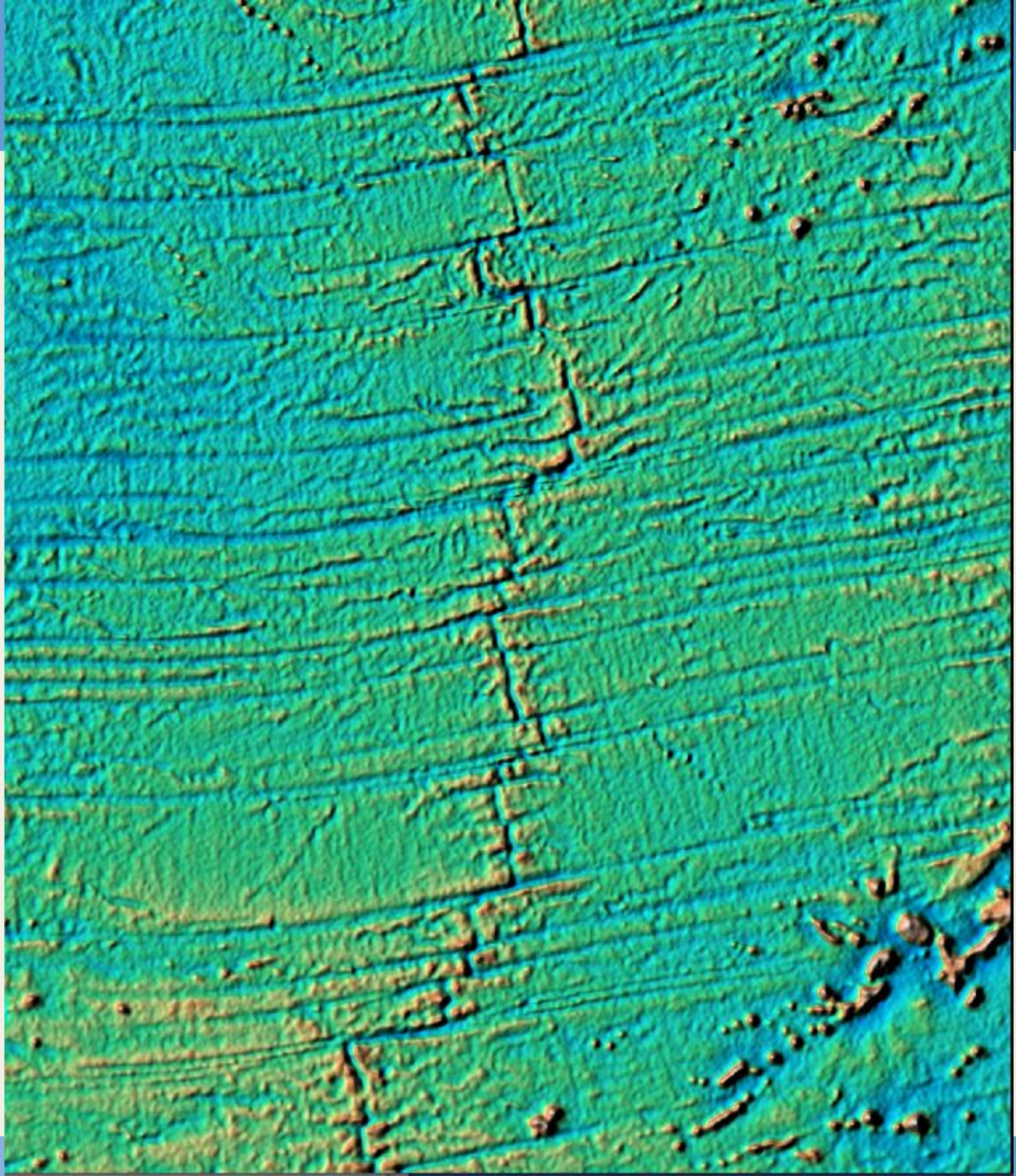


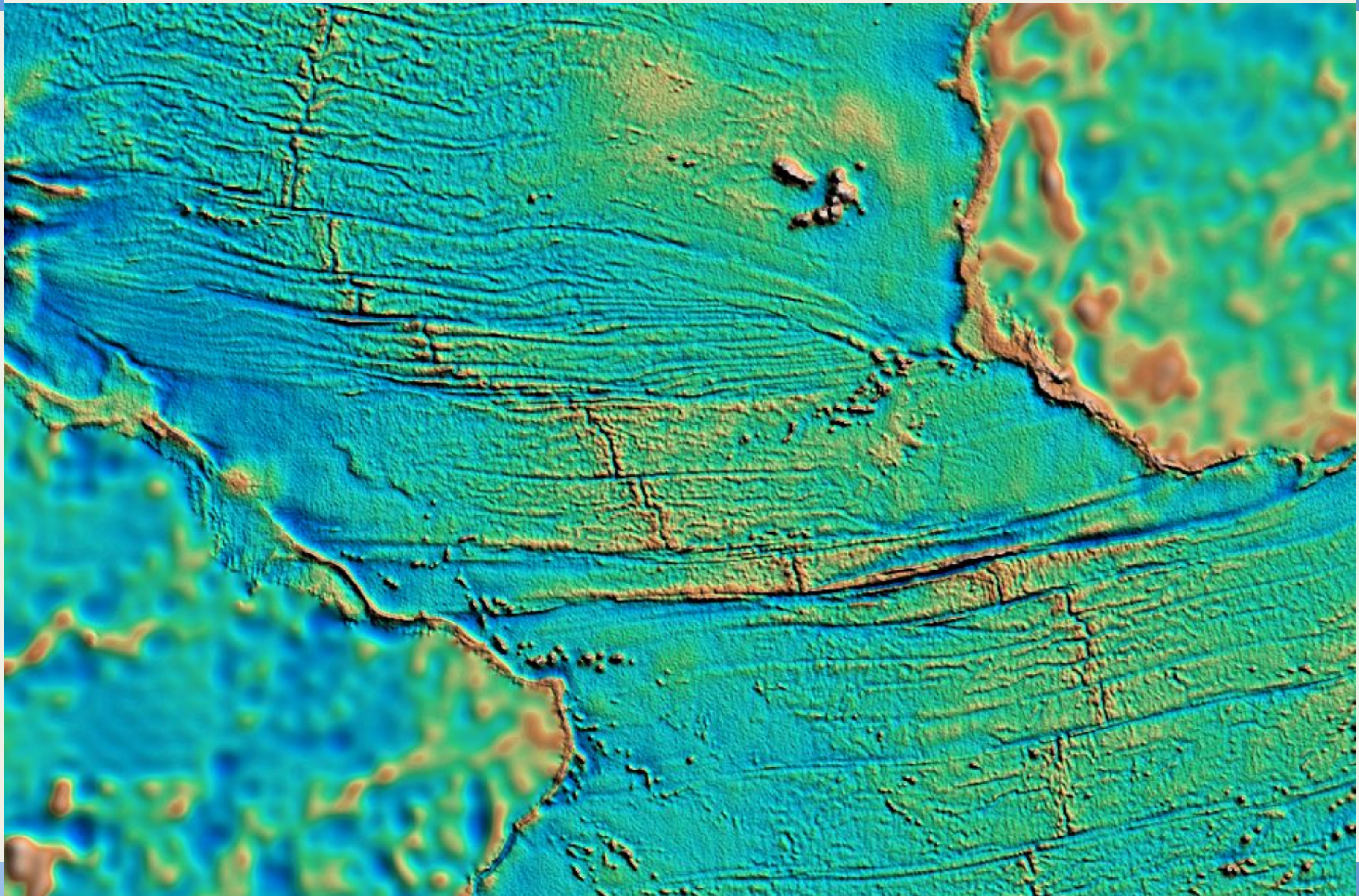
Plate Tectonics textbooks tell us that:

- seafloor spreading happens at mid-ocean ridges.
- Ridges are straight but offset by right-angle zig-zags at transform faults.
- These leave fracture zones on the seafloor.

