Satellite Altimetry: an aid to Global Bathymetric Charting

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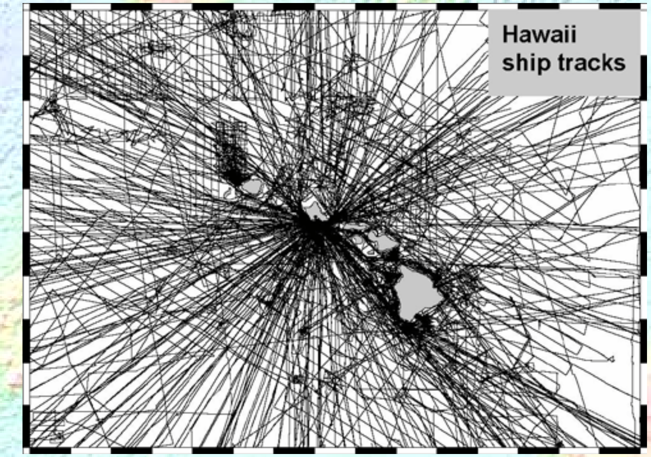
Advantages of satellites

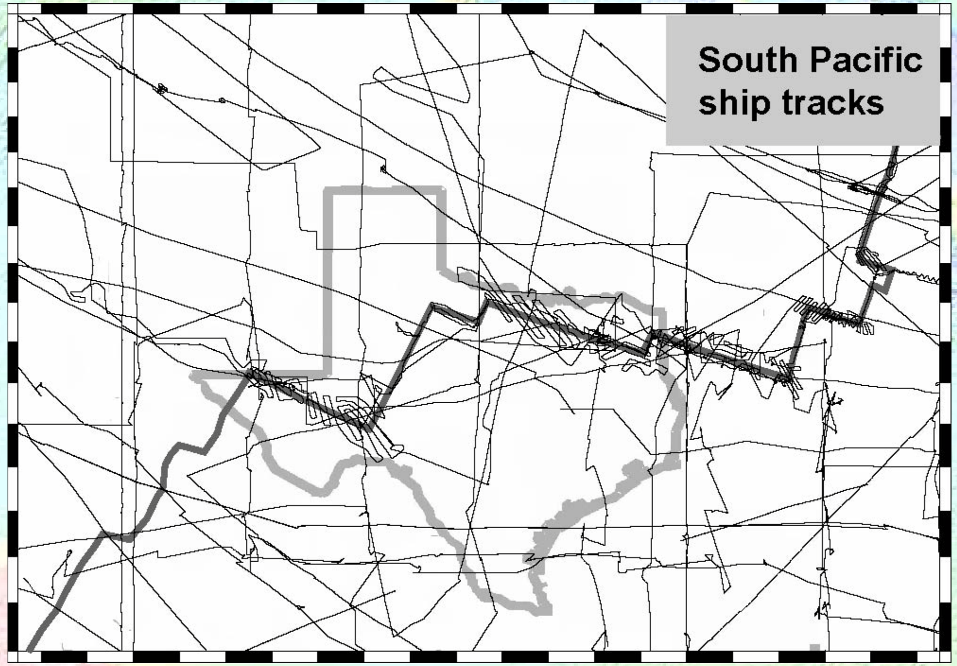
- Uniform and global coverage
  - No preference for ports
  - No national or peer-review bias
- High speed and low cost
  - Dense (5 km) global coverage in one year
  - Multi-year mission cost ~ 60 M USD
  - Compare to global deep water ship surveys:
    - > 100 years of ship time
    - > 1 G USD

Ship track distribution

- **Coverage is variable**
- **Global resolution only of long-λ depths**

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

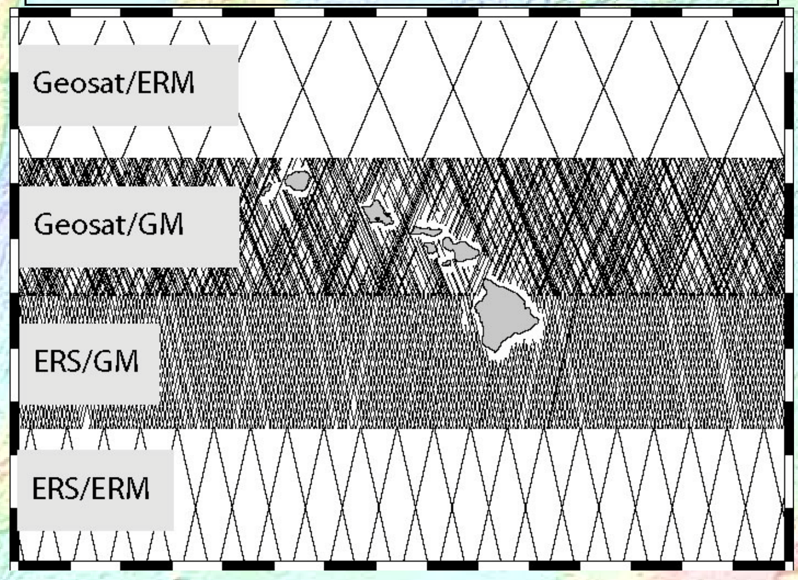




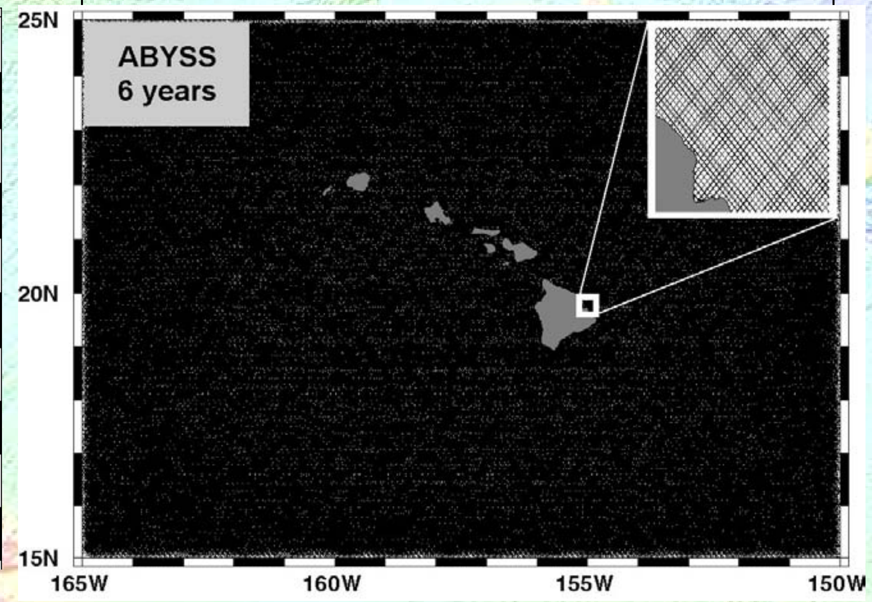
Satellite track coverage

- **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).



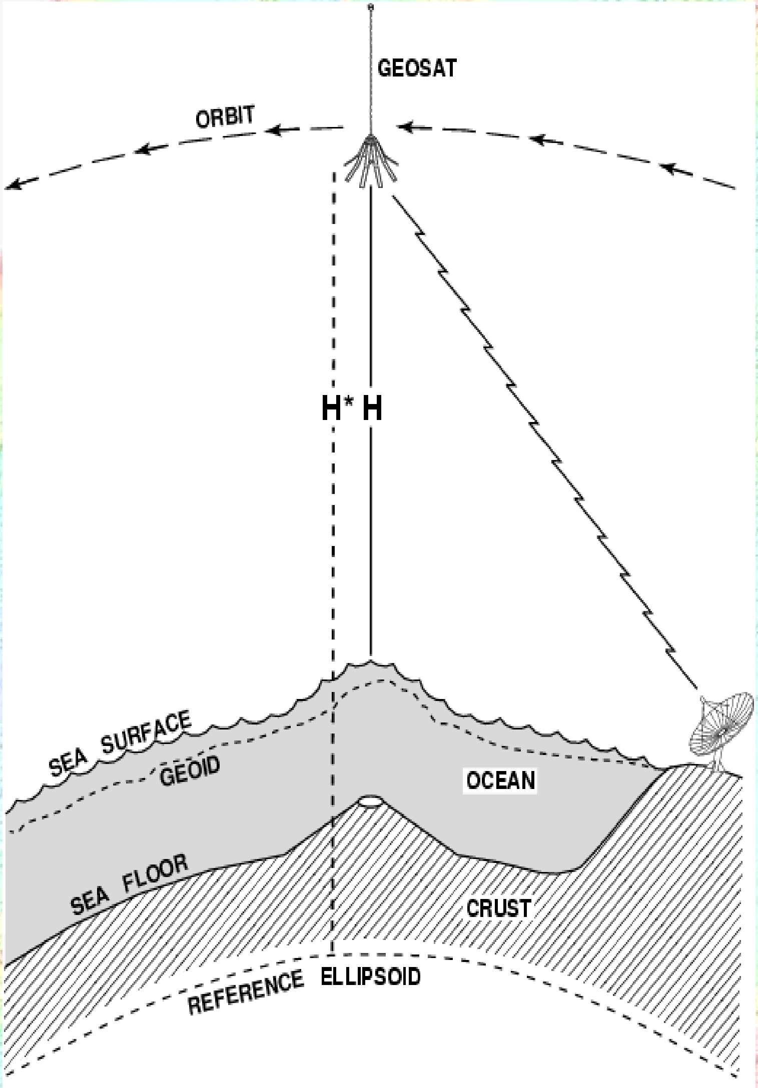
ABYSS will have good E-W control, low noise, and very dense track spacing.



