Bathymetry from Space: New capabilities, new questions

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Bathymetry is basic infrastructure

- For Science
  - Oceanography, geology, biology, ecology
    - To climate via oceanography?
- For Economics
  - Resource exploration, cable routing, shipping
- For Management and Policy
  - Fisheries, Law of the Sea
- For Defense

Acoustic bathymetry is best, BUT…

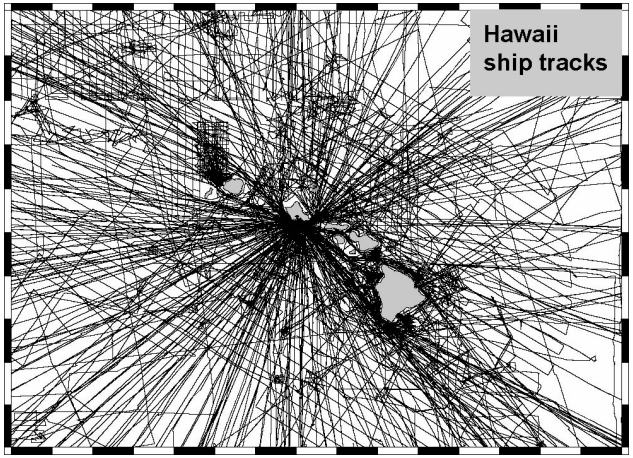
- Existing data are sparse and poor quality
  - Gaps 10^5 km^2 in area and 100s of km in length
  - Majority of data in remote areas is pre-1967 and thus only celestially navigated & single beam
  - Data collection rates have declined since 1970s
  - Swath data only a few % of total and mostly on continental margins and mid-ocean ridge sites
- Vehicles in water are slow and expensive
  - 1000 ship-years (10 G$) to do a complete survey

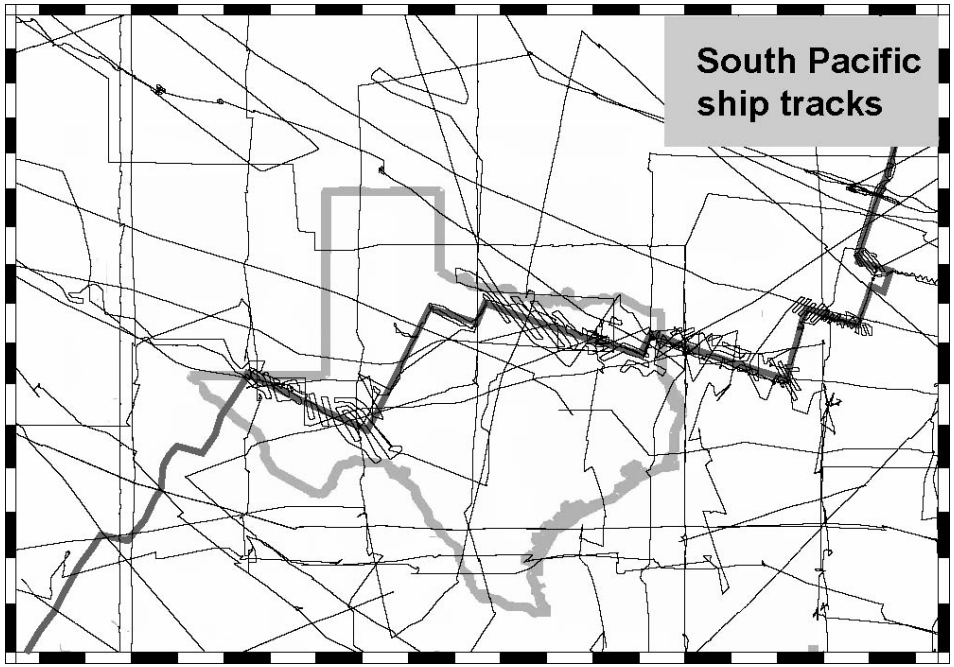
See Sharman [this meeting] and Smith [JGR-B, 1993].

Ship track distributions

- **Coverage is variable**
- **Only resolves long-λ depths**

Maps are at scale (1-deg. grid). Spreading ridge axis (right) has better-than-normal coverage.

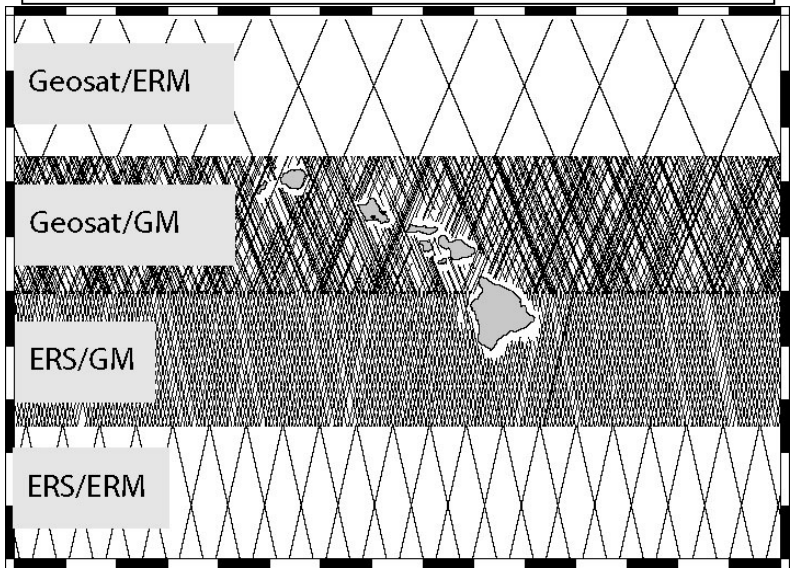




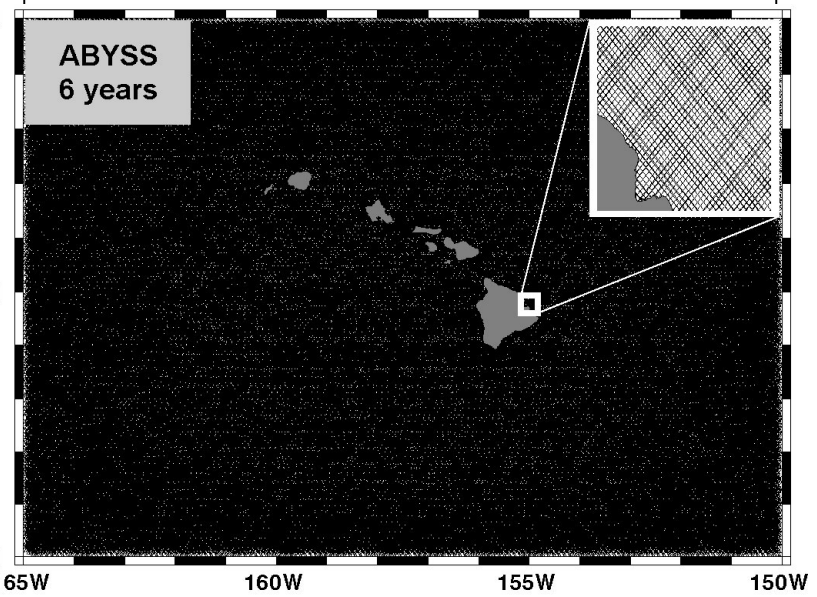
Satellite track coverage

- **Dense track network (~5 km spacing)**
- **Fast (few years) and cheap ($60M)**