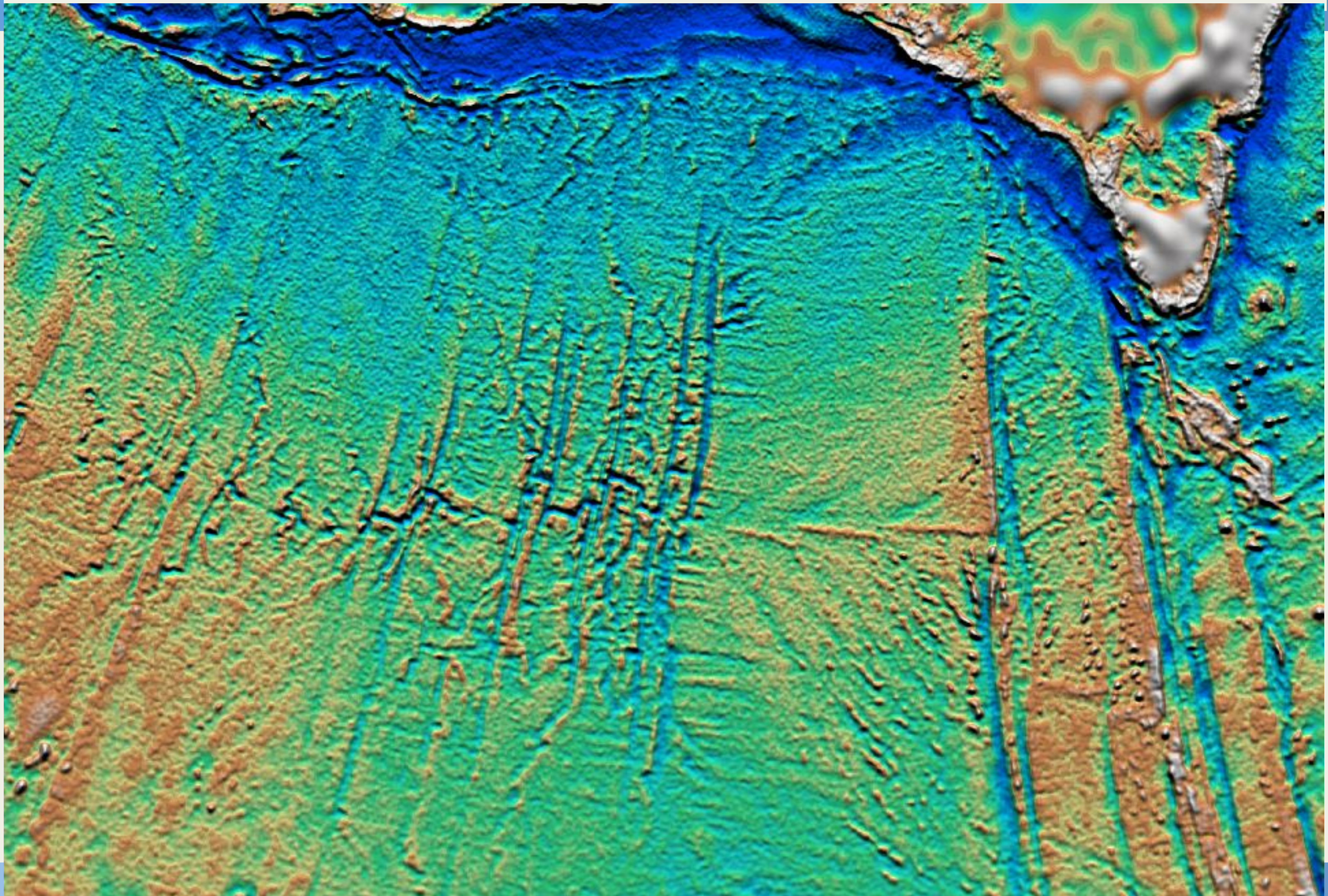
This implies that the distance between fracture zones is fixed (they are “parallel”) and the swaths between them act like conveyer belts.