Disadvantage of satellites

- Indirect measurement
  - Cannot “see” the ocean floor
  - Yields gravity anomalies, not depth
- Limited correlation with depth
  - Length scales limited to $\lambda < \sim 160$ km
  - Correlation varies with local geology
  - Must be determined empirically
  - Requires some soundings for calibration

Satellite Altimetry



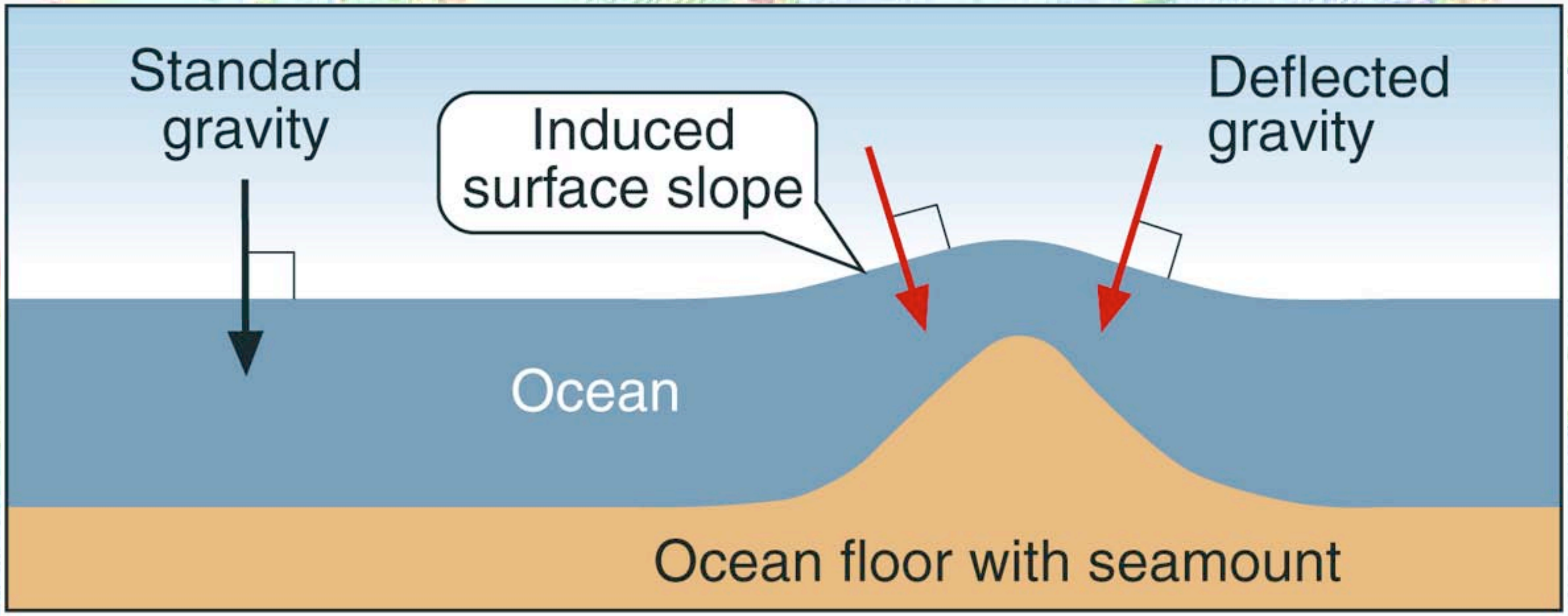
- Altimetry = height measurement
- Radar in space measures sea surface height (SSH), wind and wave information

Precision Challenge:

Differencing two large quantities to measure one small one

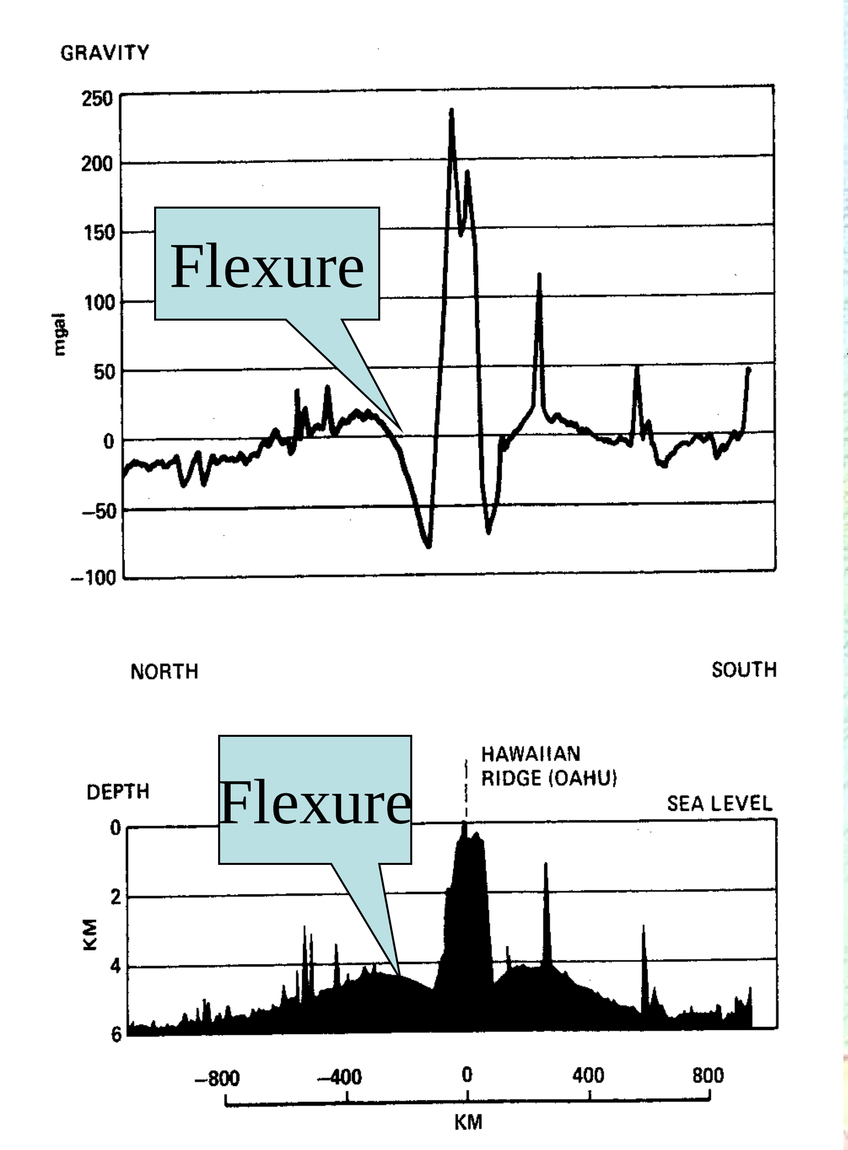
SSH = H* - H

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



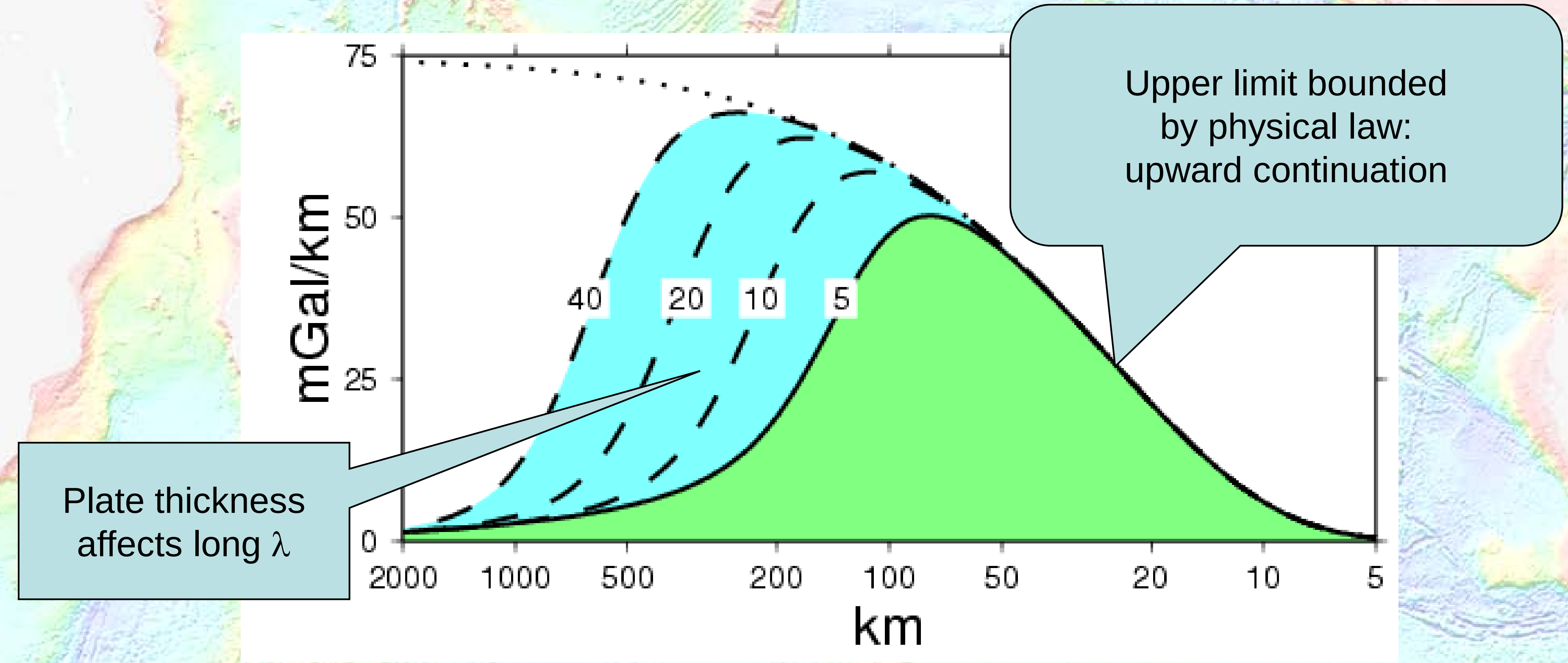
Topography generated by ocean crustal processes is related to ocean surface gravity anomalies through a simple filter.

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

Ocean crust w/ thin sediment.

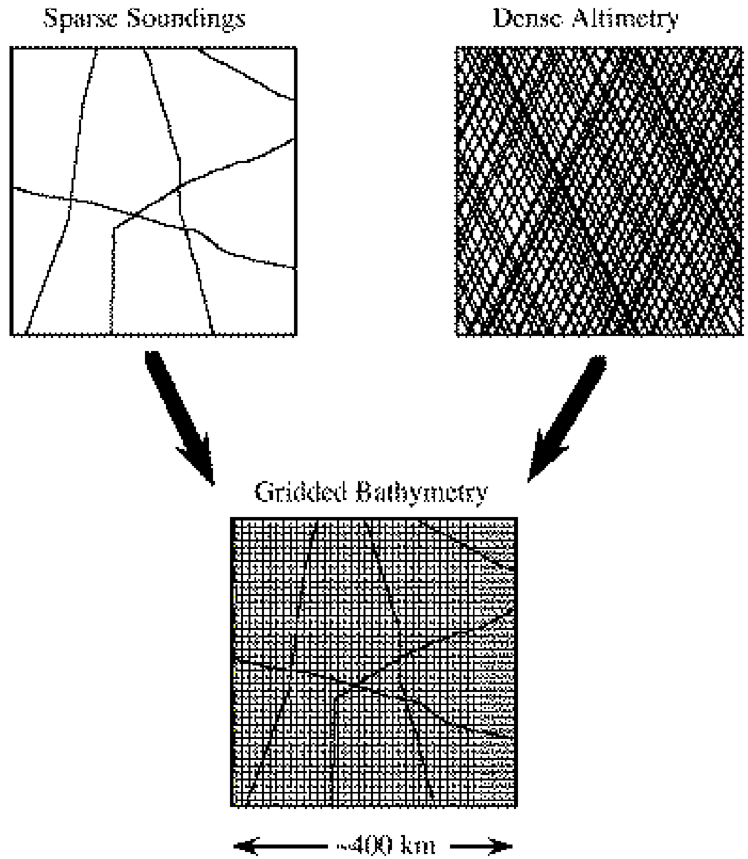
Continental margin basins are different; gravity there shows sub-surface structure.