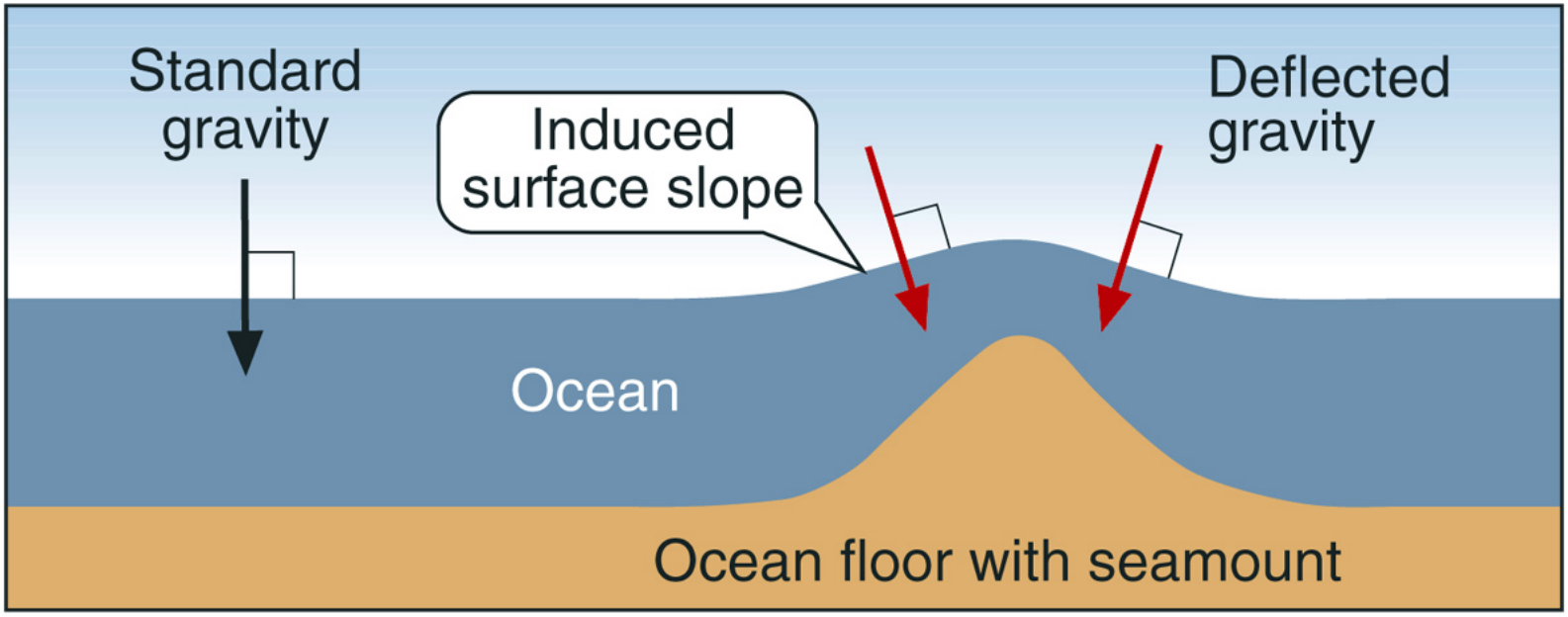
Current altimeters have poor E-W control, high noise (ERS/GM), and uneven track spacing(Geosat/GM).



ABYSS will have good E-W control, low noise, and very dense track spacing.

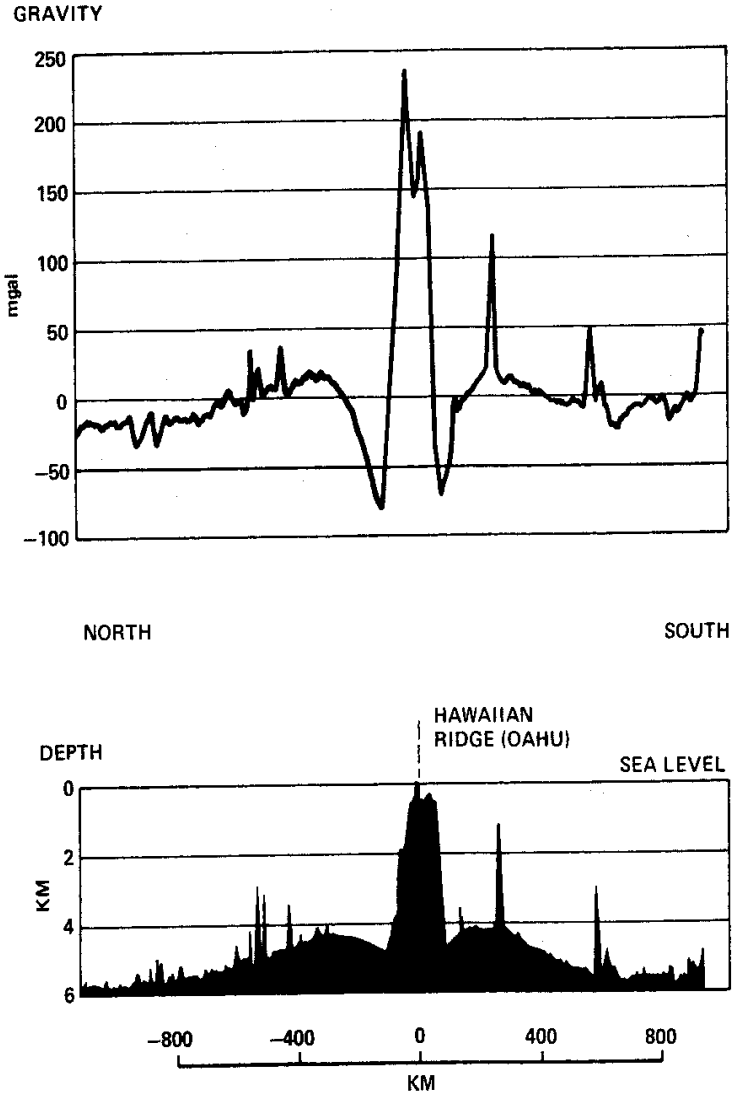


Satellite bathymetry is via gravity



Space radar can sense ocean surface slopes, manifestations of gravity anomalies in the form of deflections of the vertical. These may be correlated with sea floor structure.

Gravity and bathymetry can be correlated



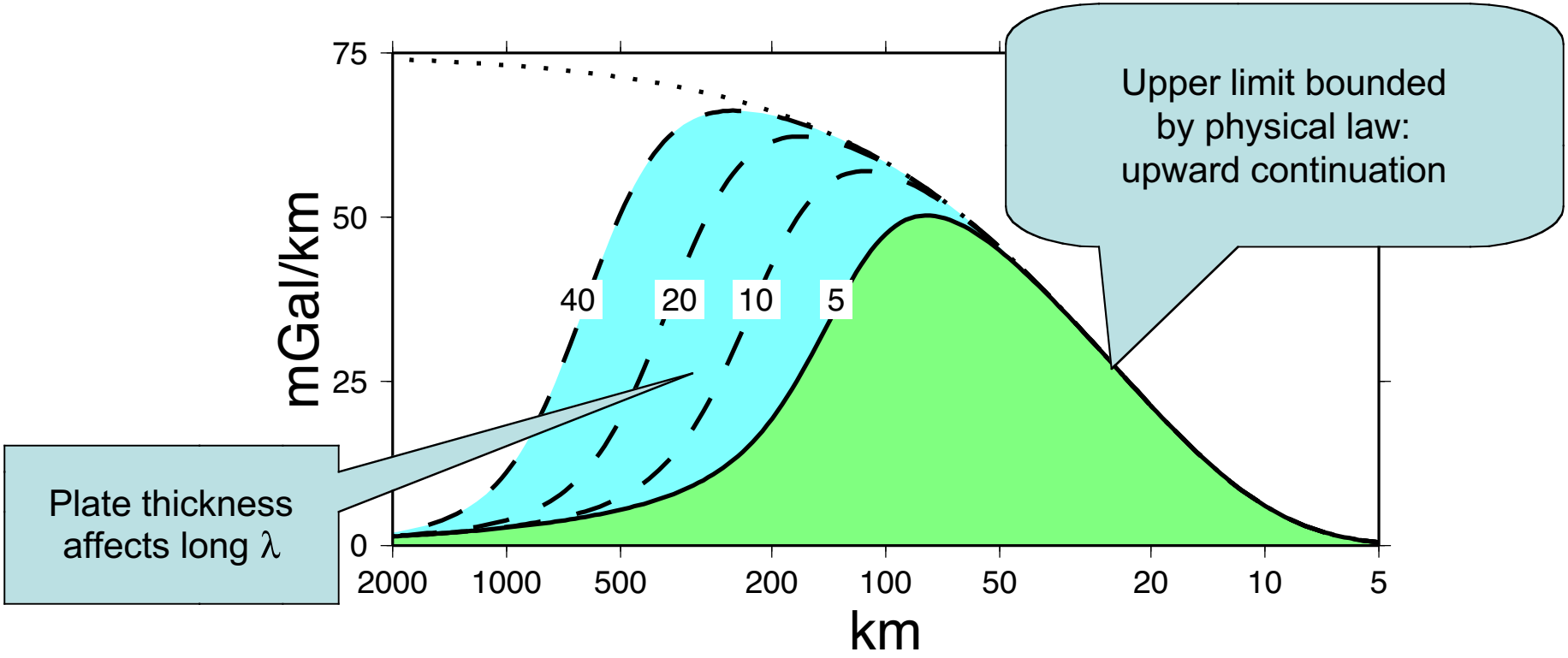
Topography generated by ocean crustal processes is related to ocean surface gravity anomalies through a simple filter.

