Satellite Altimetry and the USS *San Francisco* accident: assessment of existing data and work plan for next steps

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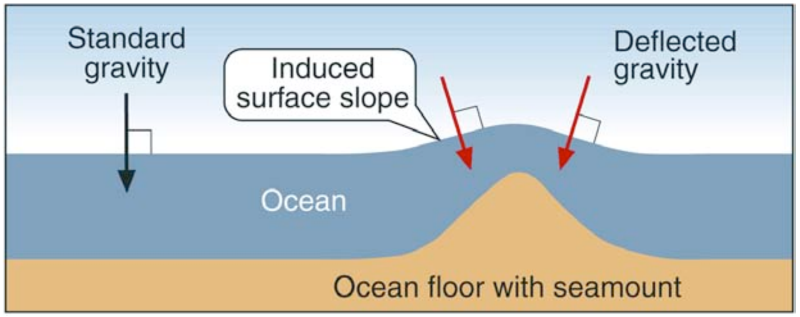
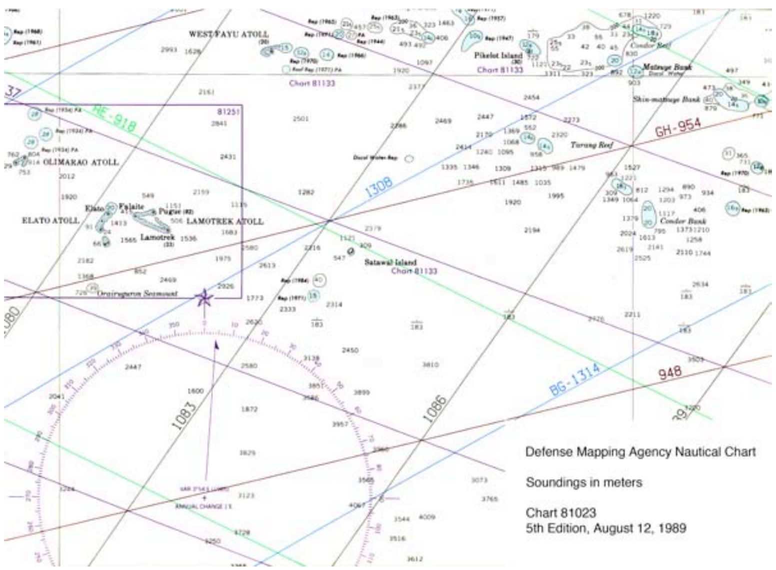
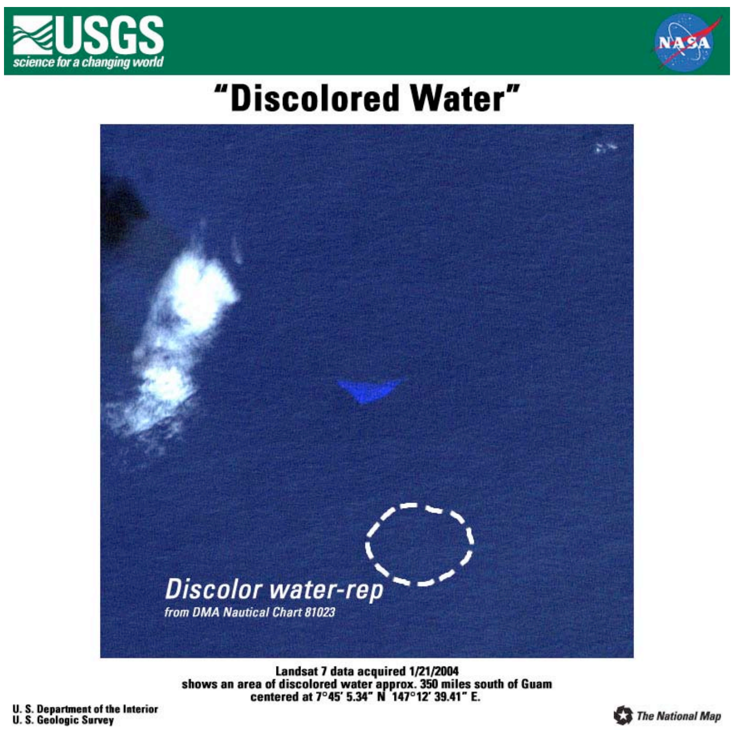
Outline

- Vertical Deflection, Gravity & Bathymetry at *San Francisco* accident site
- How to make these products better:
  - Near-term work plan
  - Ultimate goal: new delay-Doppler altimeter mission
- Seamounts important for tsunami hazard as well as submarine navigation