Topography to gravity bandpass filter

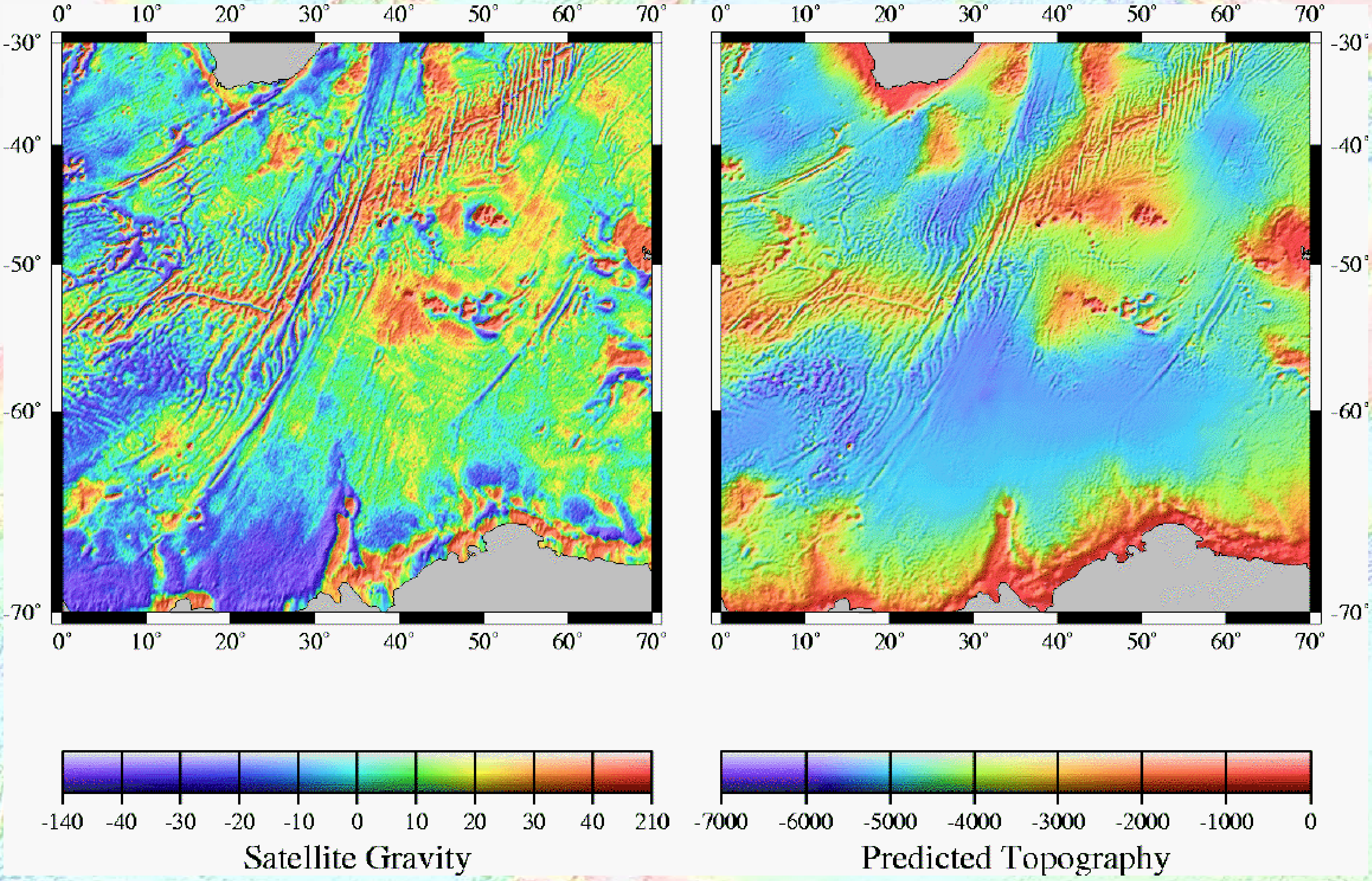


"Isostatic compensation" attenuates topographic gravity at full-wavelengths longer than ~160 km. "Upward continuation" limits resolution when full-wavelength << 2 π x distance from sea floor to gravity measurement (sea surface, shown here, or in space).

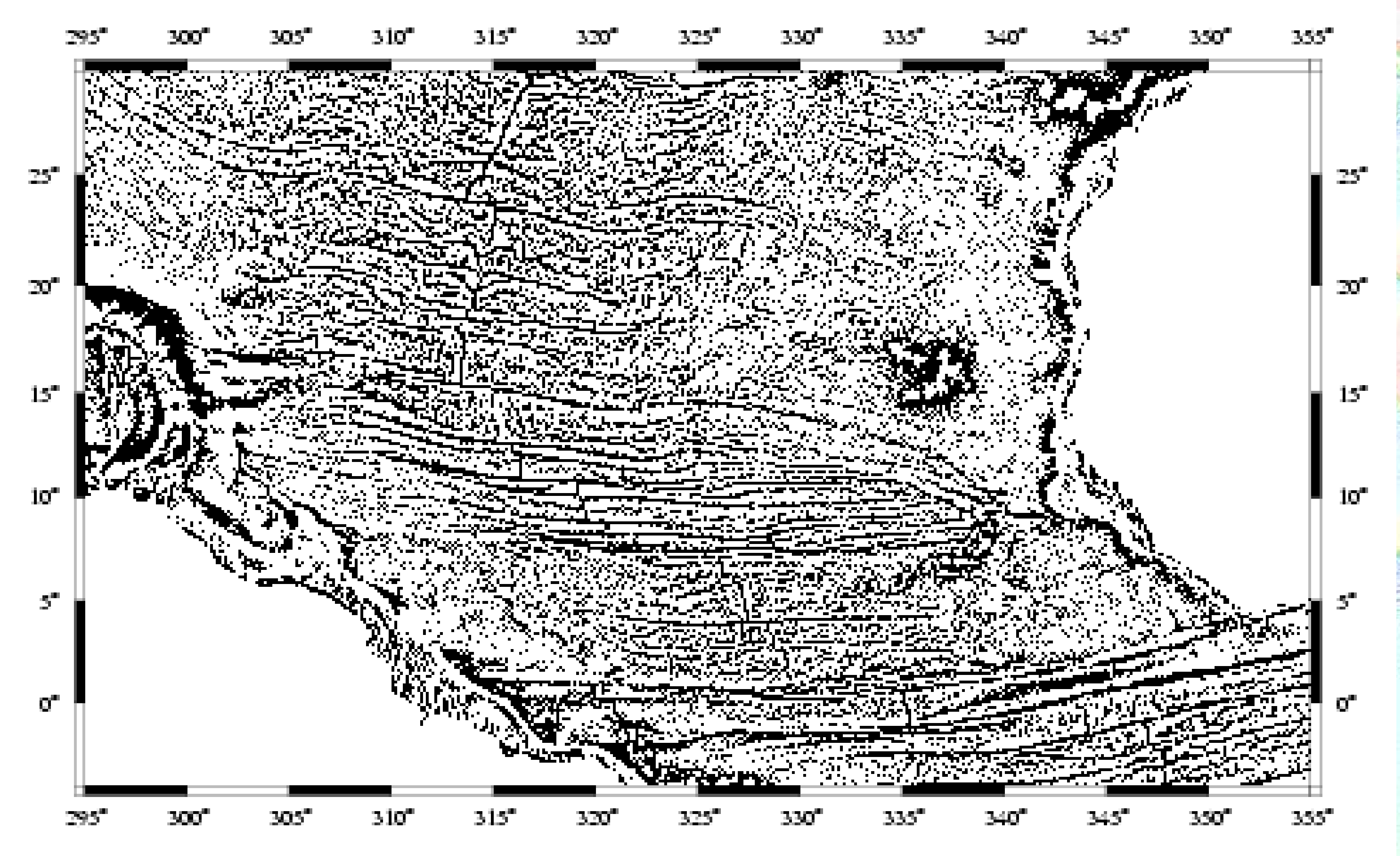
Recipe: satellite gravity interpolates sparse ship bathymetry surveys