Exploitation of satellite gravity can thus yield filtered depths, if geologic conditions are right:

Ocean crust w/ thin sediment.

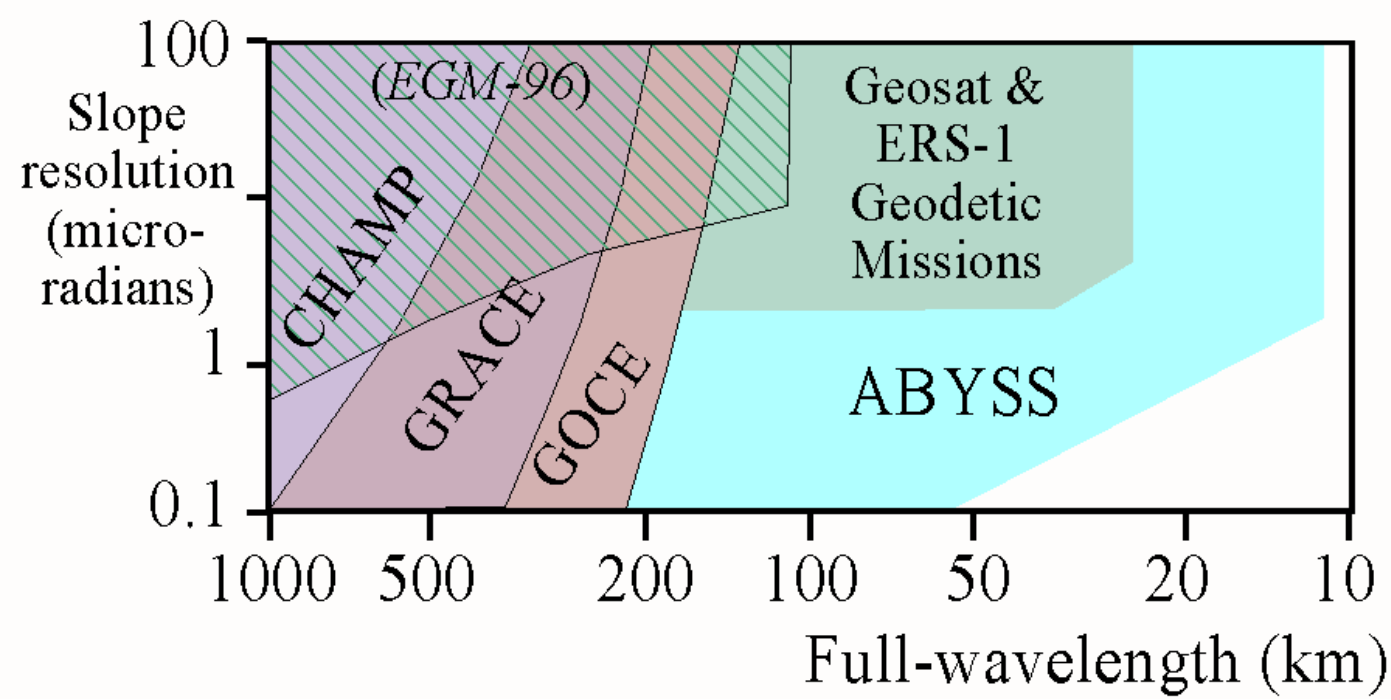
Continental margin basins are different; gravity there shows sub-surface structure.

Topography to gravity bandpass filter



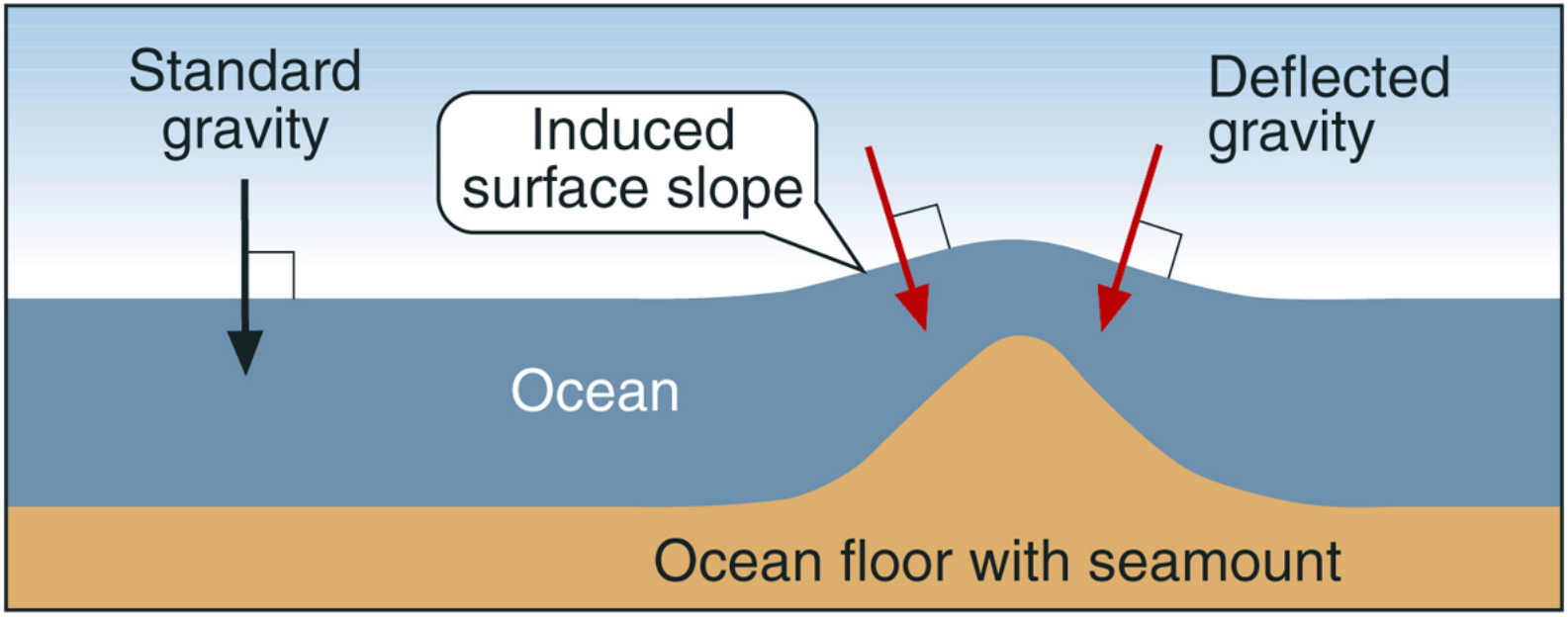
"Isostatic compensation" attenuates topographic gravity at full-wavelengths longer than ~160 km. "Upward continuation" limits resolution when full-wavelength << 2 π x distance from sea floor to gravity measurement (sea surface, shown here, or in space).

Bathymetry requires altimetric gravity



Altimetric sea surface slopes measure gravity at sea level and so capture the bathymetric gravity wavelength band. Gravimetry in orbit (CHAMP, GRACE, GOCE) measures gravity at satellite altitude, much higher than 160 km. Upward continuation that far wipes out the bathymetric signal.