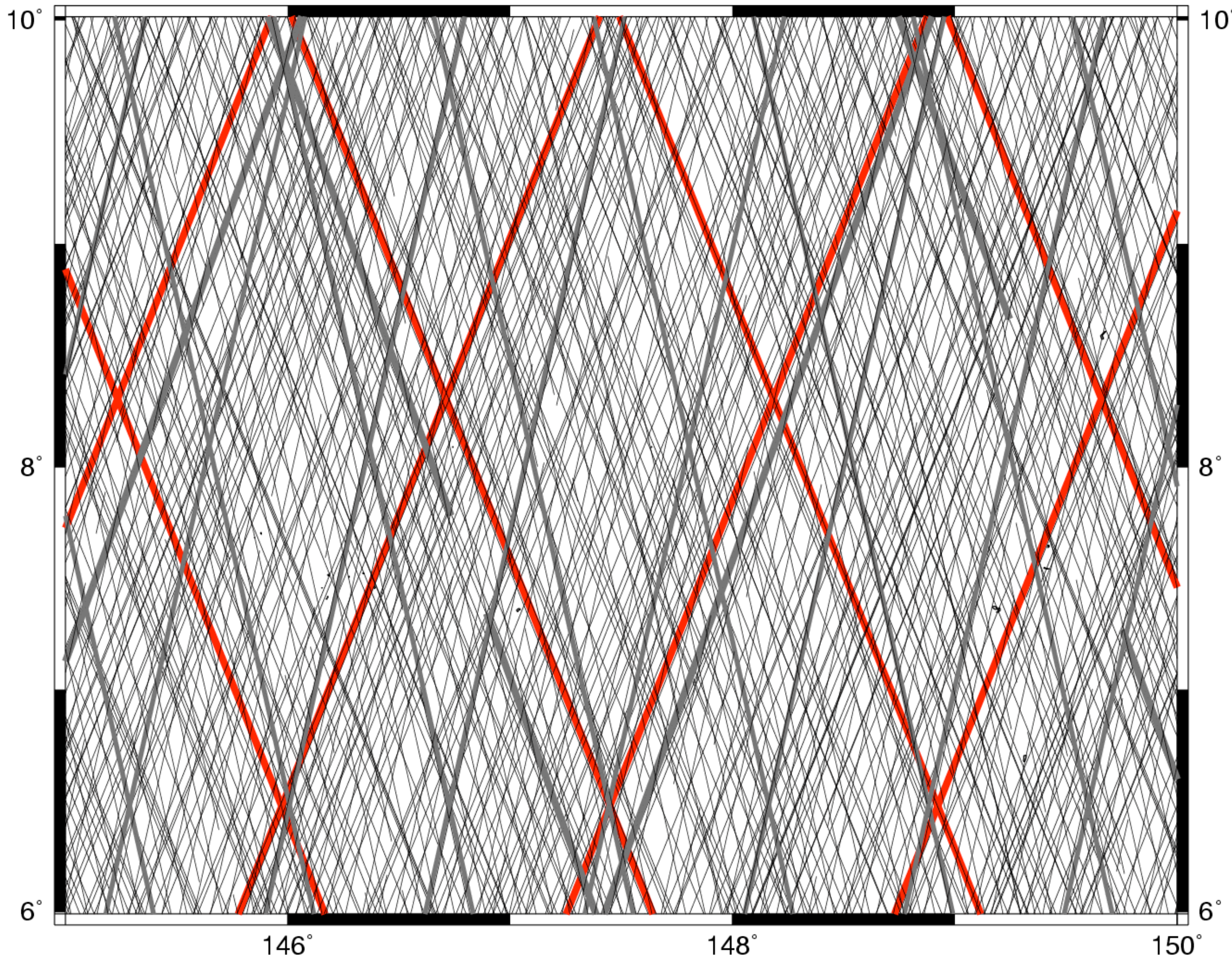
VD, G, and B in collision region







Altimeter tracks near SSN711 site

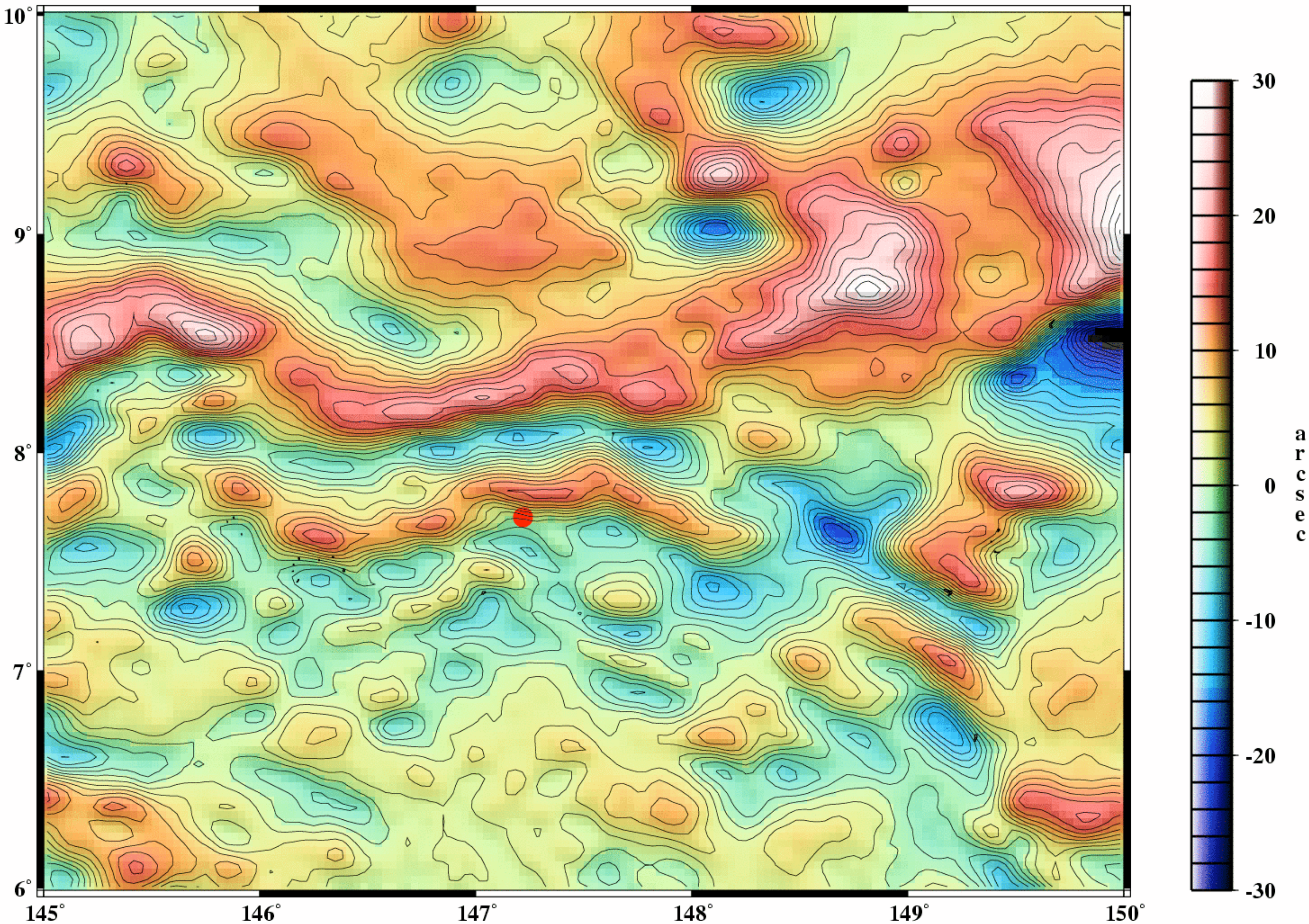


Geosat ERM & GFO in red.