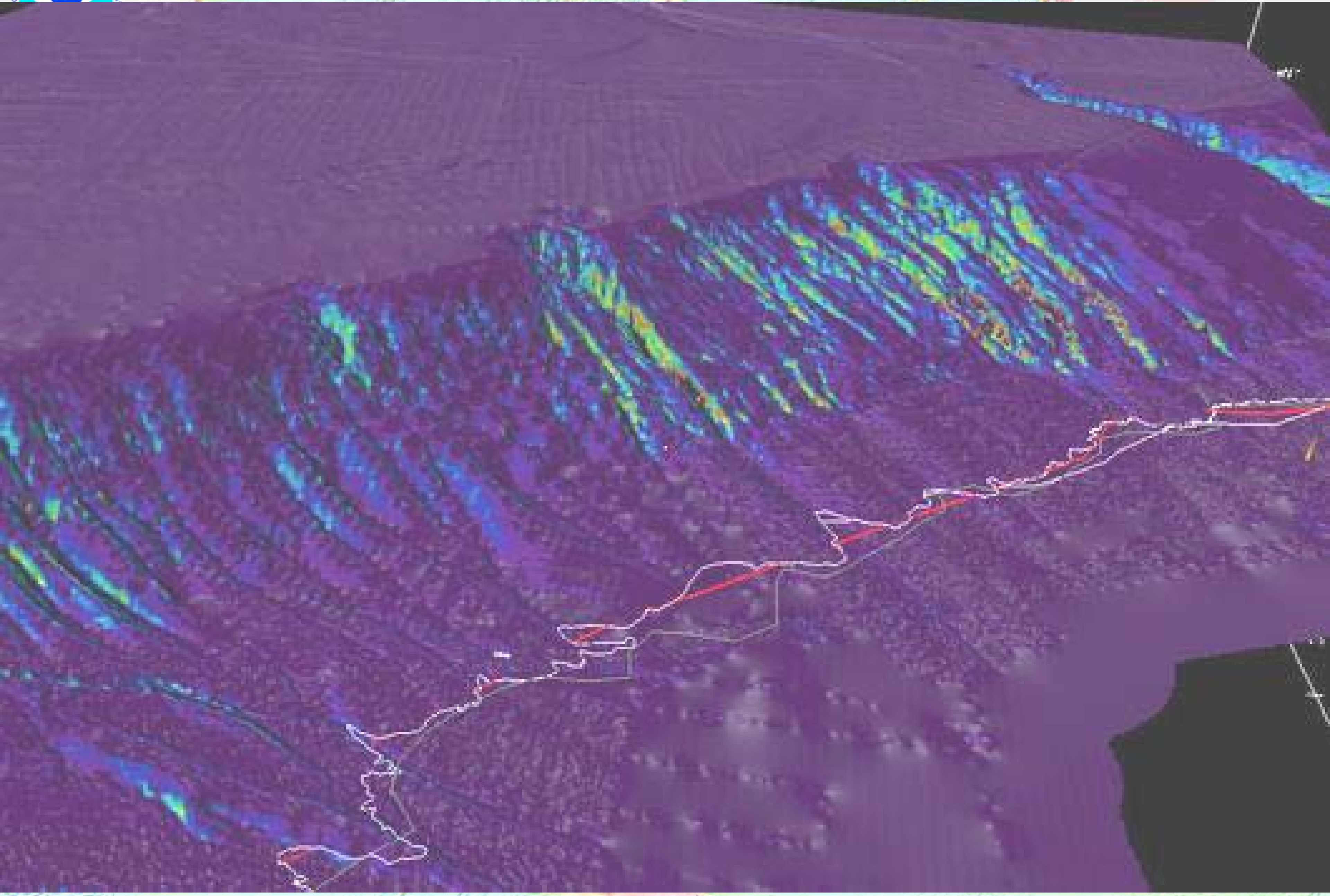


Example: SW Indian Ocean



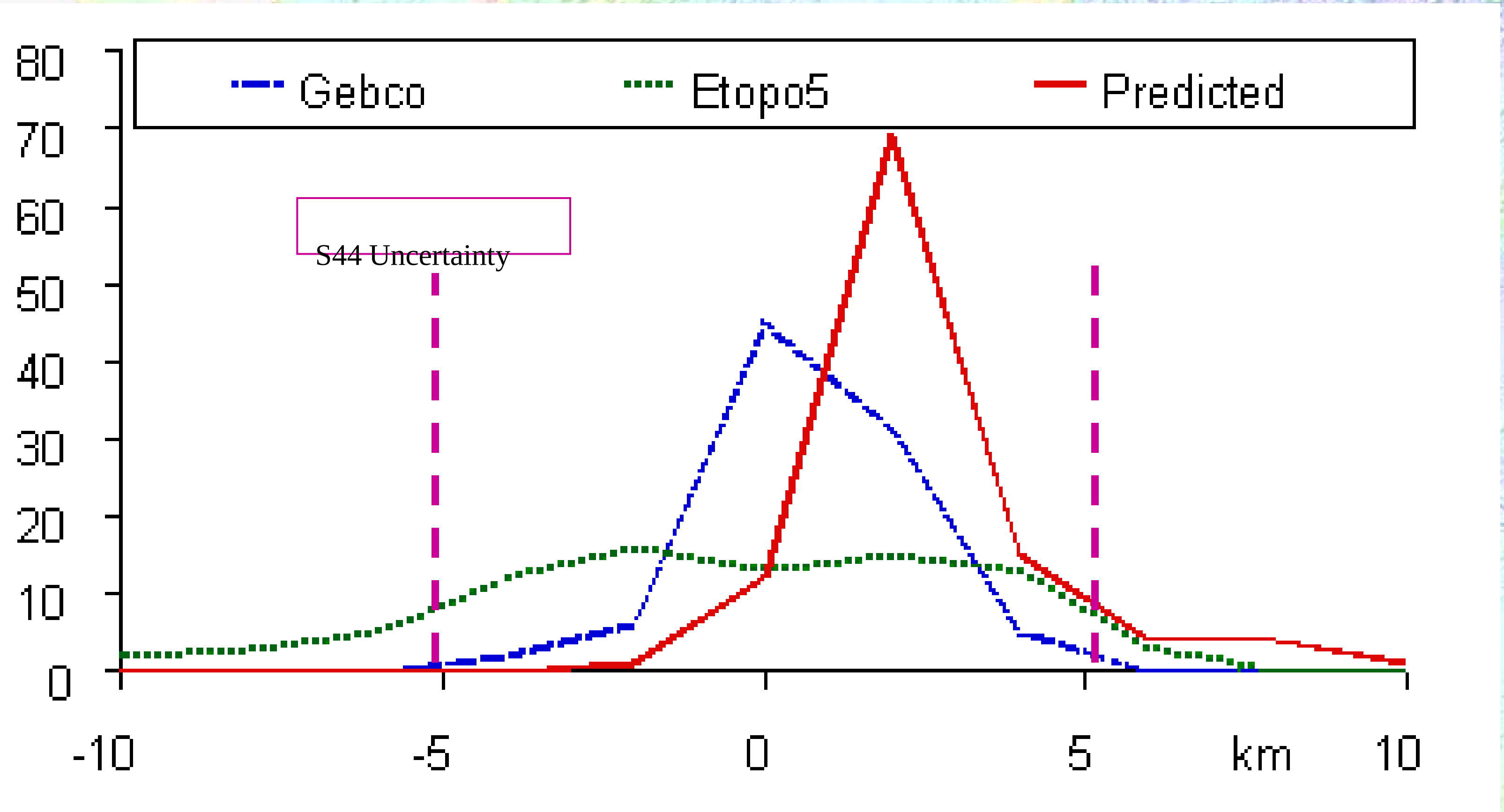
Equatorial Atlantic tectonic fabric



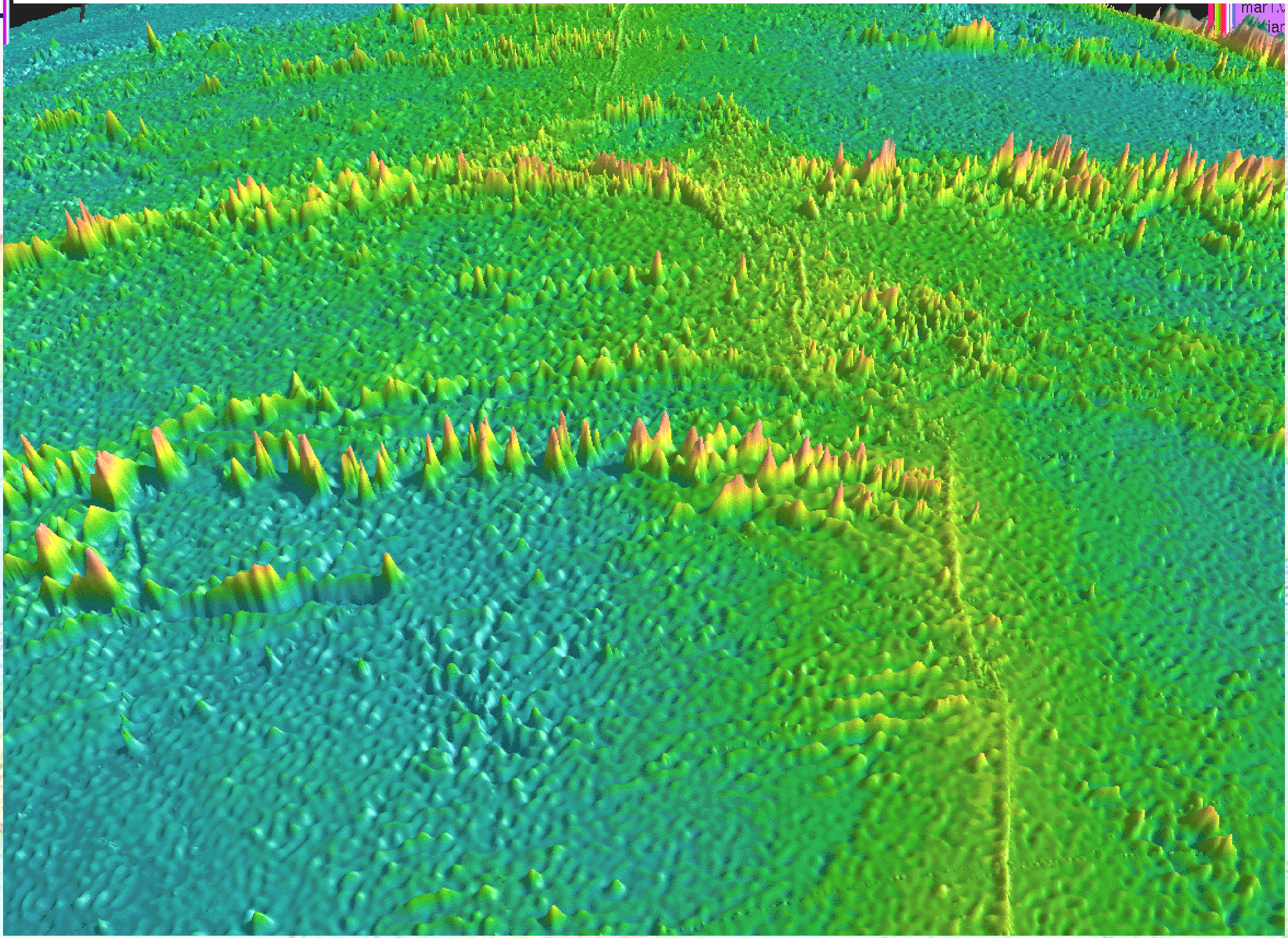


ETOPO5, Predicted, GEBCO and multibeam survey.

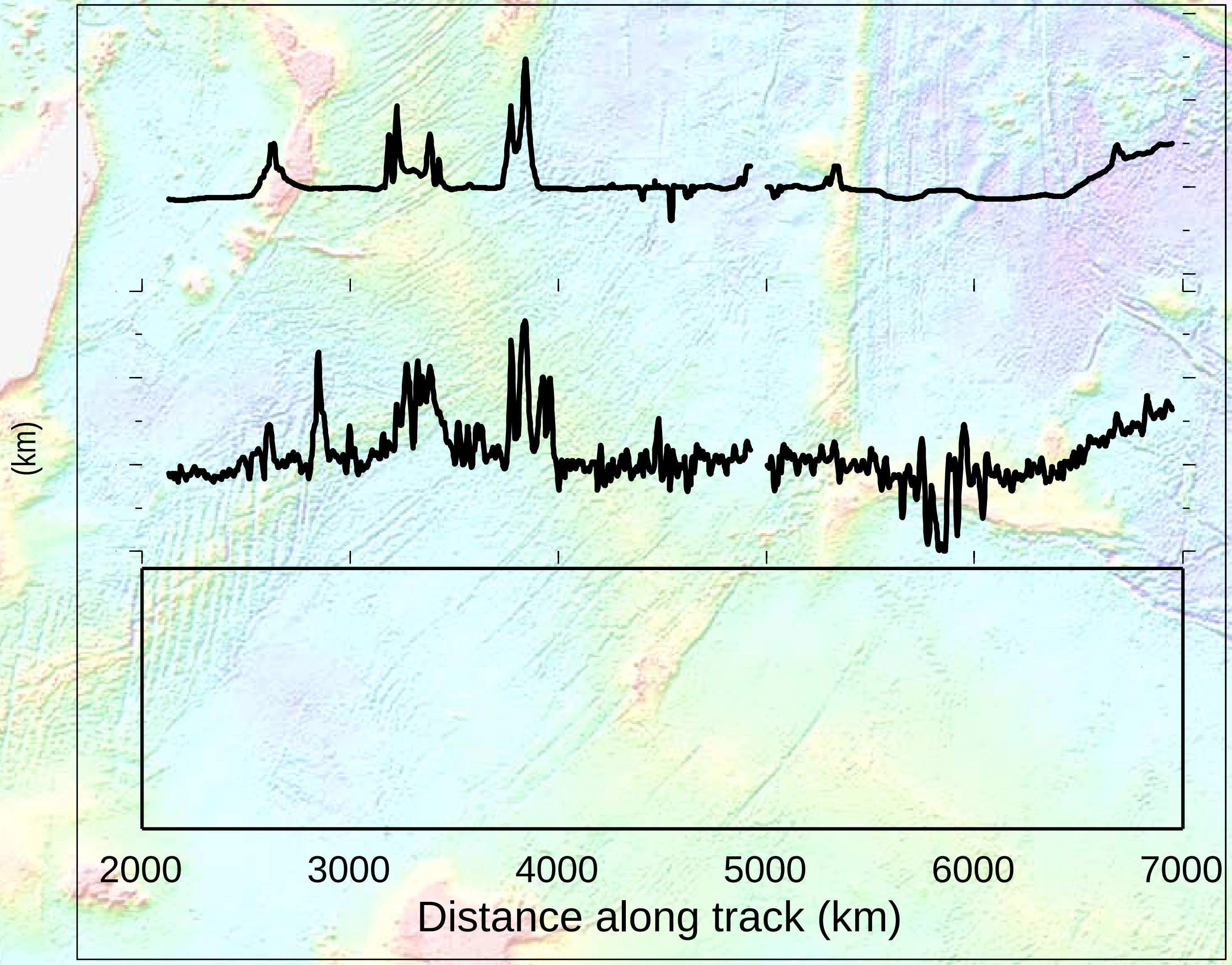
Multibeam is considered true and the displacement of the other three measured seawards (+) or landward (-).