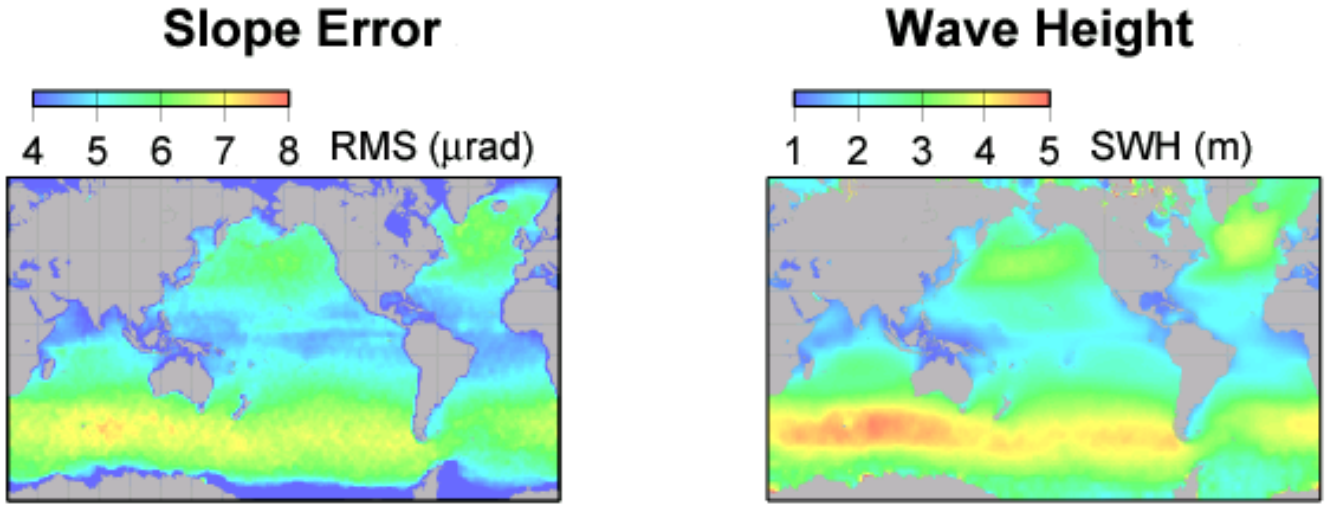
Band-limited measurement is easy



We only care about $\lambda < 160$ km error sources.

We don't need absolute height accuracy, only local slope (height gradient) accuracy.

Slope error at $\lambda < 160$ km is mainly due to waves.

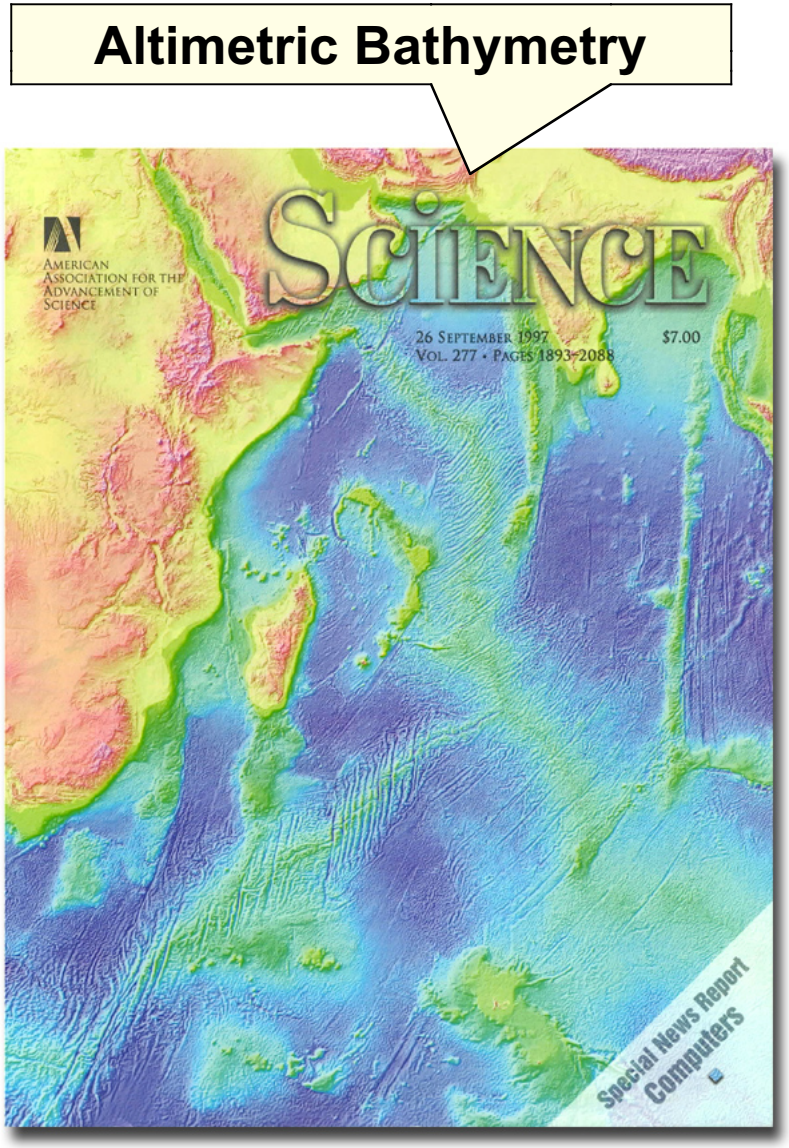


Map pattern of RMS slope error looks like map of wave height, but does not resemble pattern of variability of currents, ionosphere, etc.

Slope RMS variability from Geosat ERM (1 frequency, no radiometer).
Seasonally averaged wave heights from P. D. Cotton.

Higher precision requires an altimeter less prone to random noise induced by ocean surface waves.