Other exact-repeats grey.

Geodetic Mission tracks are single lines.

VD in N-S plane, "ξ", positive south



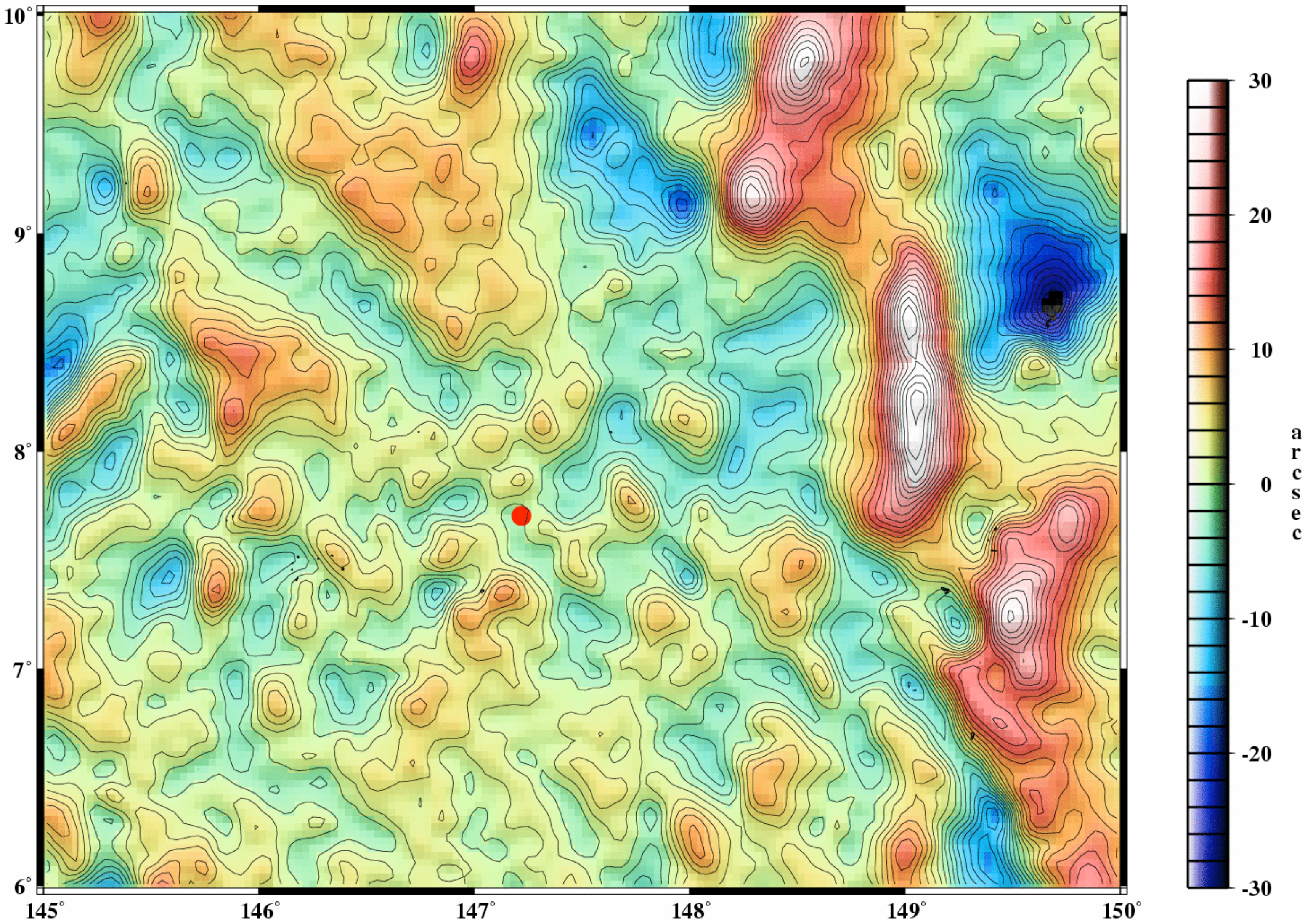
North Vertical Deflections, Version 14.2 C.I.=2 arcsec

+15 arc-sec near "discol. water" site (red dot).

+/- 34 in area.

ξ is <10 over most (95% ?) of Earth.