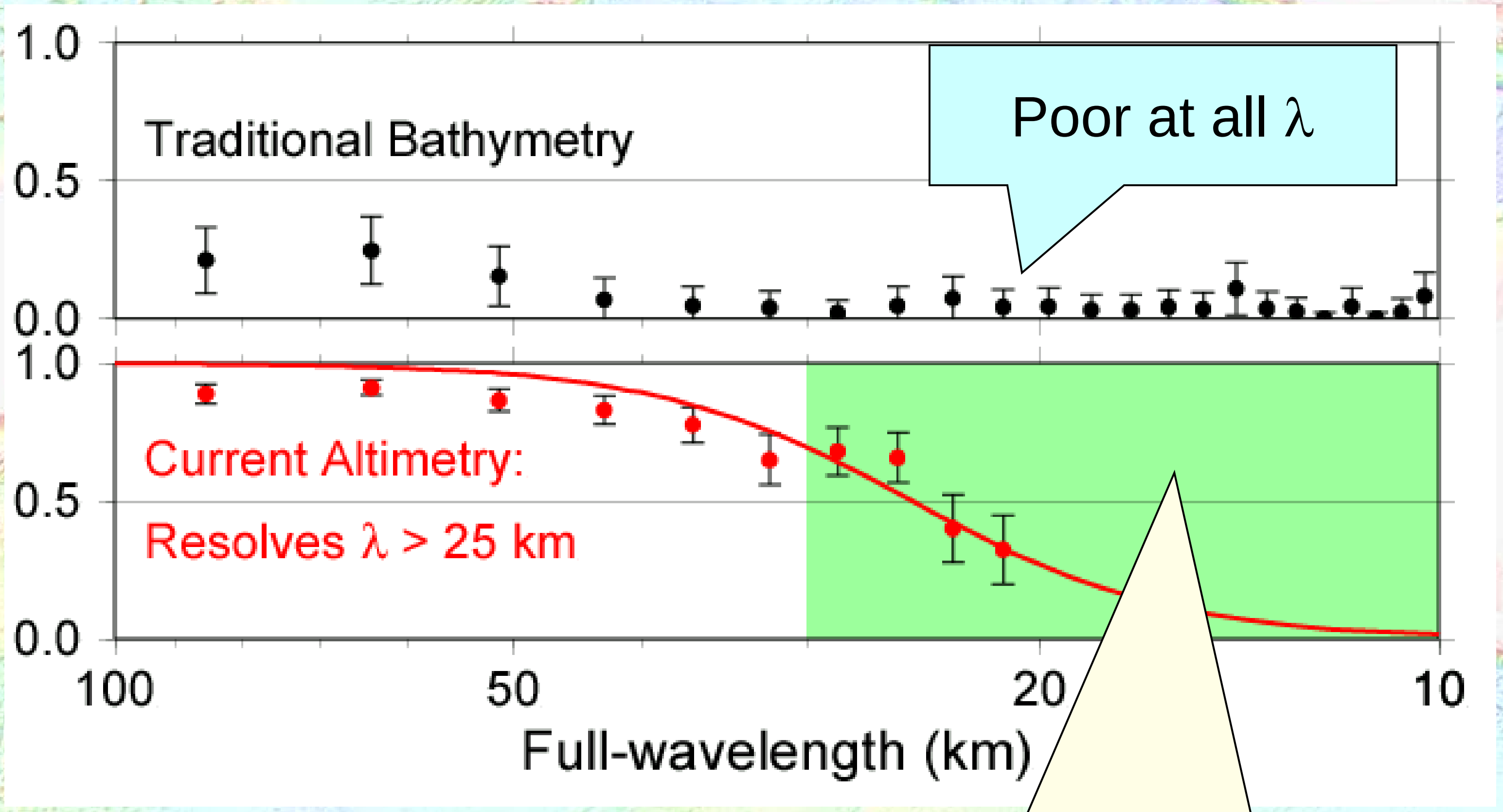
“Foundations” Seamounts



“Foundations” Bathymetry Profile

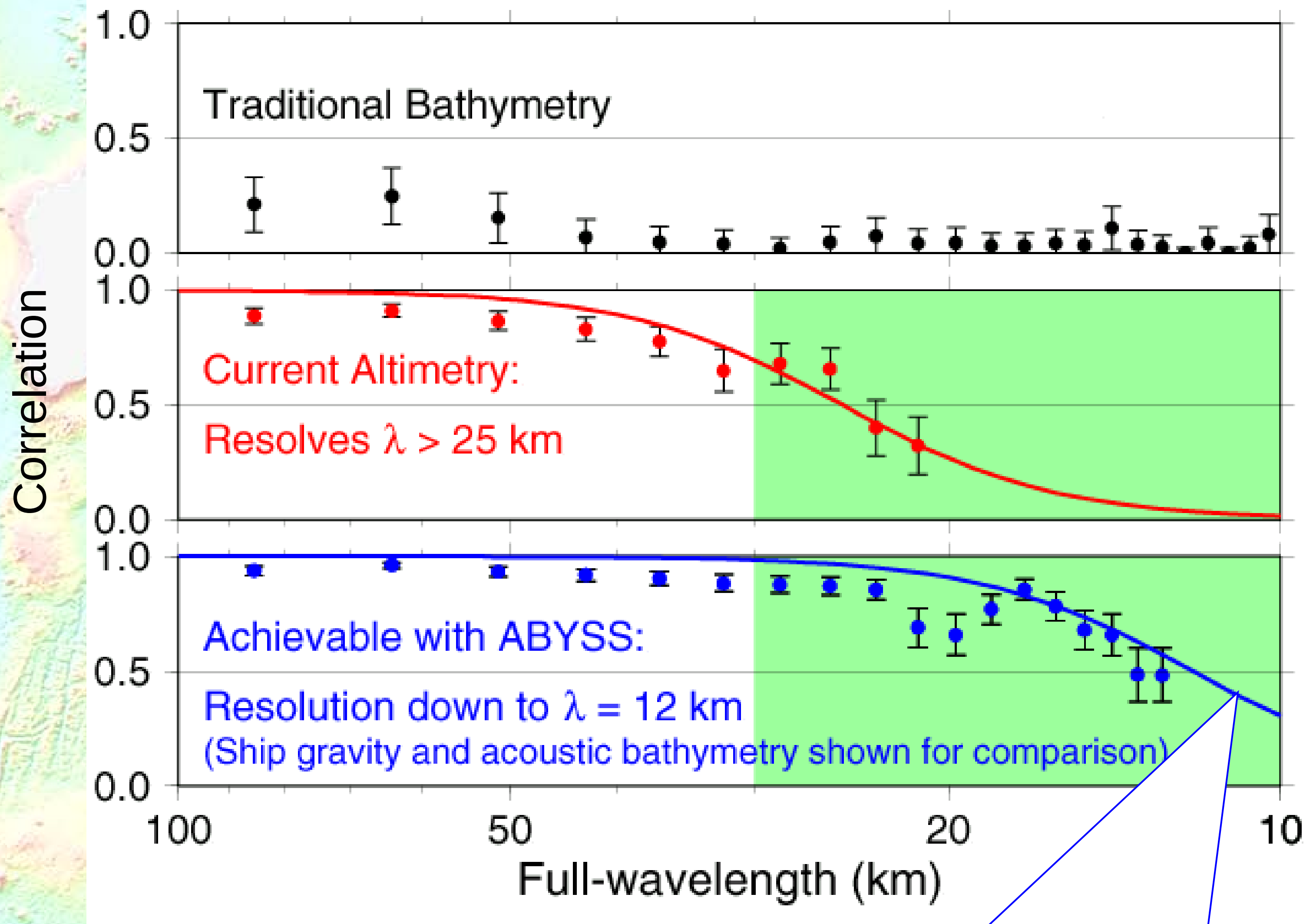


Profile Correlation by Wavelength



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)