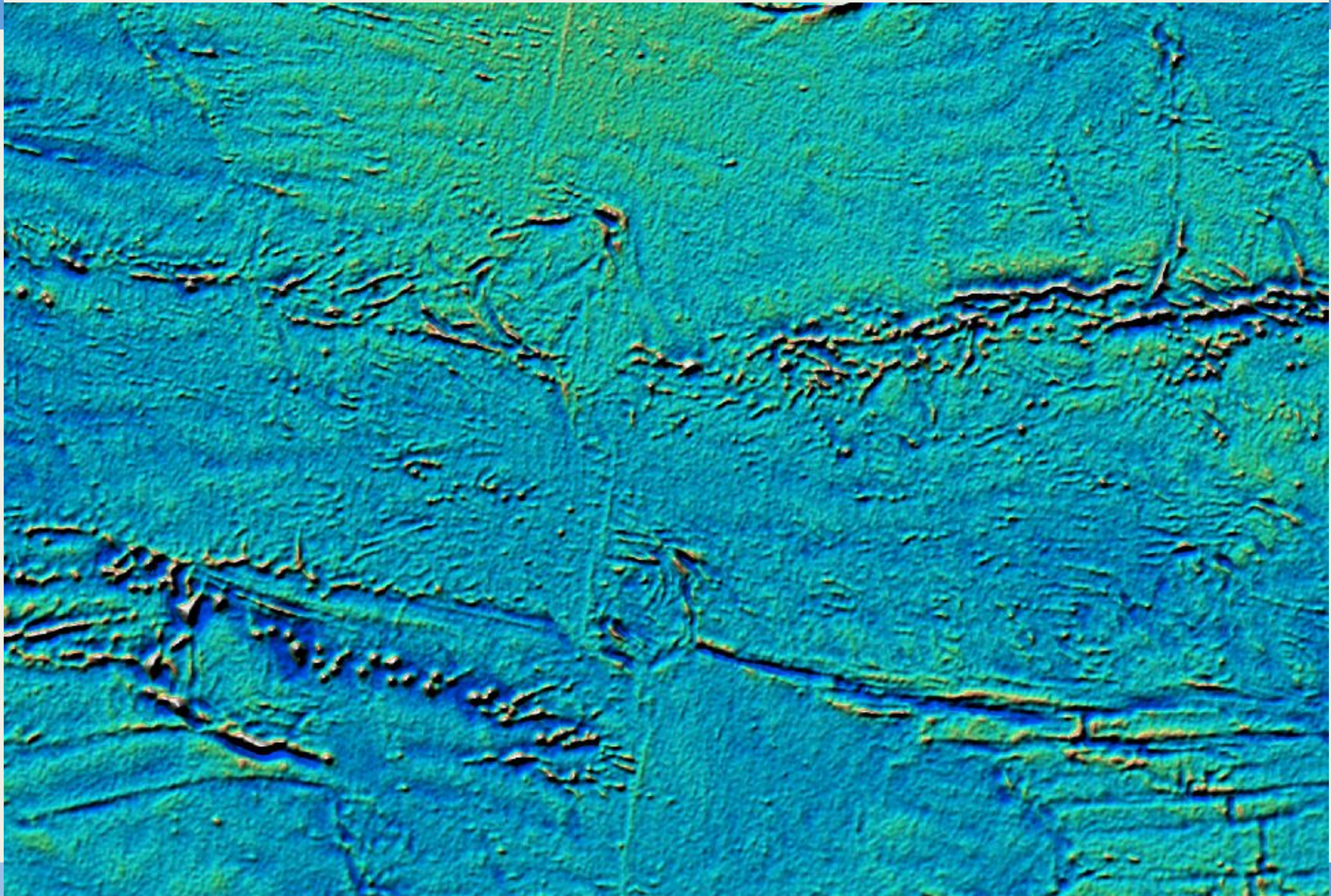
Fracture zones coming together



Propagating rifts



Microplates



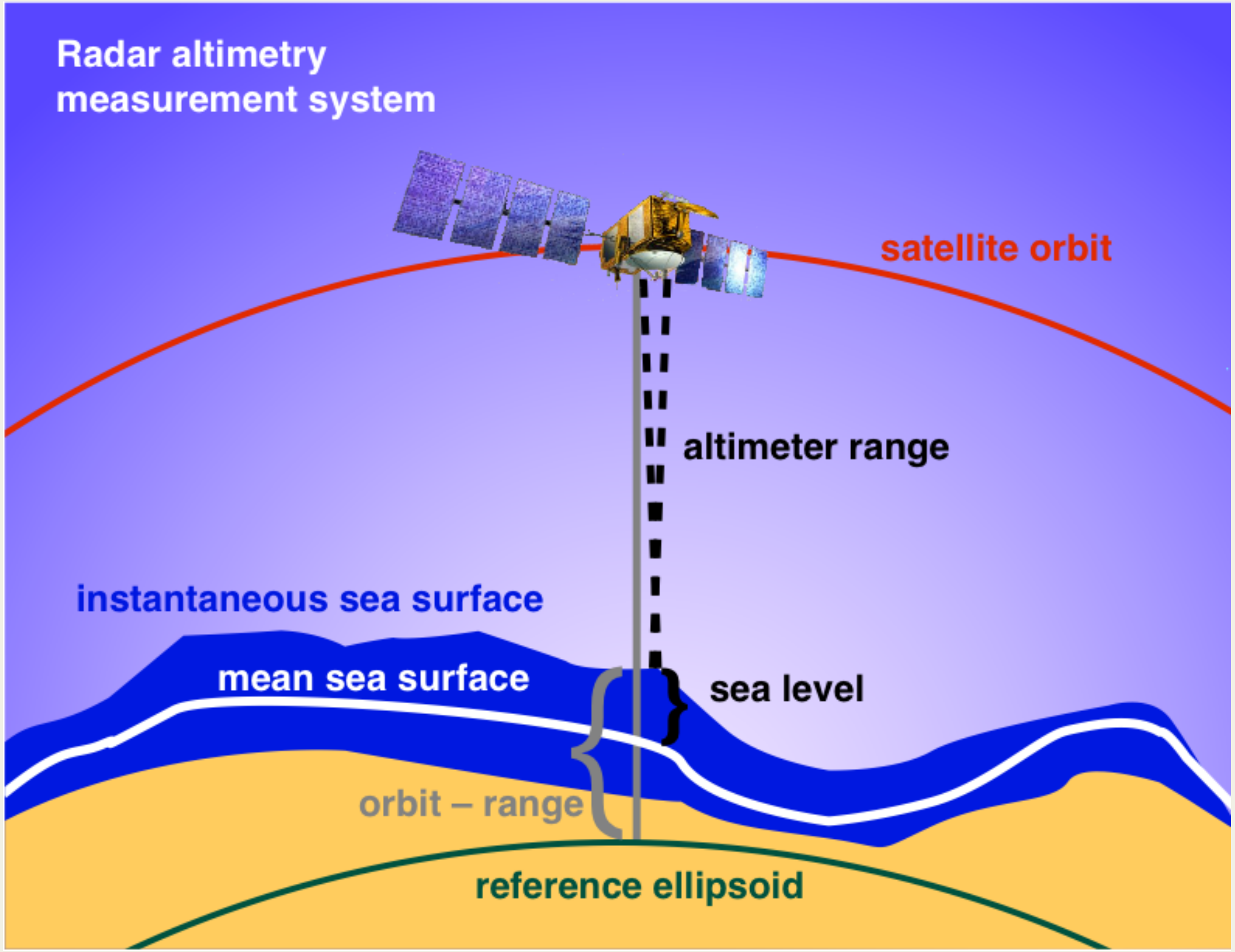
Satellite Radar Altimetry

The radar measures the satellite's height above the surface of the Earth.