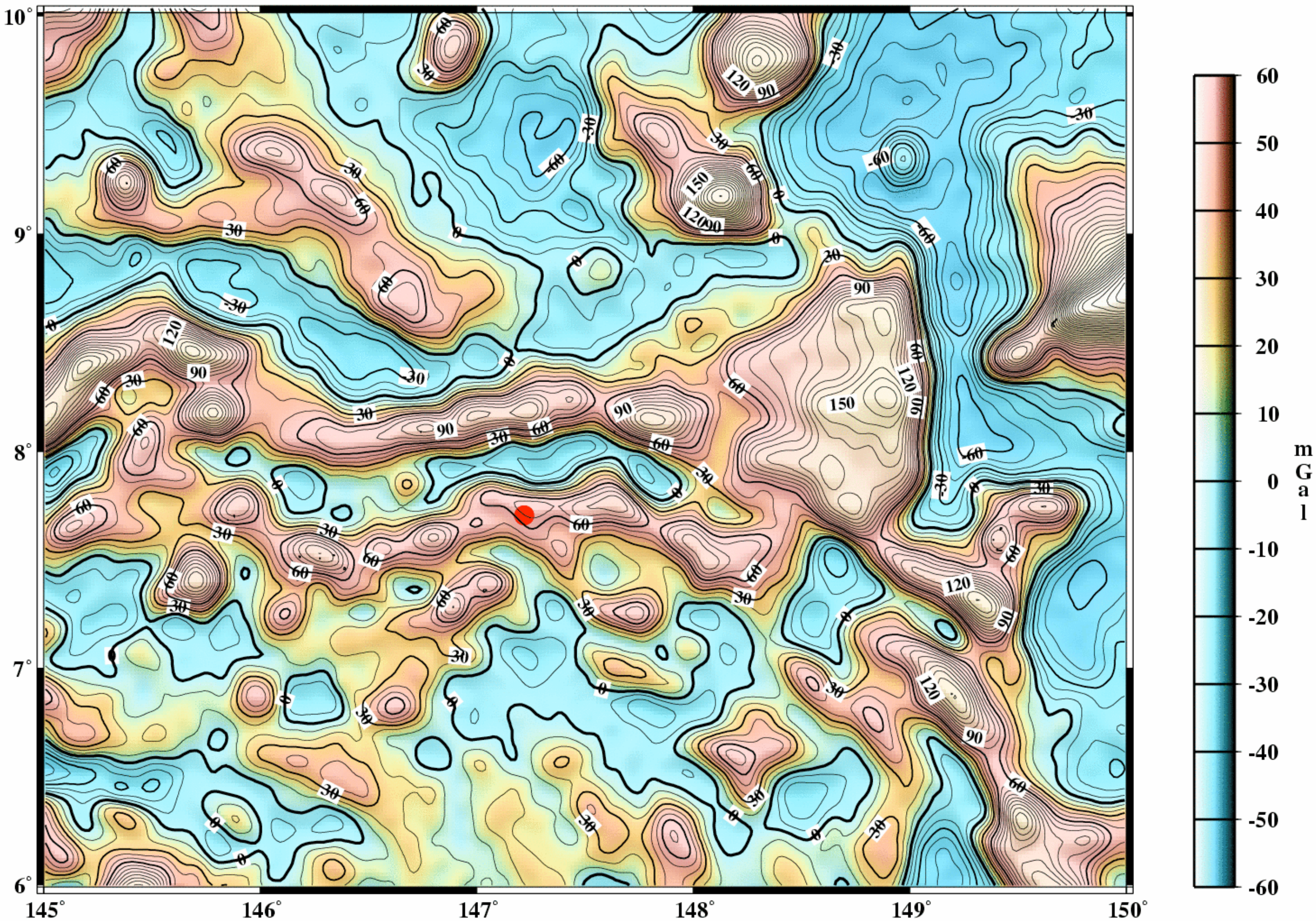
VD in E-W plane, η



East Vertical Deflections, Version 14.2 C.I.=2 arcsec

We can combine north and east VD to estimate gravity anomalies. (next slide) These can be checked against shipborne gravimetry.