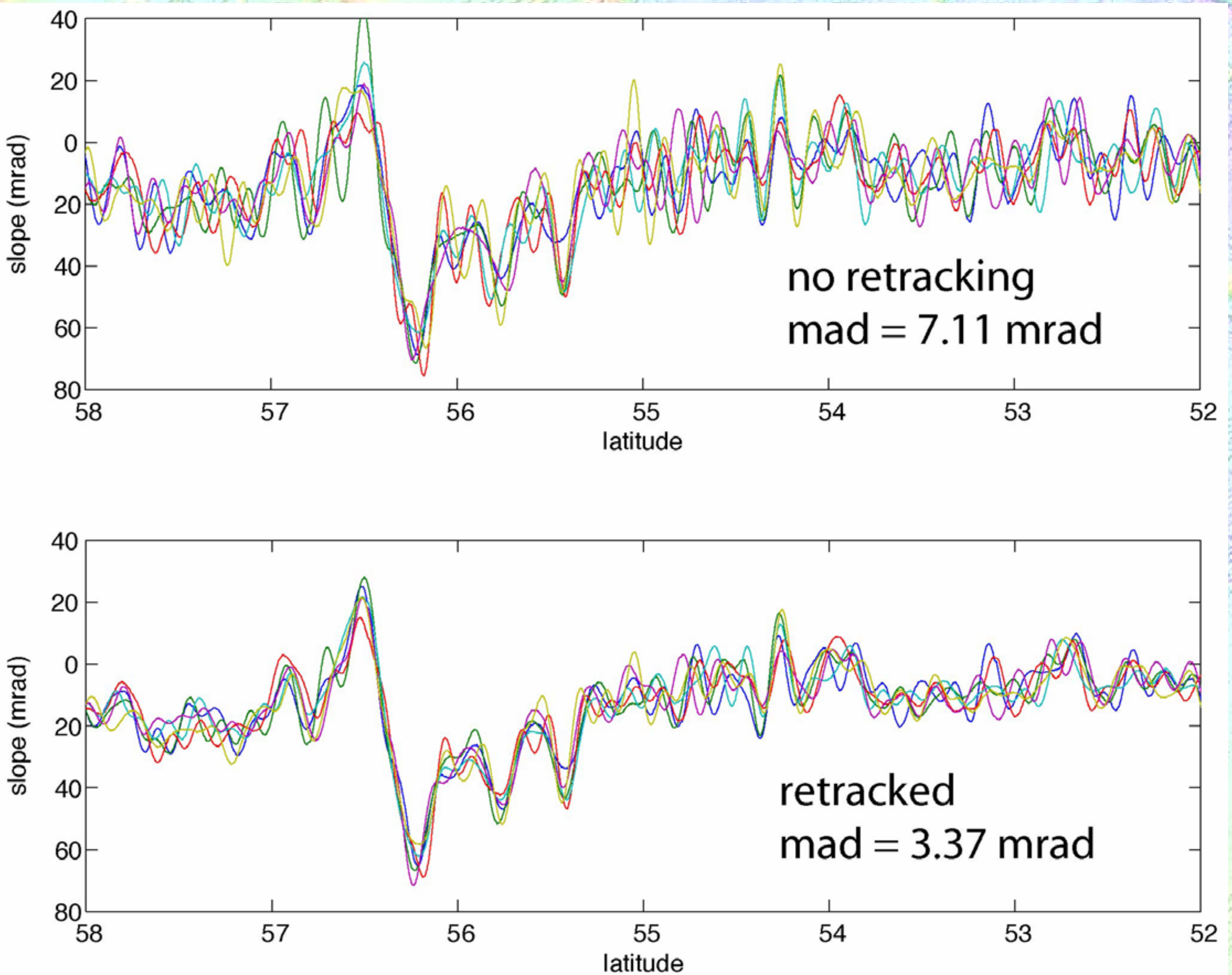


This limit is physical, not instrumental

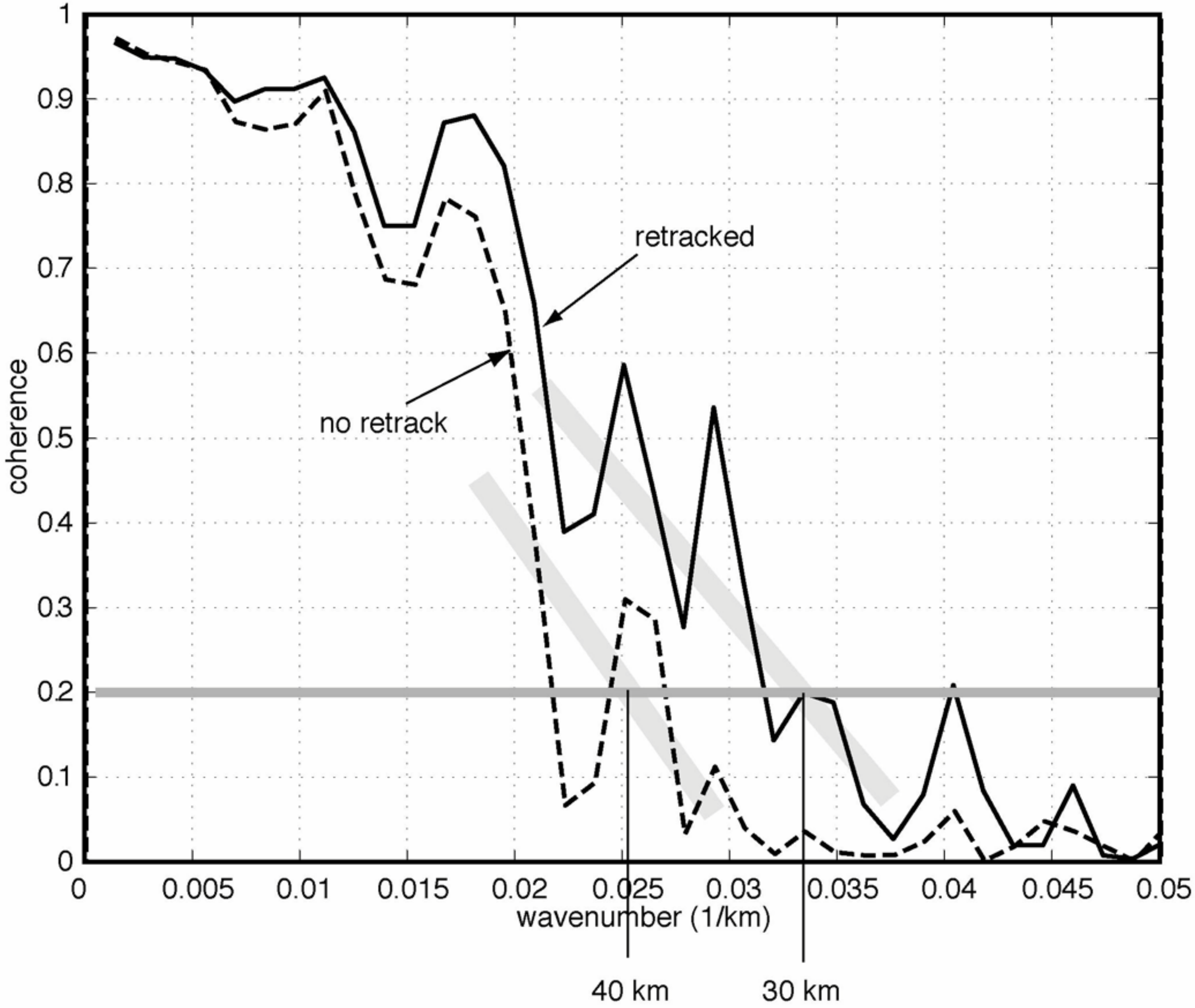
Current and Future Altimetry

- Existing data as commonly processed
  - “See” things larger than abyssal hills
  - Some isobaths may meet IHO standard S-44
- Improve existing data by “retracking”
  - Better editing; more near-shore recovery
  - Modest gain in precision; anisotropy remains
- Do a new, optimized mission (“ABYSS”)
  - Achieve resolution to the physical limit
  - “See” abyssal hill-scale fabric