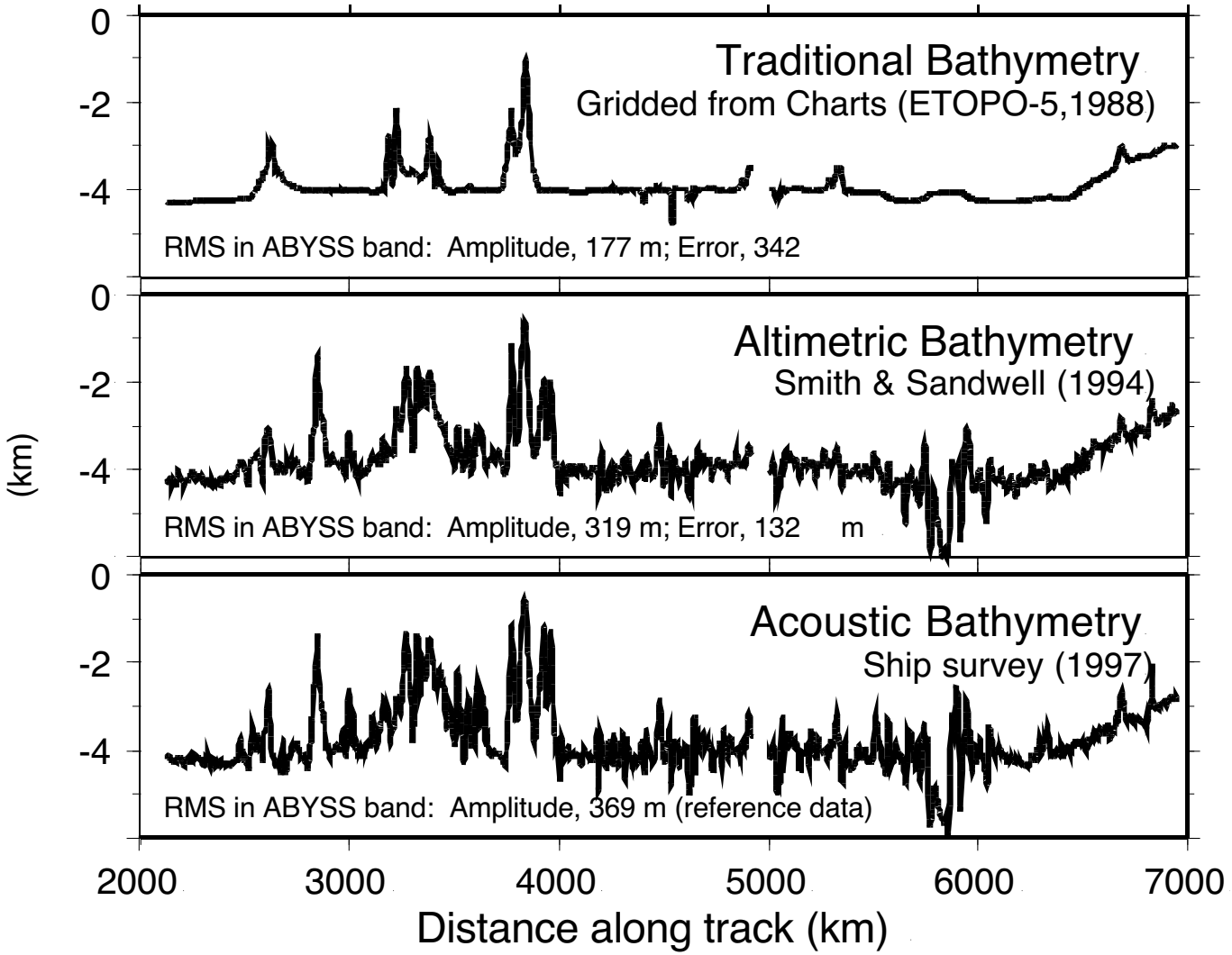
Altimetric bathymetry thus far



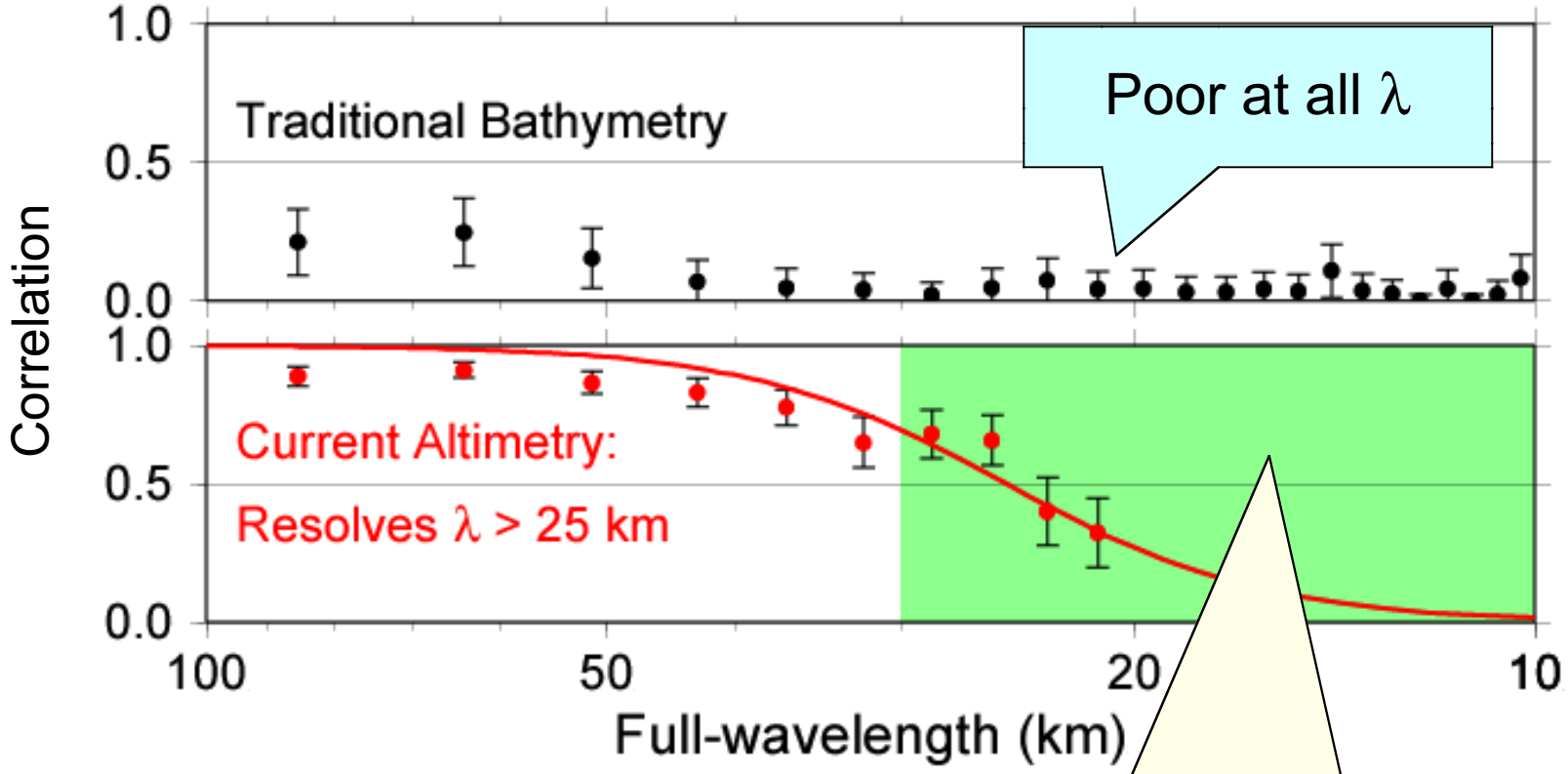
- **A proven technique**
- **Needs only simple altimetry (Geosat, w/ no troposphere or ionosphere measurement, did just fine.)**
- **Has resolved many interesting tectonic features**

Can we do better?