Gravity anomaly from VD

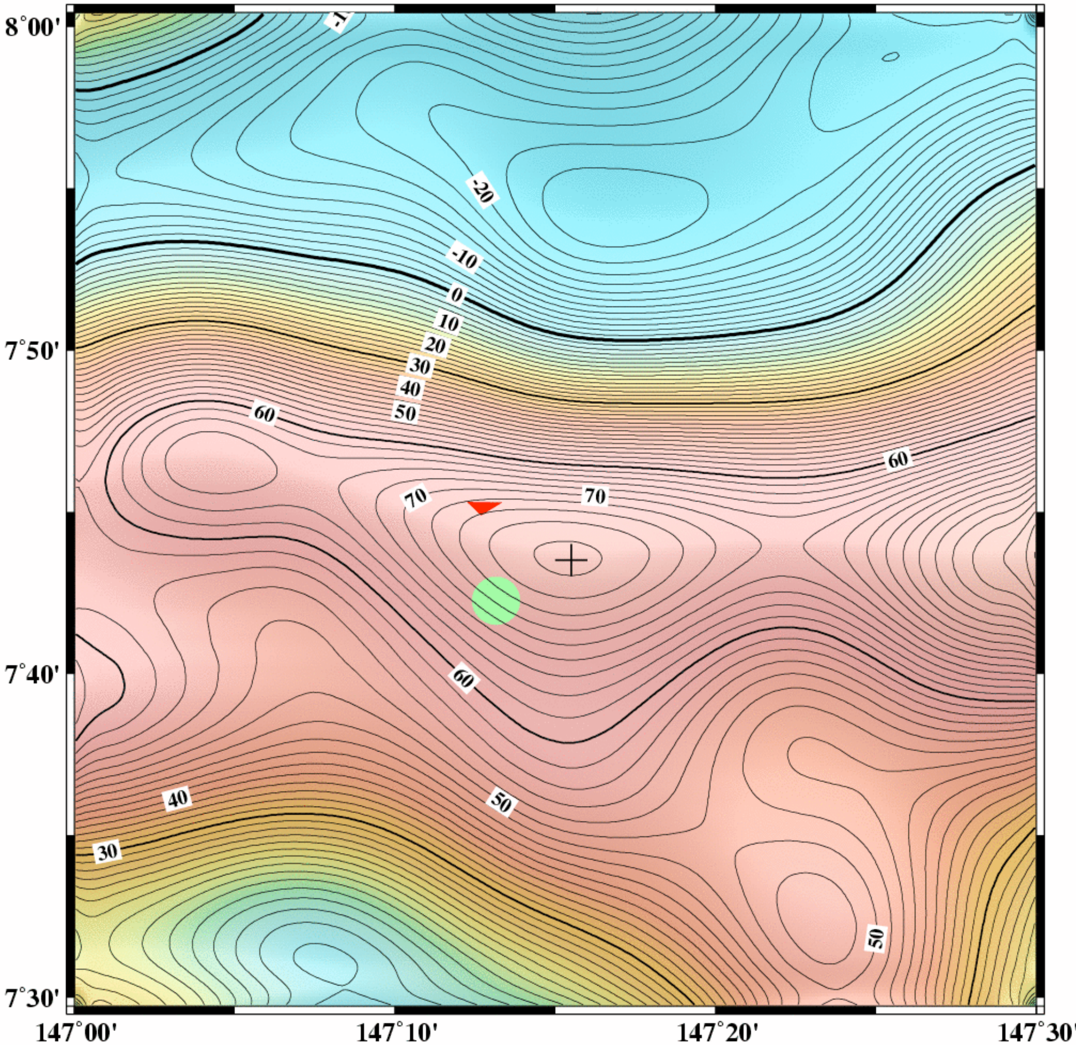


Gravity, Version 14.1 C.I.=10 mGal

Local max. ~+79 mGal at site. E-W trending features w/ >100 mGal relief in the area of site.

Expect to find ~ 2 km of relief on sea floor at these ridges.

Gravity maximum near collision



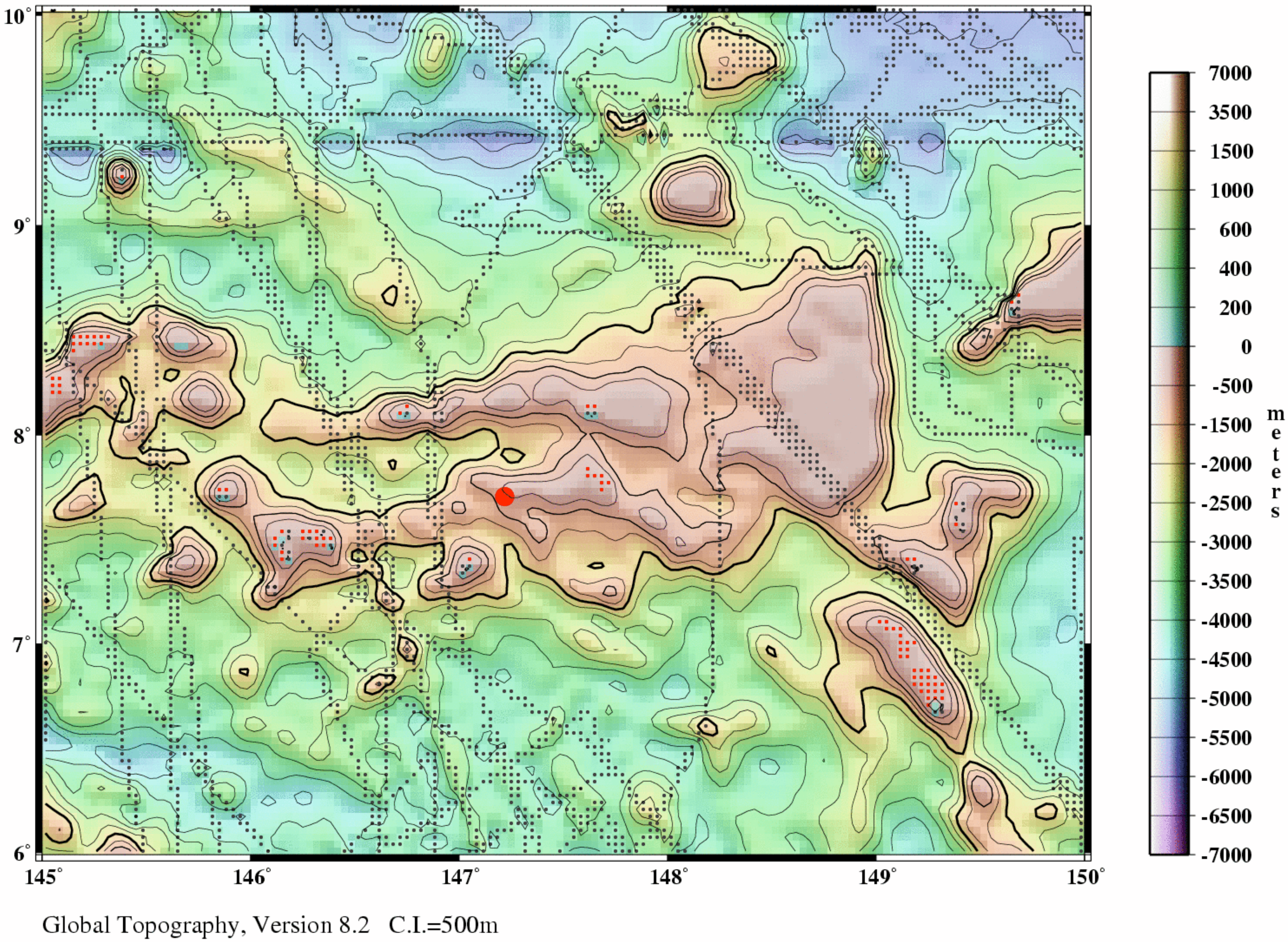
Gravity, Version 14.1 C.I.=2 mGal

+79mGal @ 7°43'30"N, 147°15'30"E. Gravity maximum may be skewed toward resolved center of mass of seamount; not shallowest point.

3 n.m. from Landsat shoal (triangle, actual size); and DMA chart 81023 discolored water report (circle, actual size).