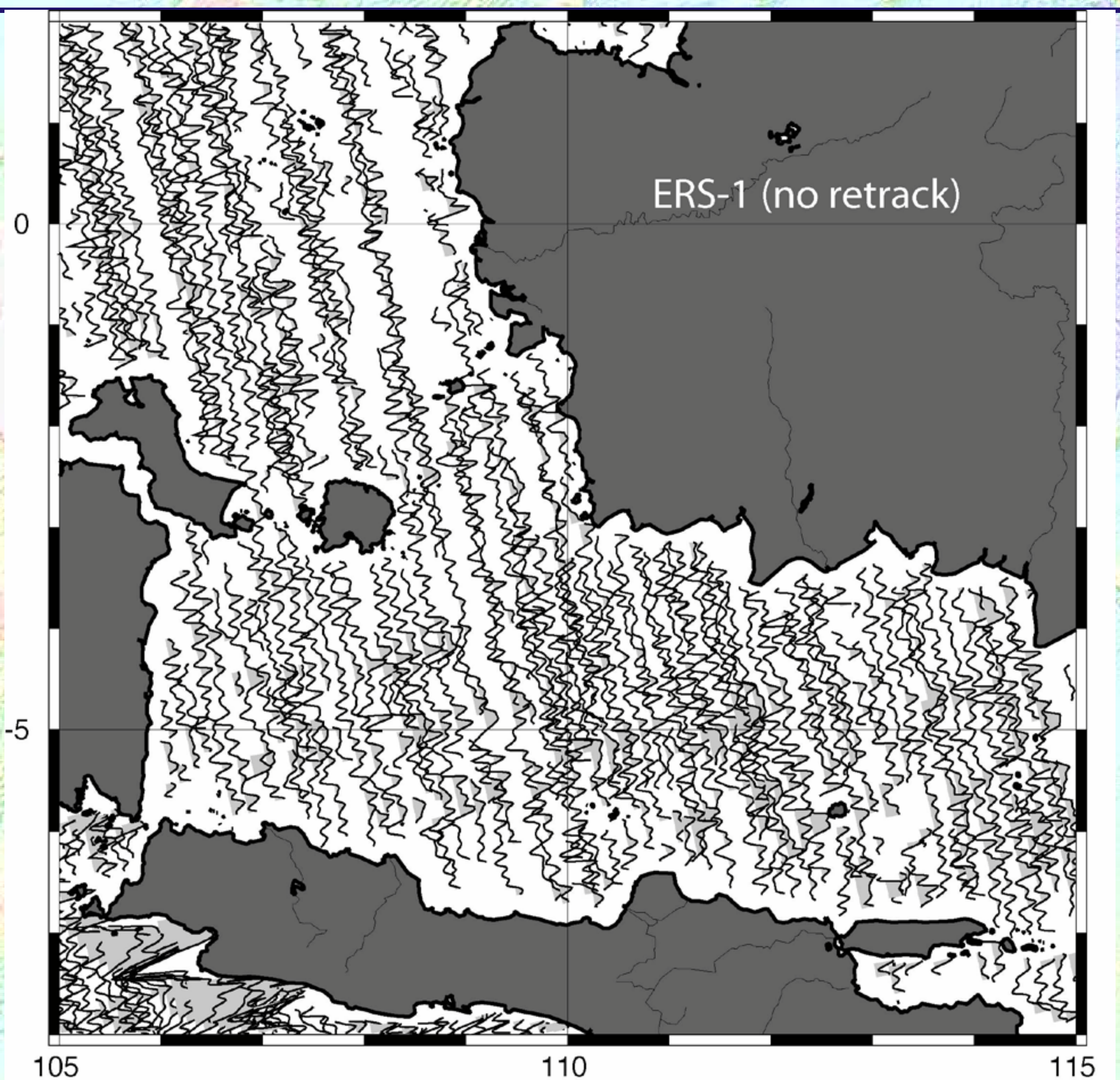
Pacific repeat profiles - accuracy



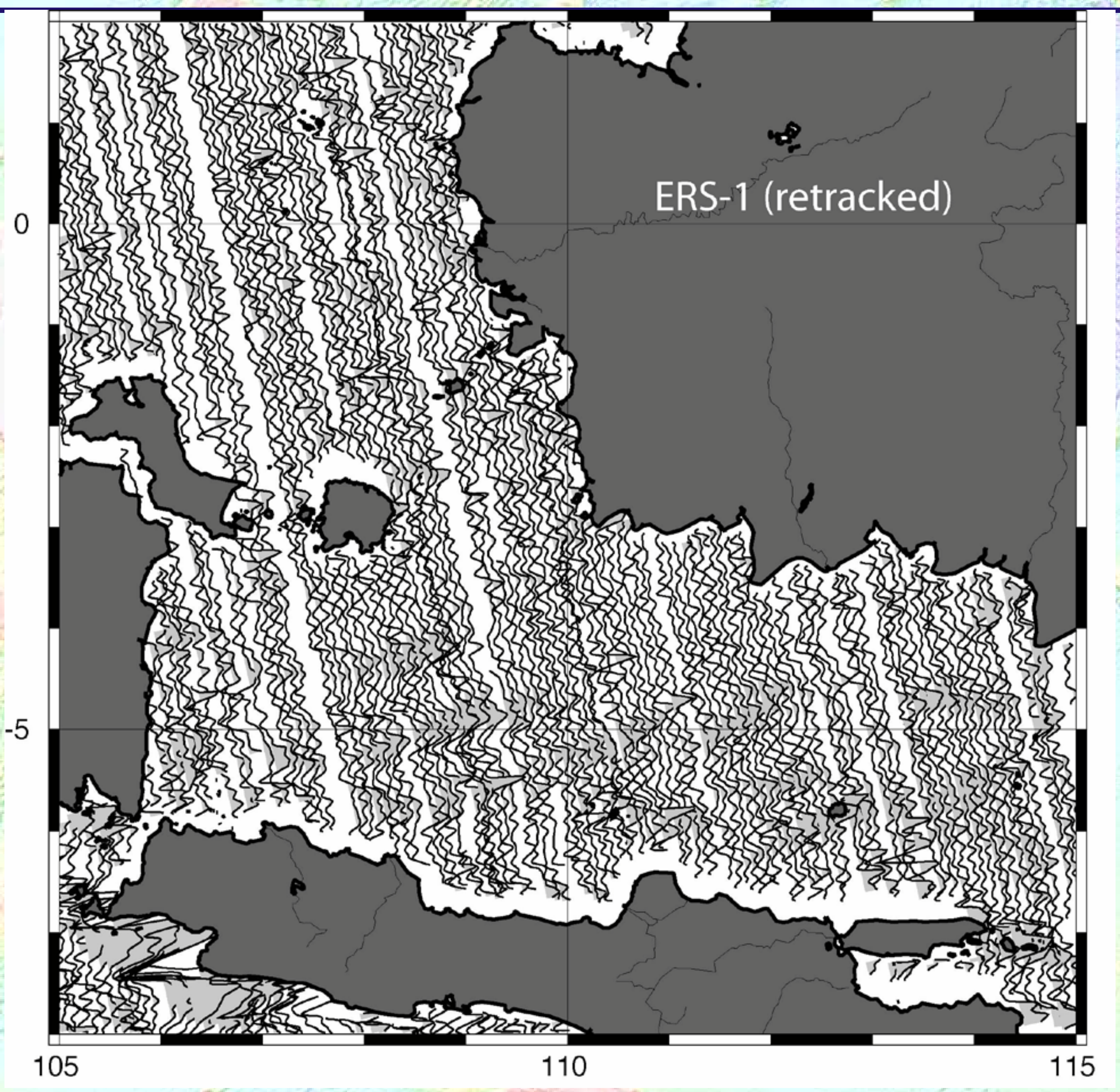
Pacific repeat profiles - resolution



ERS-1 profiles - no retrack

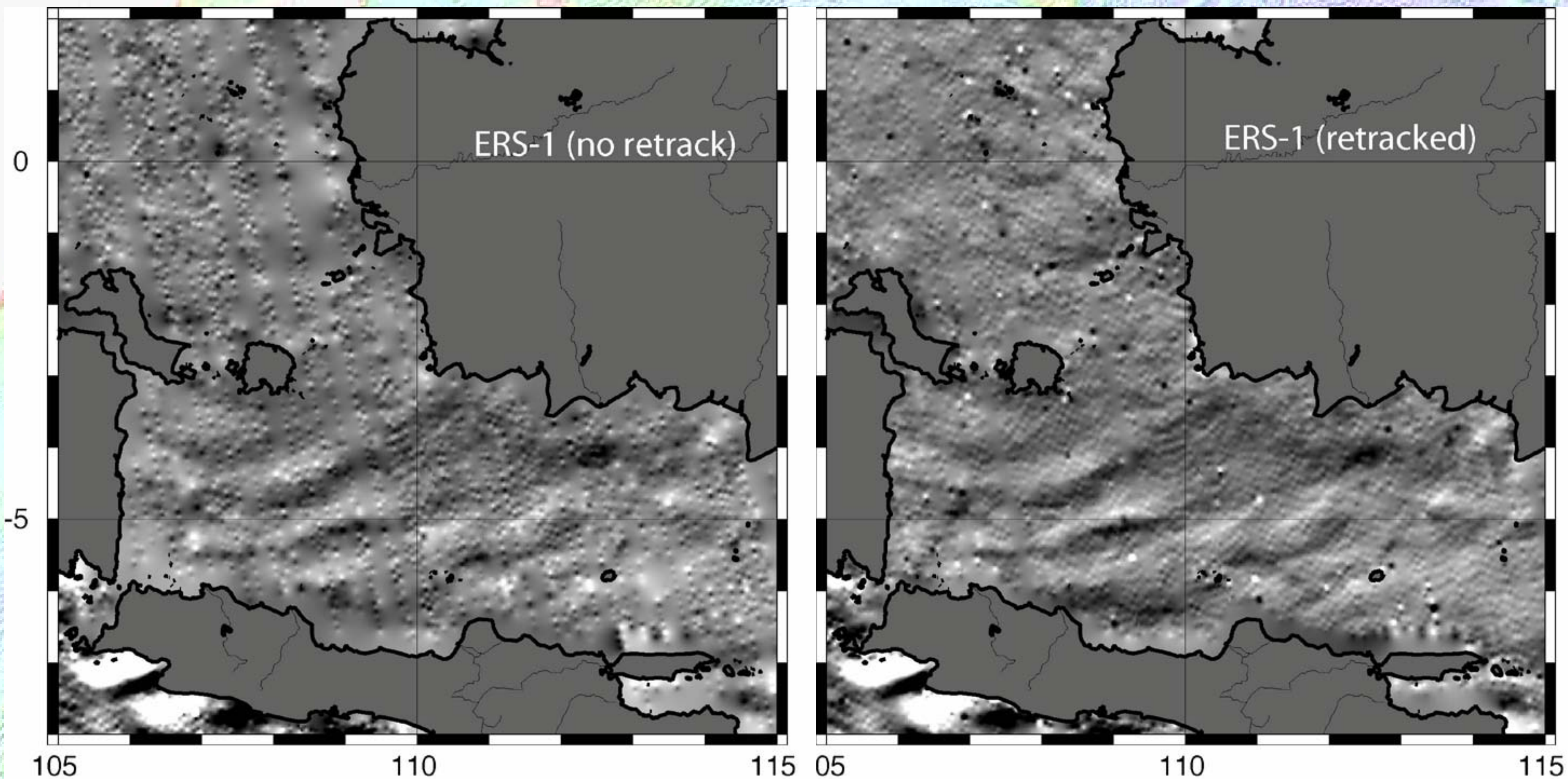


ERS-1 profiles -retracked

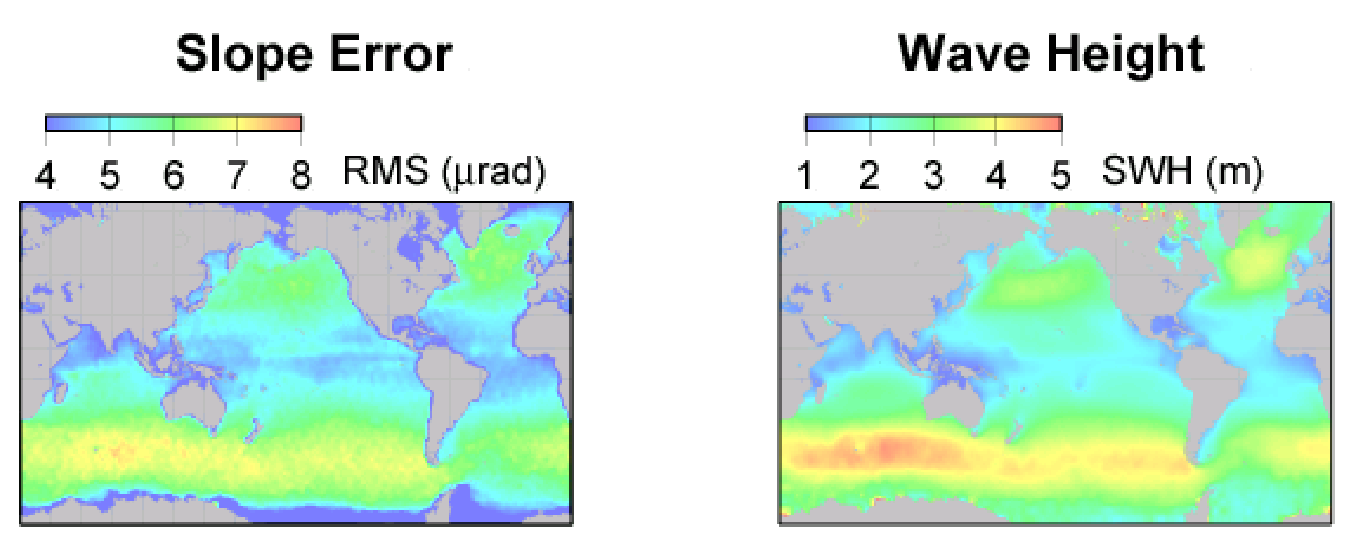


ERS-1 no retrack

ERS-1 retrack



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



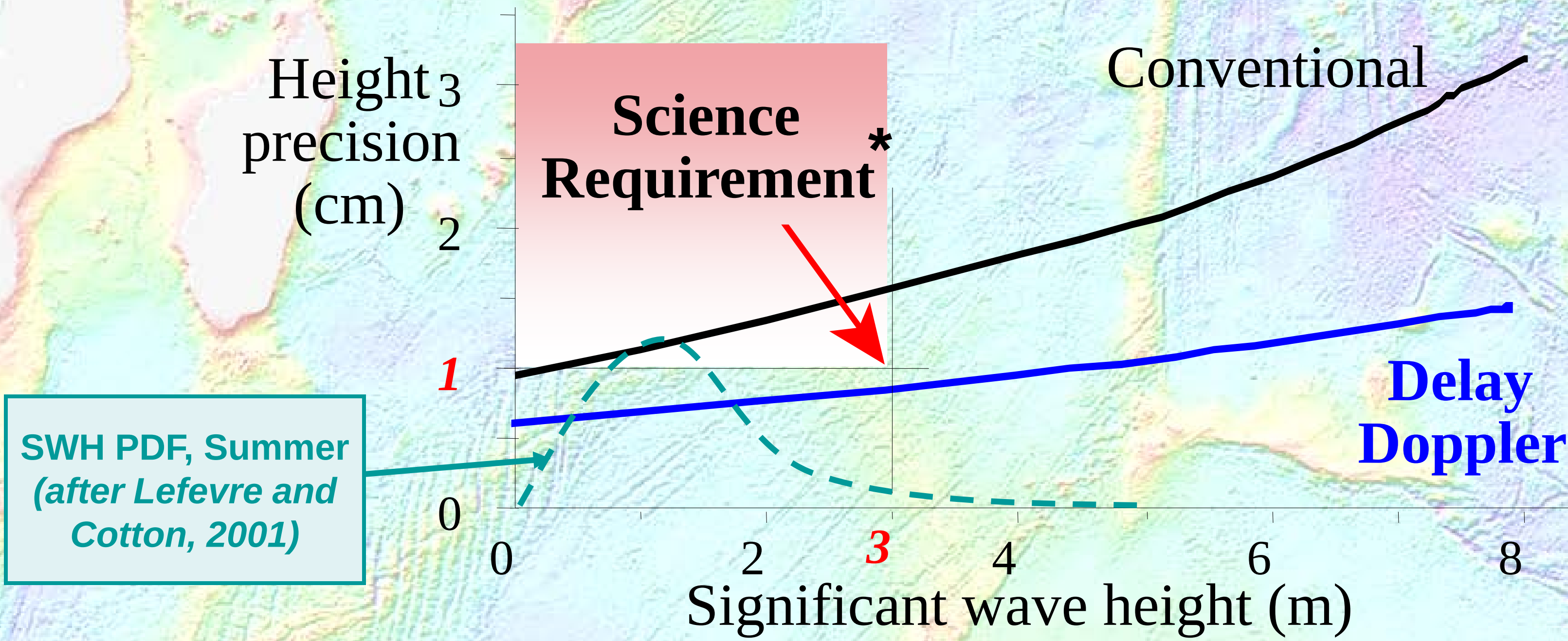
Map pattern of RMS slope error looks like map of wave height, but does not resemble pattern of variability of currents, ionosphere, etc.

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.