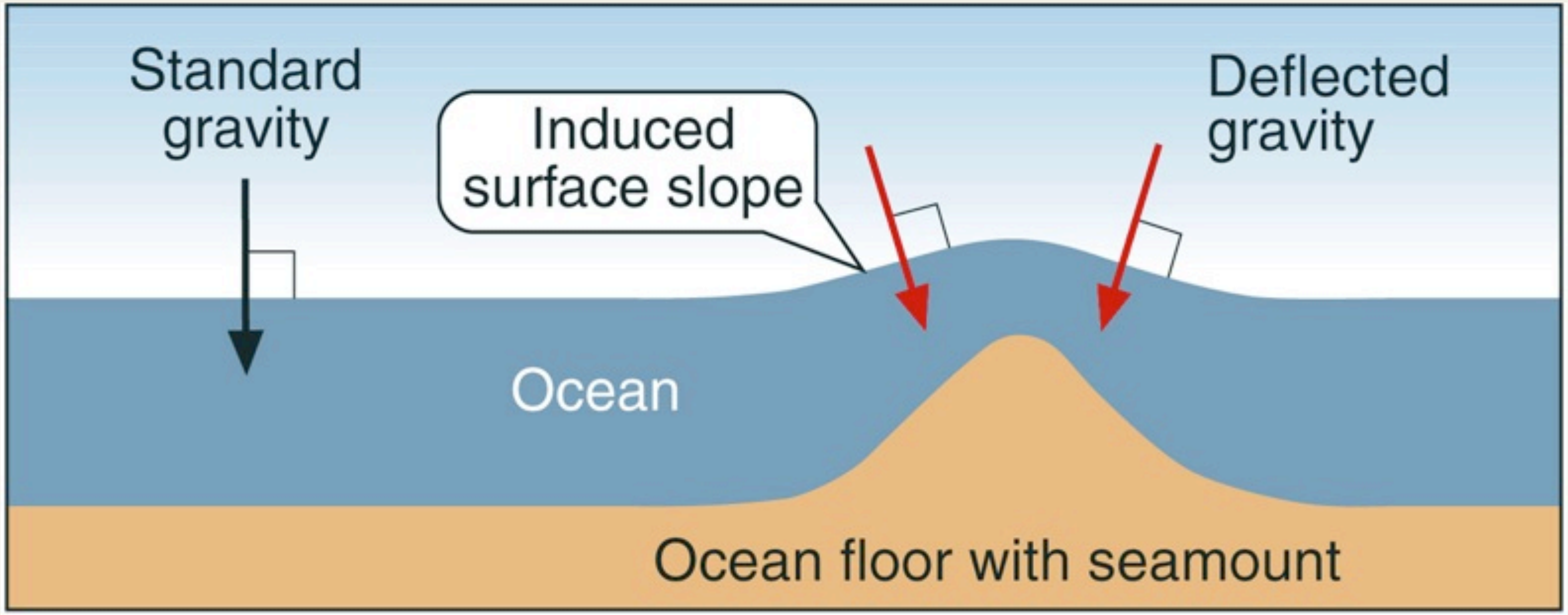
Orbit tracking and modeling locates the altimeter above a reference Earth ellipsoid.

Differencing the two yields the Earth surface height.

Sea surface height is the net result of dynamic heights (the ocean's response to tides and weather) plus the "geoid" height, the hydrostatic equilibrium level in the presence of gravity anomalies.



Inferring depth via sea surface altimetry



The gravitational attraction of seafloor geology distorts the hydrostatic equilibrium shape of the sea surface (the "geoid", where sea level would be at rest in the absence of winds, tides and currents).

Hydrostatic equilibrium and level surfaces

A fluid surface at rest in a gravity field is a "level" surface.

The pull of gravity is perpendicular to the surface of the fluid.

Carpenters use a tool called a "level", but one could also use a glass of wine.

Geoid versus sea surface: height & slope

Fluid at rest: level surface.

Fluid in motion: not level.

When wine orbits a glass at one revolution per second, the surface is far from level.

When sea water orbits an ocean basin, or even an eddy, the surface is almost level.