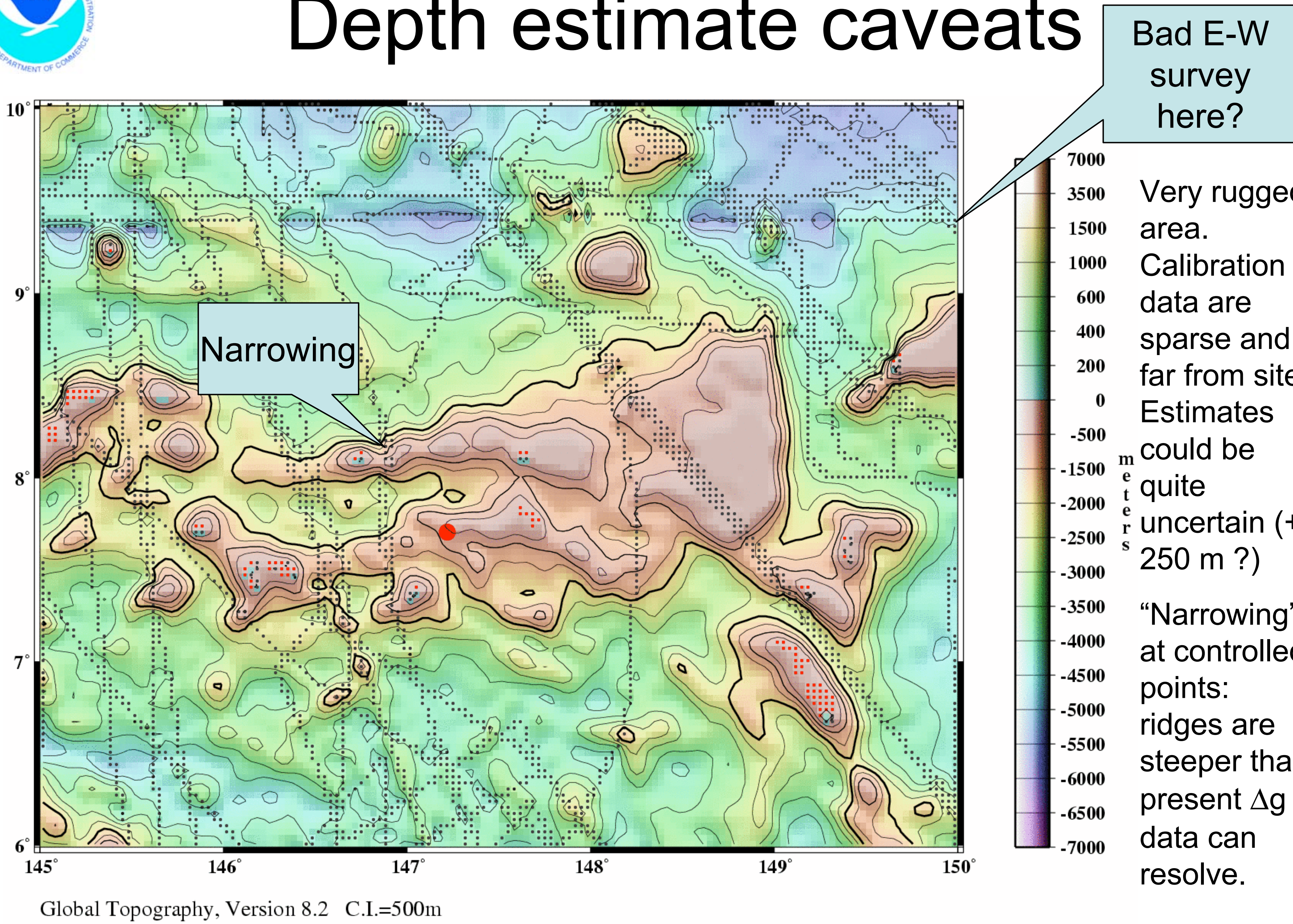
Note large gravity gradient in area: 100 mGal in 10 n.m.