ABYSS Altimeter Height Precision

1-second average, ISS orbital parameters (height and velocity)

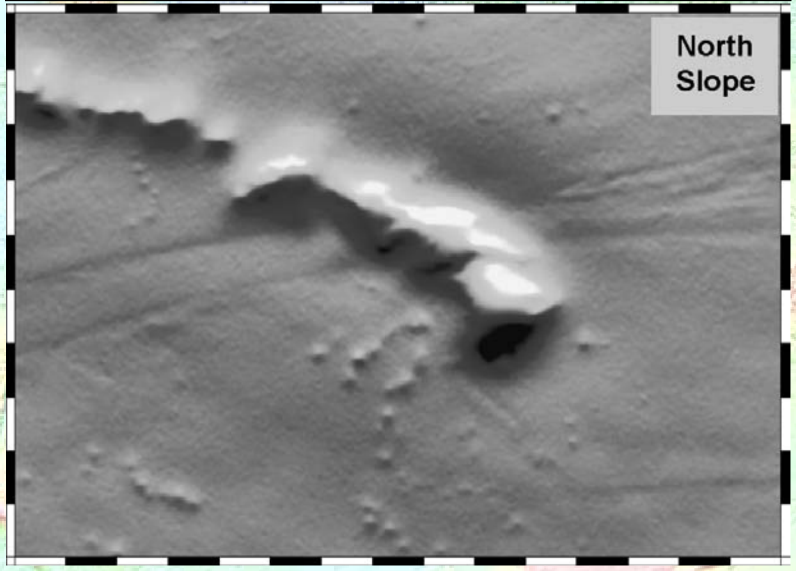


> Acceptable precision AND less sensitivity to SWH !

* *Derived from white Gaussian noise process over the ABYSS band*
$\rightarrow$ *one-sigma 1μrad slope error ~1-cm height precision*

Existing data have anisotropic slope resolution due to too-polar orbital inclination

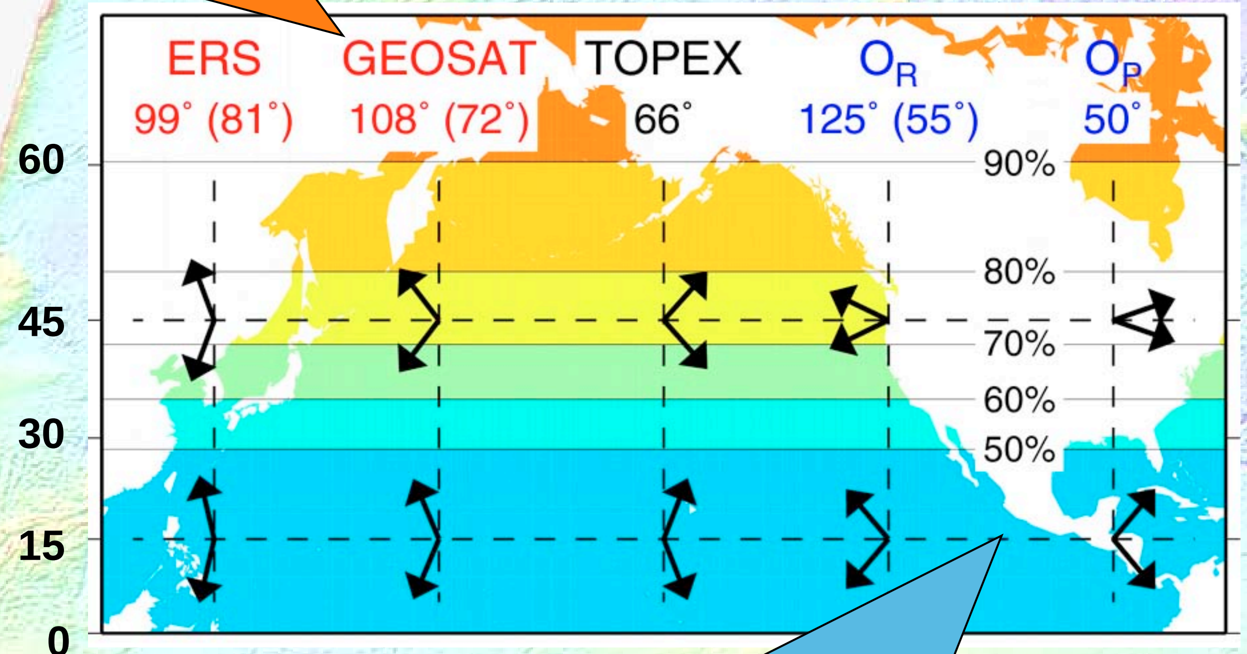
Current altimeters provide ~3 X higher noise in the east slope than in the north slope because of their high inclination orbits.



ABYSS will reduce the noise by a factor of 6 in the east slope and a factor of 3 in the north slope.

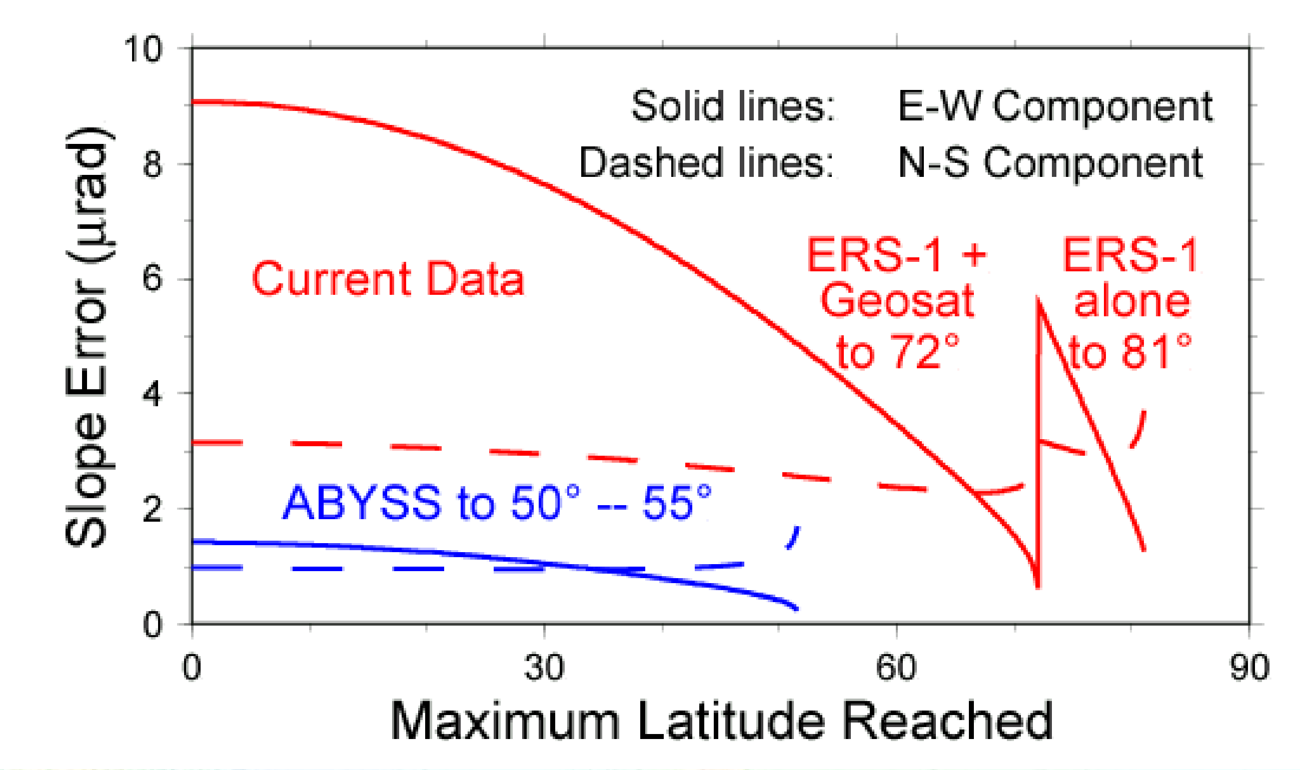
Track Crossing Angle Depends on Inclination and Latitude

Nearly orthogonal in a small area of ocean



Nearly orthogonal over a large area of ocean

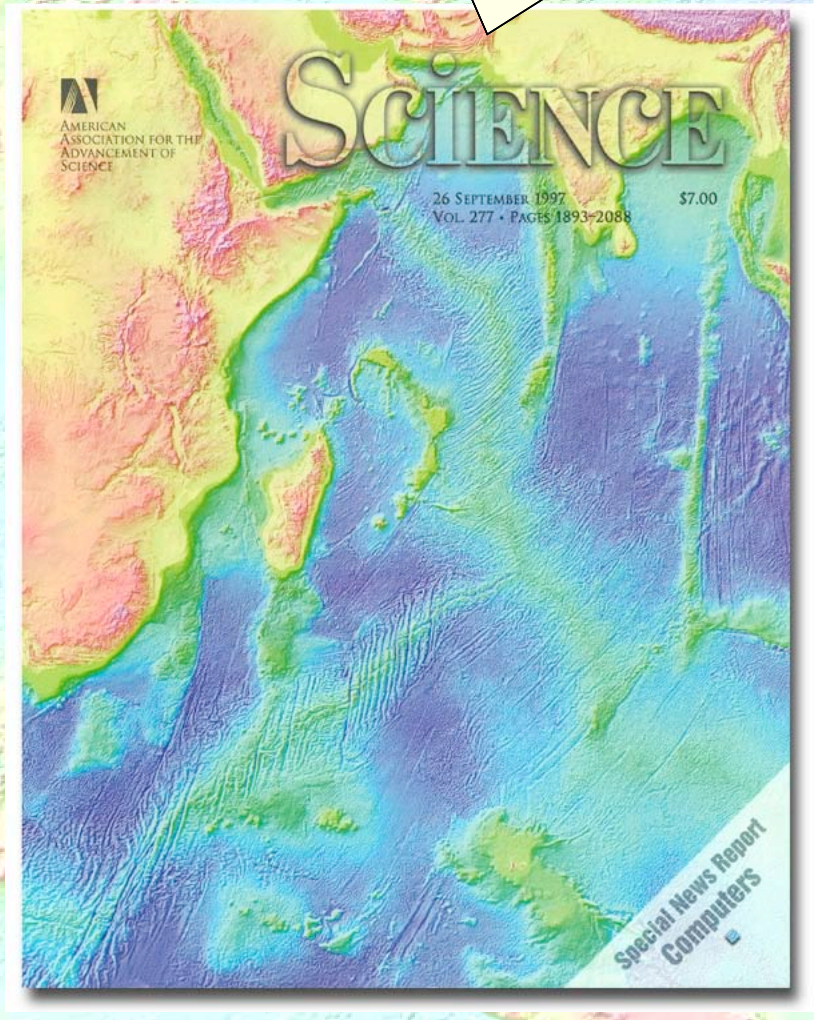
Optimal Orbit Covers the Key Areas



ABYSS gets more precise slopes, and more nearly equalizes N and E errors, in the band of latitudes where existing data are poor (80% of ocean area), optimizing resolution.

Altimetric bathymetry: not done yet!

Altimetric Bathymetry



- **A proven technique**
- **Needs only simple altimetry (Geosat, w/ no troposphere or ionosphere measurement, did just fine.)**
- **Has resolved many interesting tectonic features**
- **1st order plate tectonics confirmed**
- **2nd order mysteries found**

We can do better! Abyssal hill scales still to come.