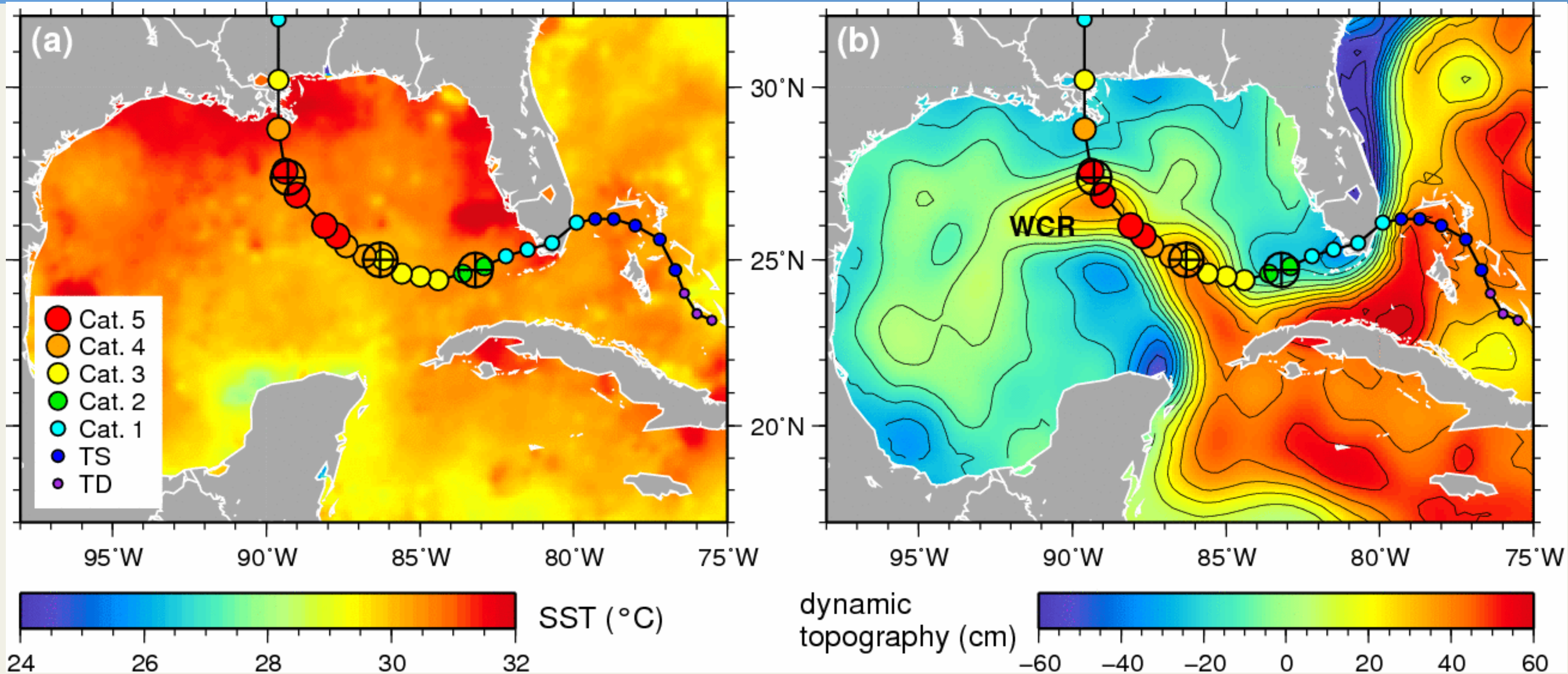
The departure from level is seldom more than 2 micro-radians (1/8 inch of sea level per mile.)

Ocean dynamic height can depart from the geoid height by up to 1 meter, but sea surface slope is almost always within 1-2 micro-radians of the geoid slope (gravity deflection angle).

We use sea surface slopes to infer gravity anomalies and thence bathymetry.