South Pacific Bathymetry Profile

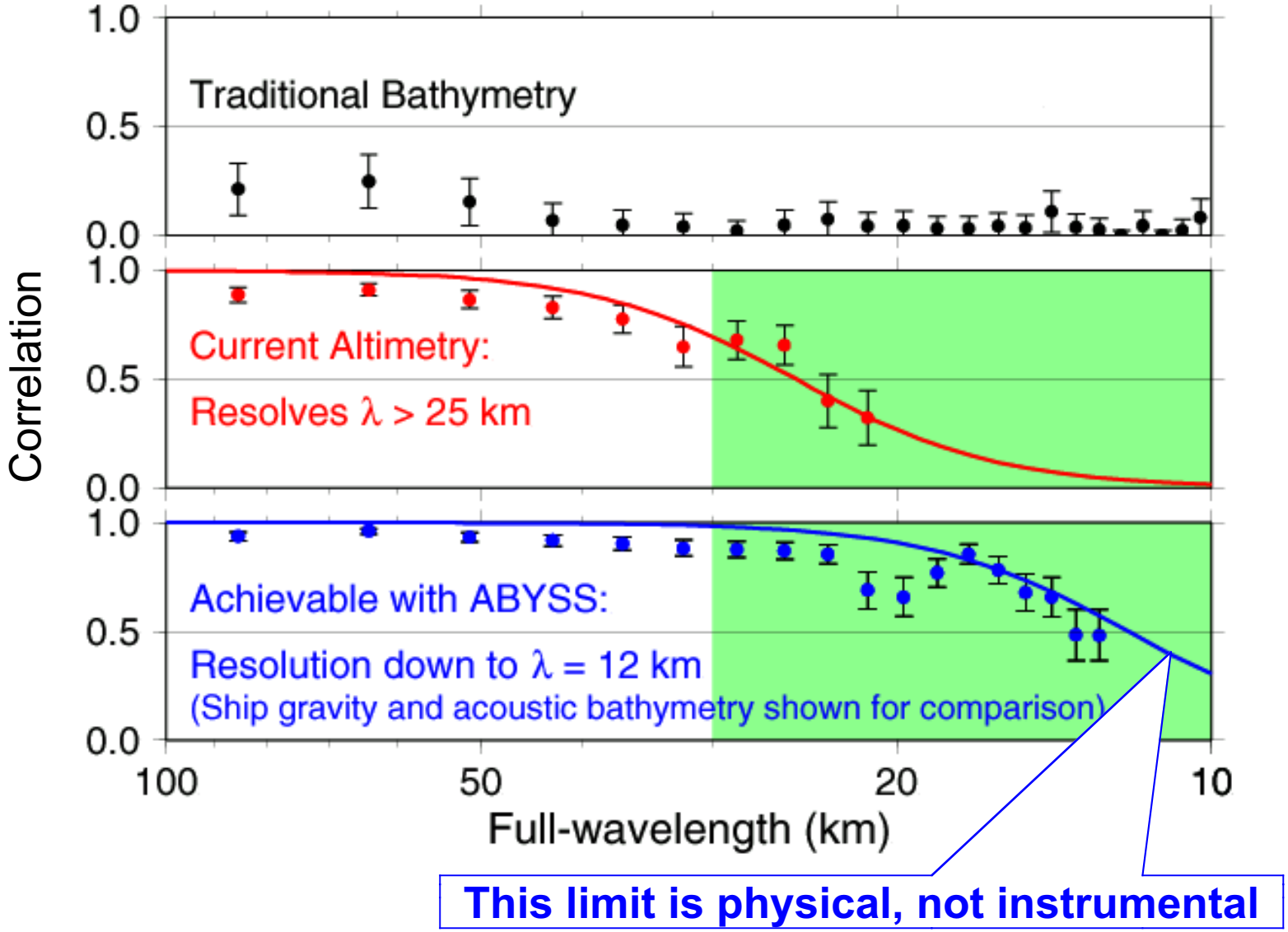


Profile Correlation by Wavelength

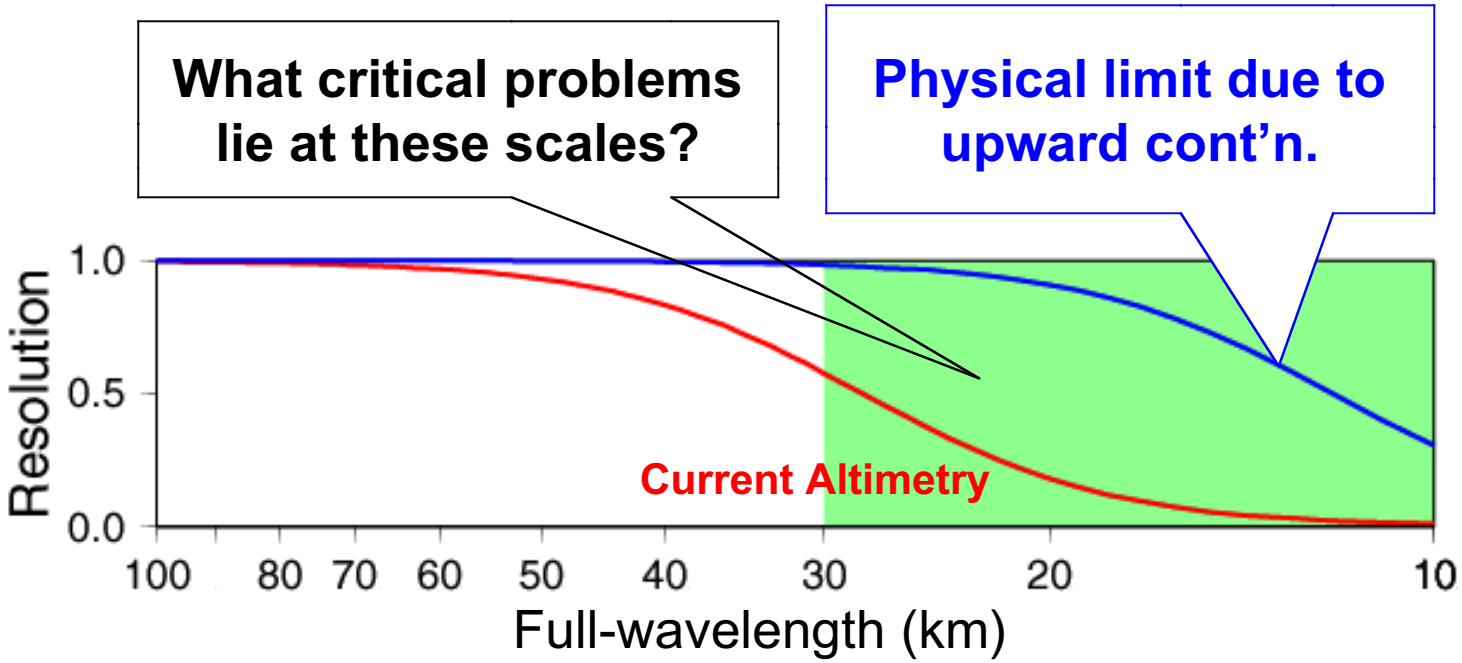


This band is not resolved yet, but could be with a new mission

Best Possible Resolution: Measure Gravity as Well as a Ship Can (to ~1 mGal, or 1 μrad of sea surface slope)



What new science is in this band?

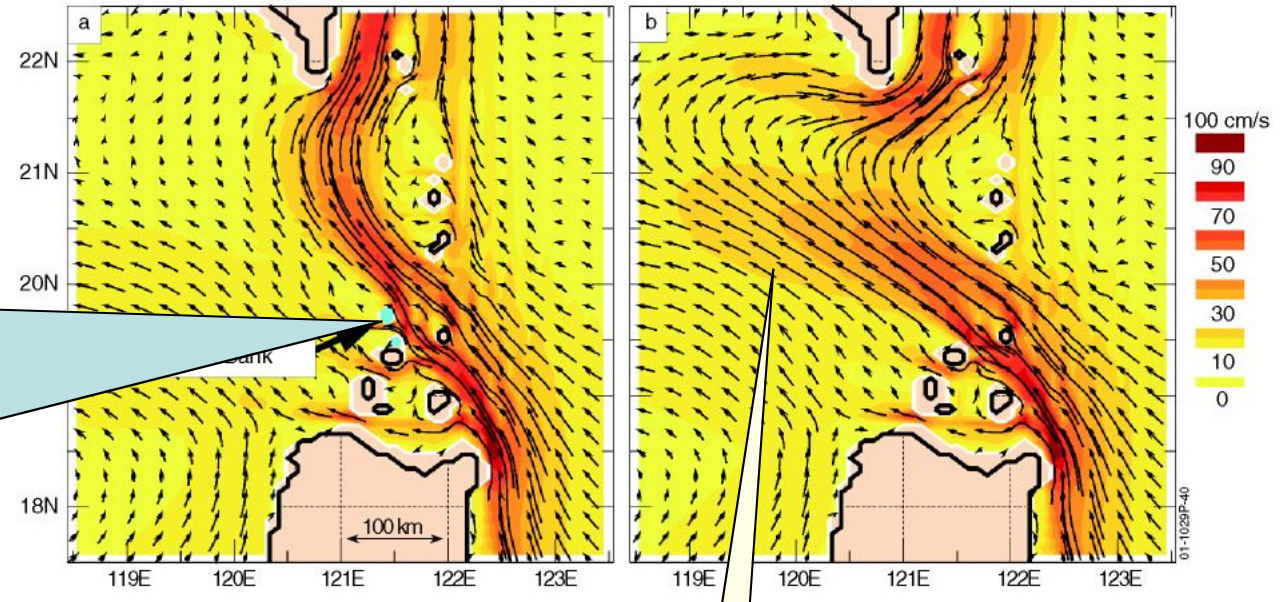


Is this resolution improvement sufficient to characterize nearly all the interesting bottom roughness properties? Can it capture the transition to fractal topography?

Does 20-km-Scale Bathymetry Steer Ocean Currents?