Depth estimate from gravity



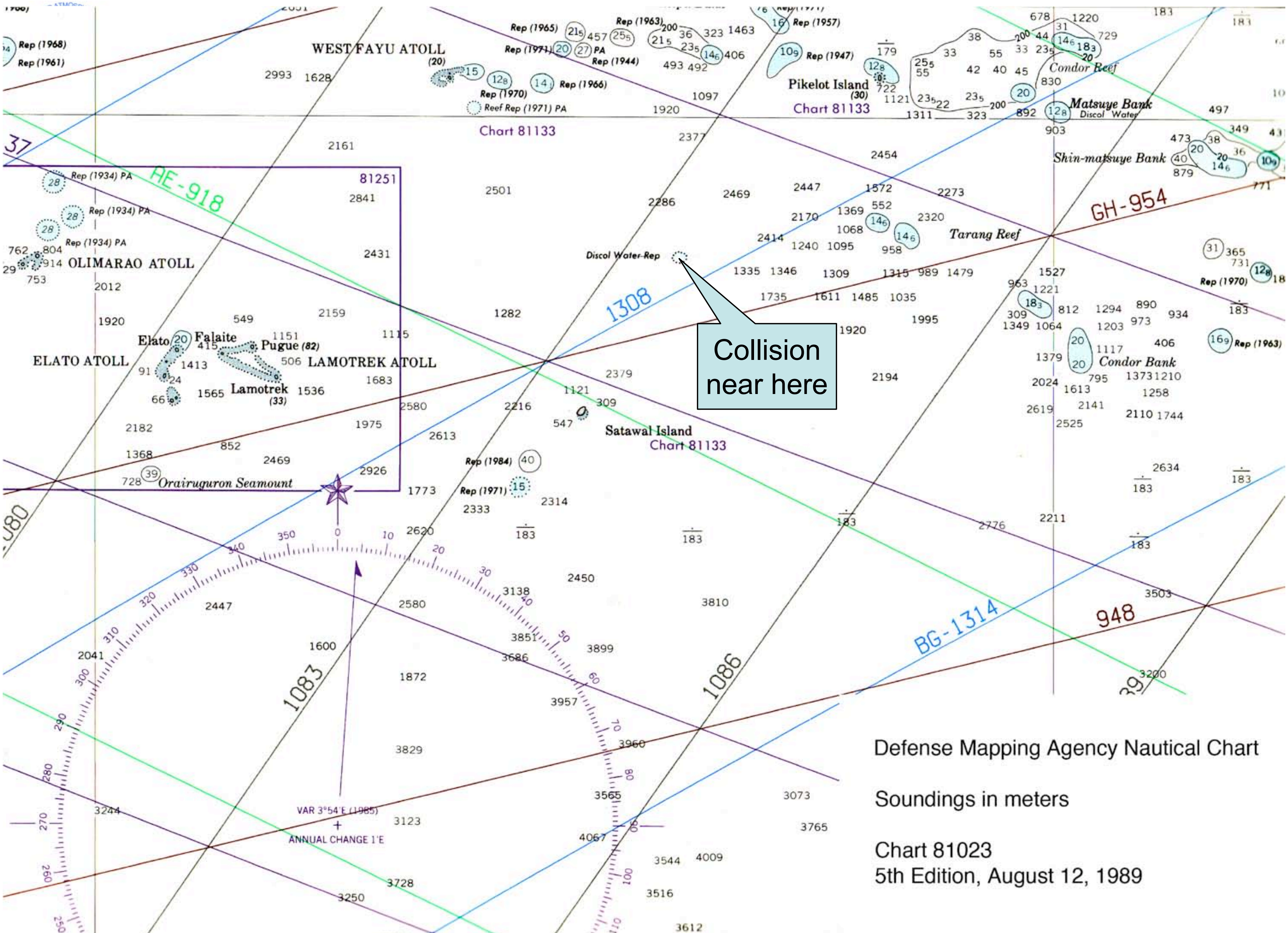
Requires ground-truth for calibration: soundings (black dots) and reefs (small red dots). A ridge is expected to run from Tarang Reef to site following trend of gravity anomaly.

Depth estimate caveats



Very rugged area. Calibration data are sparse and far from site. Estimates could be quite uncertain (+/- 250 m ?)

"Narrowing" at controlled points: ridges are steeper than present Δg data can resolve.