The intensification of Hurricane Katrina

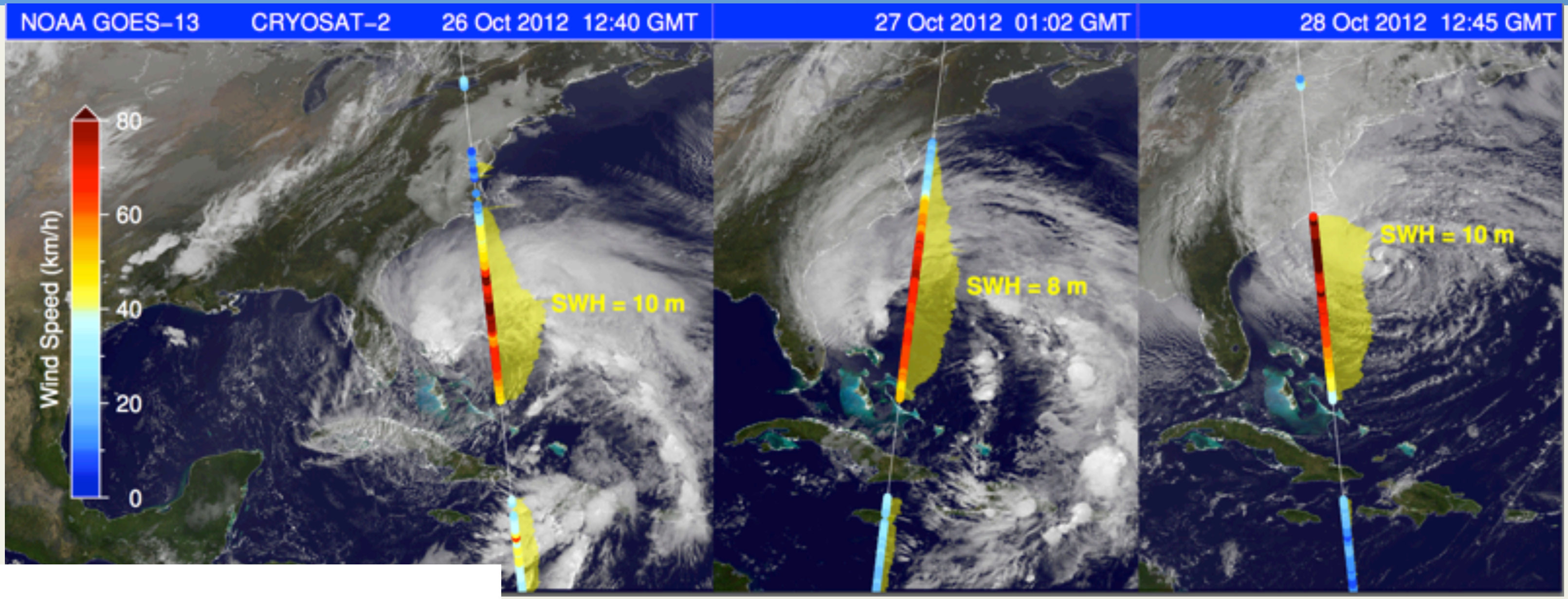
DOI 10.1029/2005EO400004

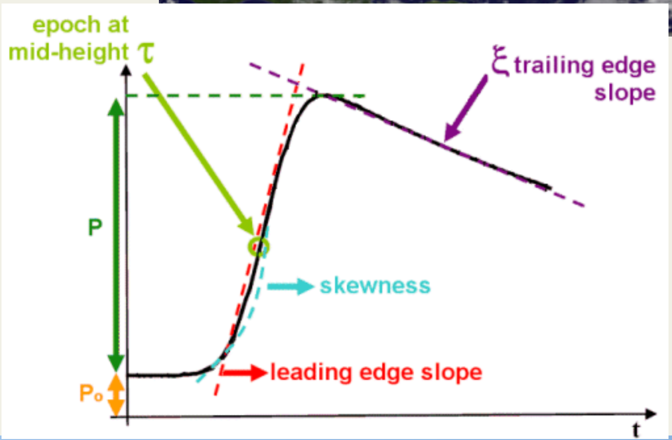


Intensification is not correlated with Sea Surface Temperature (SST), which was warm (~30°C) everywhere along Katrina's path.

Intensification occurred when Katrina was over high "dynamic topography" (sea level anomaly) indicating warm water extending to greater depth.