Forecast models require correct global bathymetry

Model Bathymetry Changed Only Here

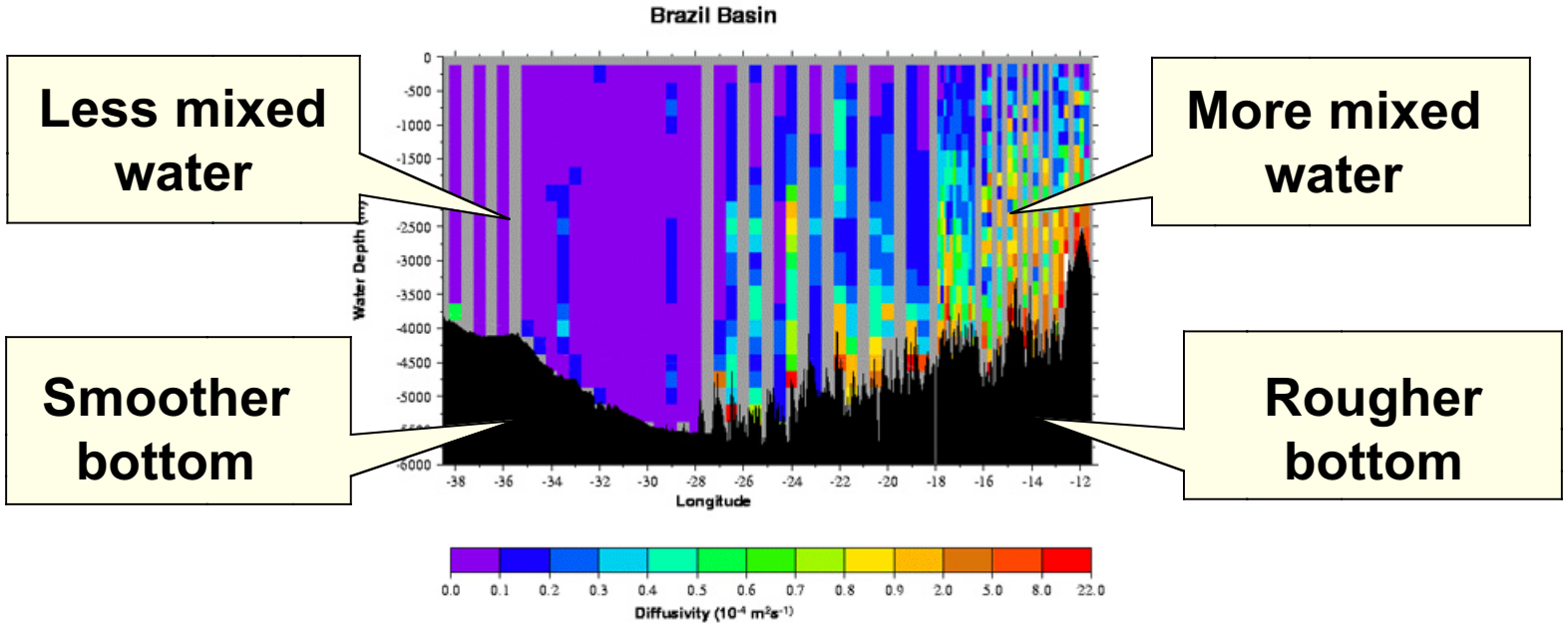


Approximates nature

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°; see Metzger, this meeting).

Bottom Roughness a Mixing Control?



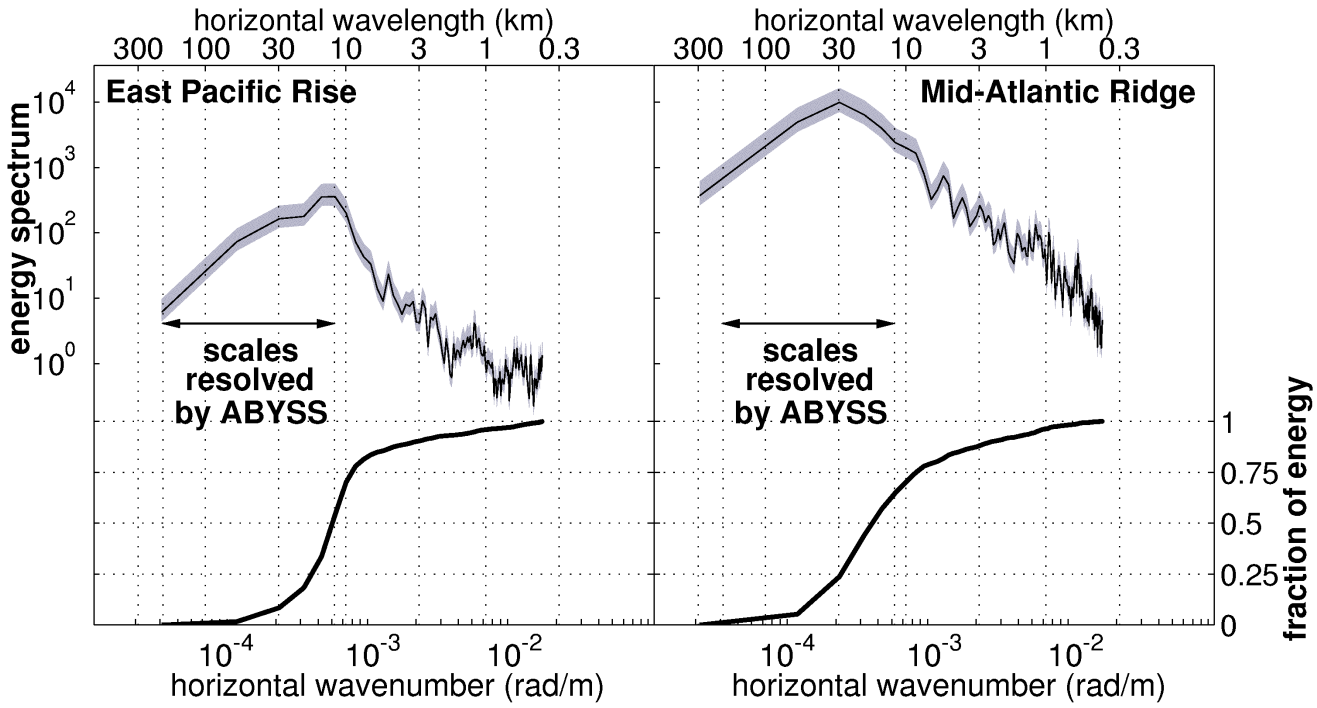
Spatial variations in bottom roughness change mixing rates by order of magnitude (vertical diffusivity < 10^{-5} at left and > 10^{-4} at right; actual in situ data shown).

10–30 km λ bathymetry controls mixing?

Seafloor spreading shapes bathymetry at these scales.

Energy Levels of Internal Waves

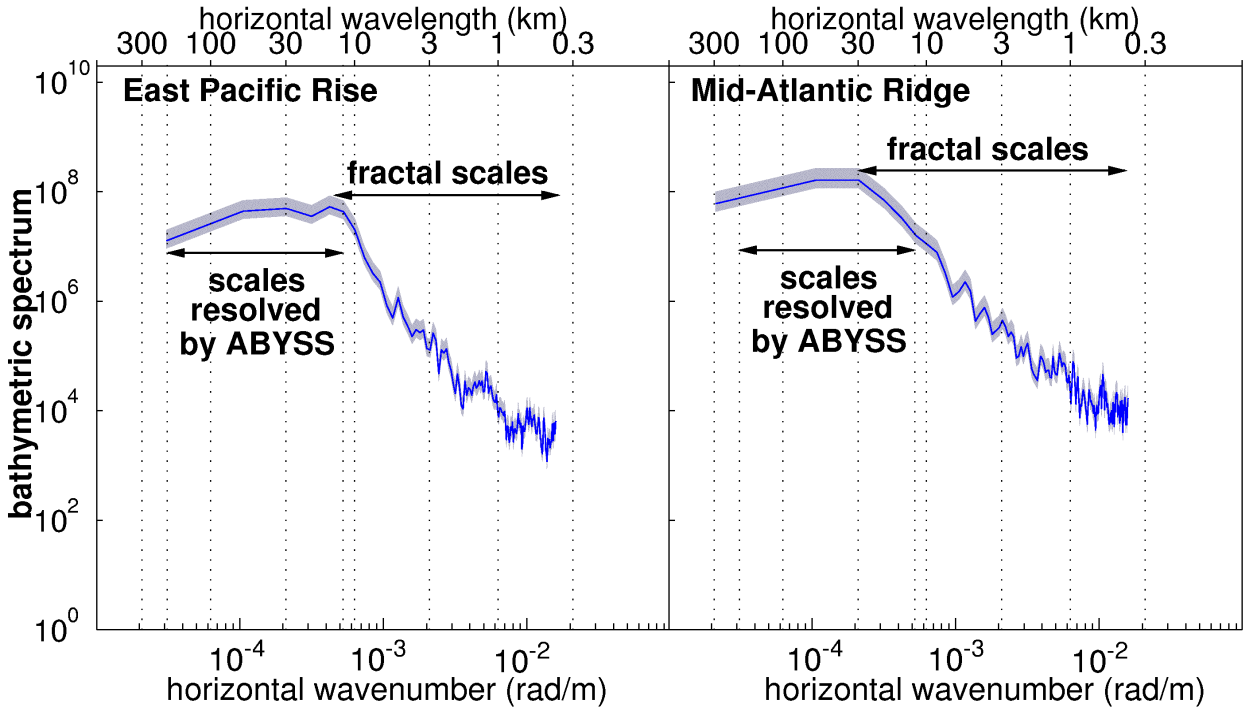
Bathymetry data is used in wave generation models to compute internal wave energy