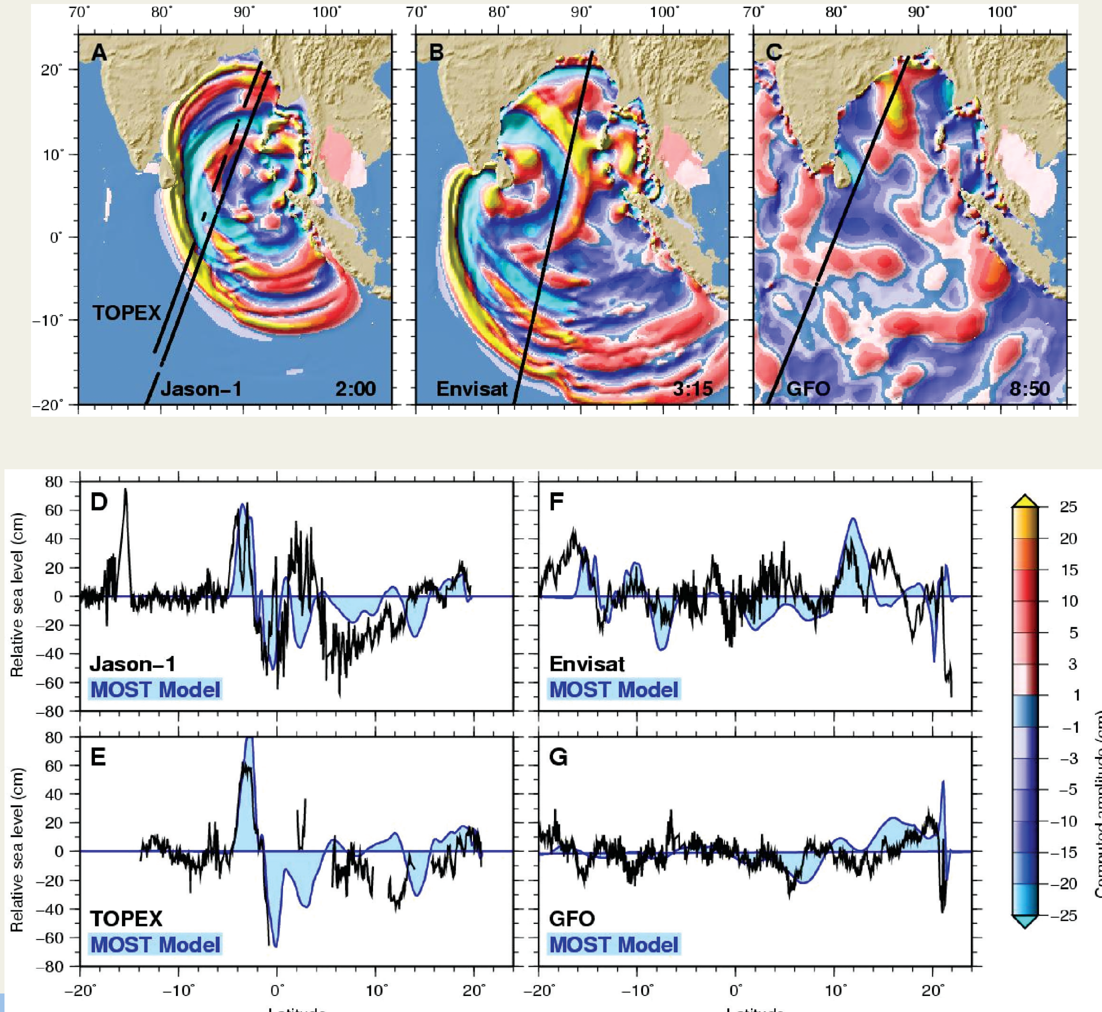
Hurricane Sandy Winds and Waves





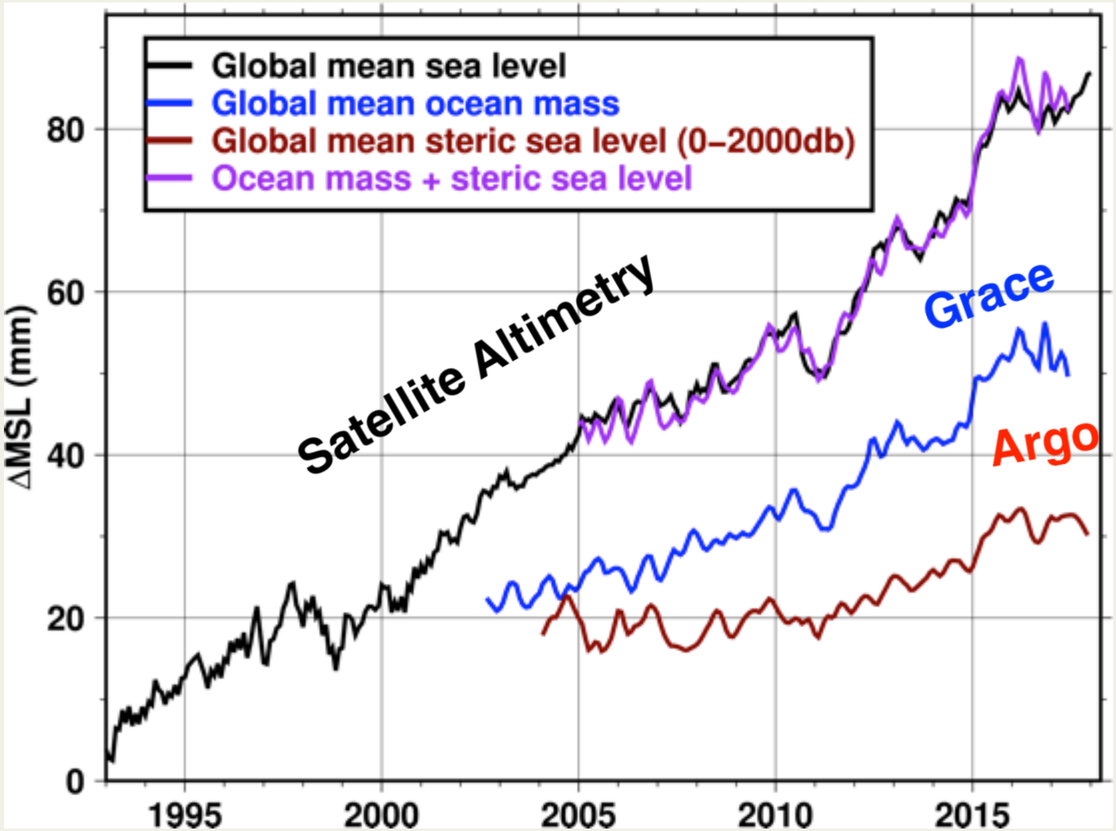
The way that power varies with time in the echoes of altimeter pulses can be used to measure wave height and wind speed at the sea surface, as well as the distance to sea level. We feed altimeter wind and wave data to NOAA's marine forecasters in near-real time.

Tsunami height (2004 Dec 26 event)



Altimeters provided the only measurements of the open-ocean height of this tsunami, and contributed to a debate about the earthquake rupture mechanism. doi: 10.5670/oceanog.2005.62

Global sea level rise and its sources



3.0 ± 0.2 mm/yr

2.0 ± 0.1 mm/yr

0.8 to 1.1
± 0.3 mm/yr

Radar range is
order 10^9 mm.

The seasonal variation has been removed in this figure. A strong La Niña in 2010-2011 temporarily moved a lot of water to the continents. doi:10.1175/2018BAMSStateoftheClimate.1

What is one part in 10 Billion $1:10^{10}$?

At last I have reached the end!