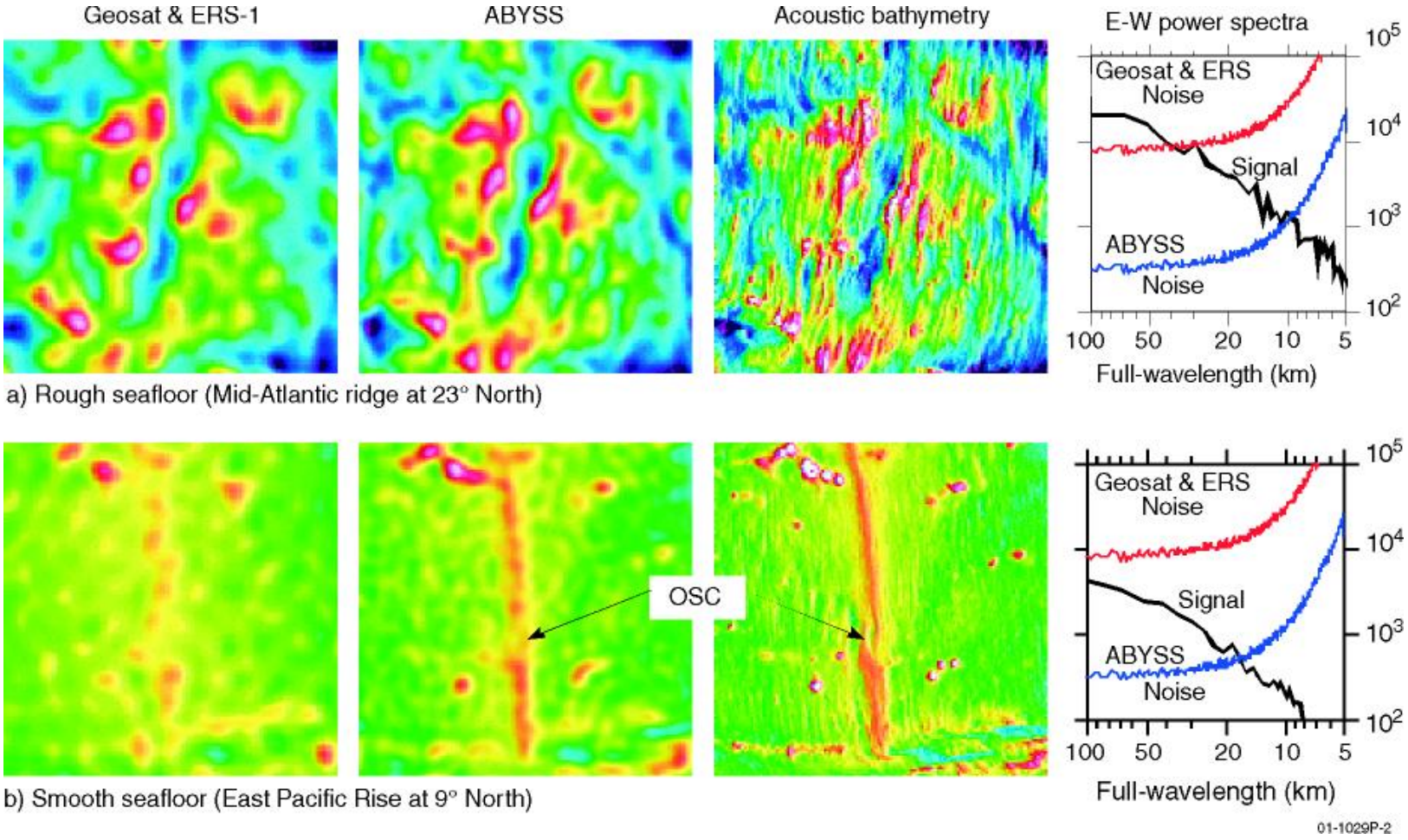
•Peak wave energy levels occur in the 10 -- 30 km band, which captures 60-70% of the wave energy

Can fractals extrapolate if needed?

At large scales, the bathymetric spectrum reflects a mixture of many geologic processes, but at small scales it is self-affine and roughness is contributed by abyssal hills. The transition to fractal topography occurs at different wavelengths, depending on the seafloor spreading details, and the abyssal hills are elongate in map view. Can we capture the statistics of abyssal hill topography?



What can we really expect to see?

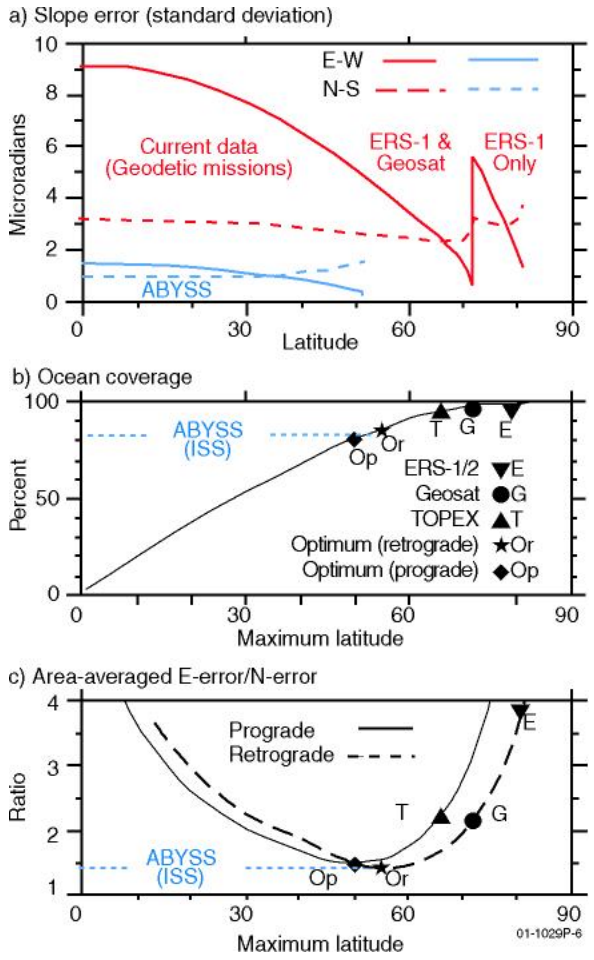


Is latitude coverage a major issue?

Current data are worst (highest error, and most anisotropic resolution) at latitudes < 50°.

ABYSS proposes a moderate inclination, covering 80% of the ocean but sacrificing the poles in order to get nearly orthogonal tracks at lower latitudes.

Will this strategy miss any critical areas?



Questions for this workshop

- What problems can 10-30 km scale gravity or bathymetry address?
- Would this make possible fractal extrapolation of roughness, if needed?
- In what latitude range can altimetric mapping be most improved? Does this cover desired areas?
- Are ocean circulation/mixing/tide models (& climate forecasts?) significantly sensitive to these scales or their fractal extrapolation?