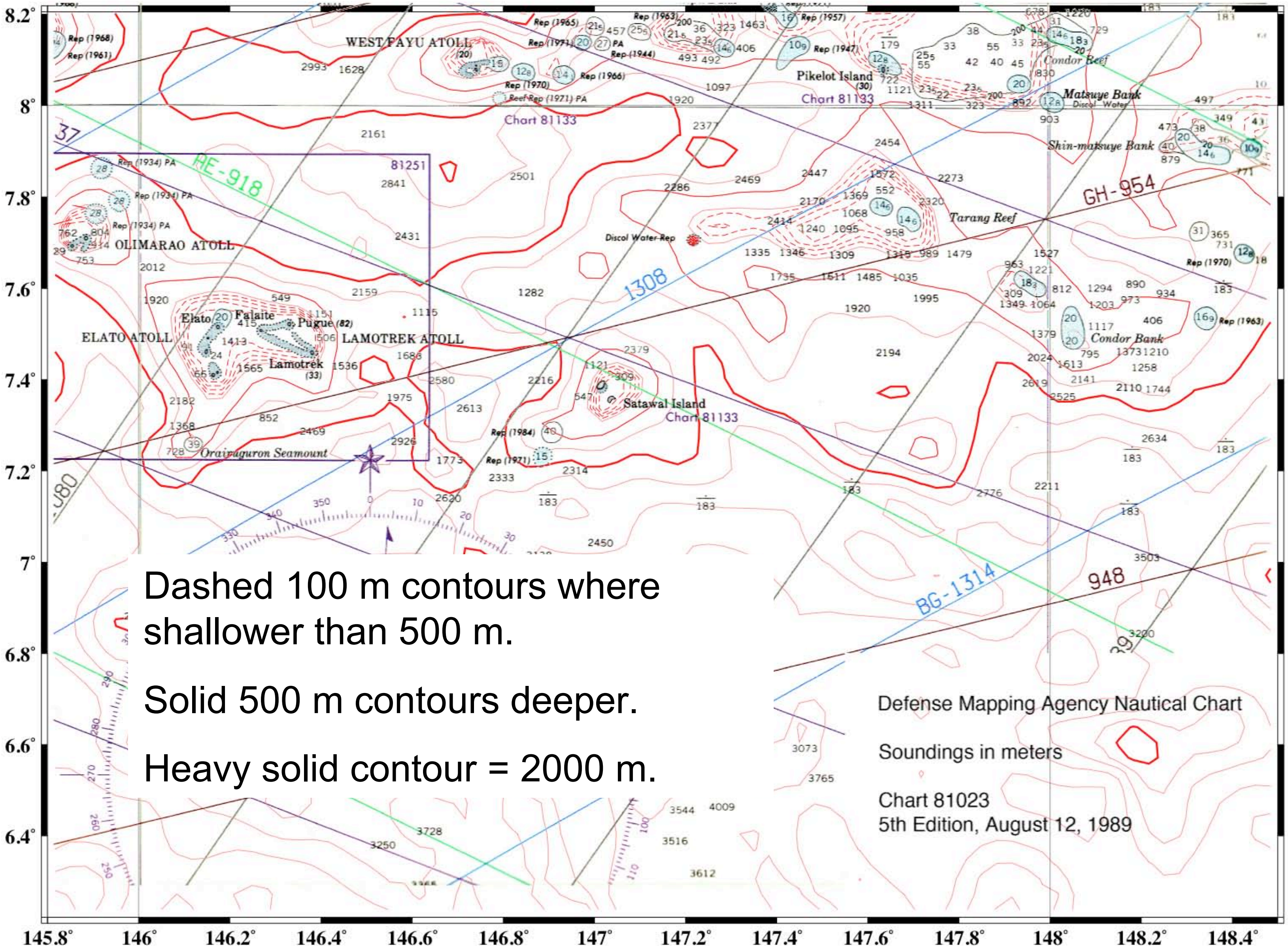


Defense Mapping Agency Nautical Chart

Soundings in meters

Chart 81023
5th Edition, August 12, 1989

Estimated depth from altimetry (contours) on DMA chart

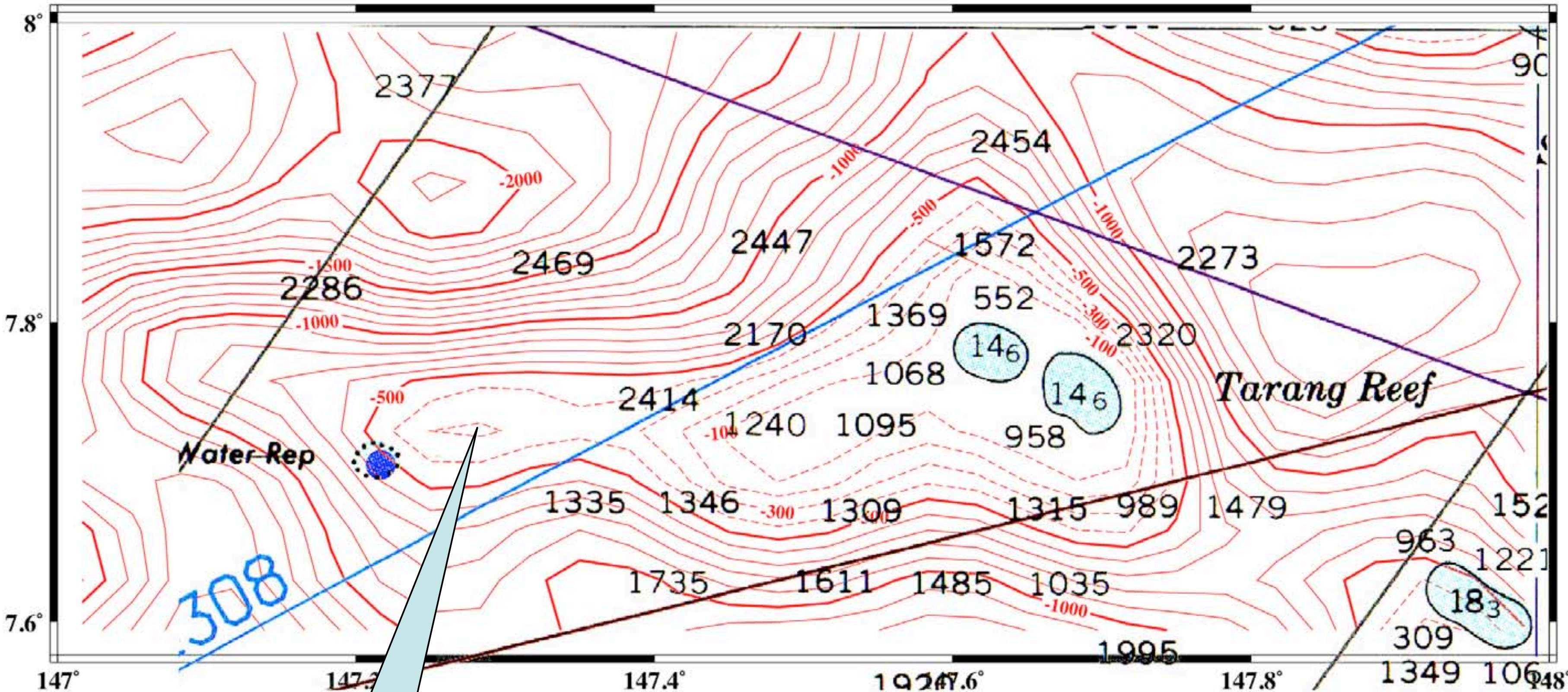


Dashed 100 m contours where shallower than 500 m.

Solid 500 m contours deeper.

Heavy solid contour = 2000 m.

Detail



147 º25' E
7 º43.6' N
278 m
estimated

Data from "topo_8.2",

Smith & Sandwell,

2000.

Satellite altimeter estimate is shallower than 100 m in a large area W of Tarang Reef where chart soundings exceed 1000 (meters? feet?). Not sure why.

What can we do now with modest resources?

Raw altimeter radar waveforms have been reprocessed by Smith and Sandwell in 2004 & 2005; expect no further improvement in VD and G resolution over what we (NOAA & SIO) have now. Bathymetry estimate needs to be revised using this reprocessed gravity field. Work plan:

- Smith (NOAA) and Sandwell (SIO) revise bathymetry estimate based on their reprocessing of gravity. NGA (Trimmer?) and Navy contribute sounding, hazard, and shoreline control.
    - Can we use classified soundings for calibration if we “hide” them somehow? What about hazards and shorelines from other imagery (e.g. Earth Sat Corp.’s work on Landsat images)?
    - Can we find $150k to rescue Geosat ERM SDR 9-track tapes?
- Navy and NGA verify Smith and Sandwell products.

What more can NGA do?

Short term:

•Consider use of altimetry for chart overlays, warning of possibly mountainous areas. See whether this can be used to quality-control old soundings. See whether altimetry can be used to flag areas where Landsat scenes should be inspected for shallow hazards.

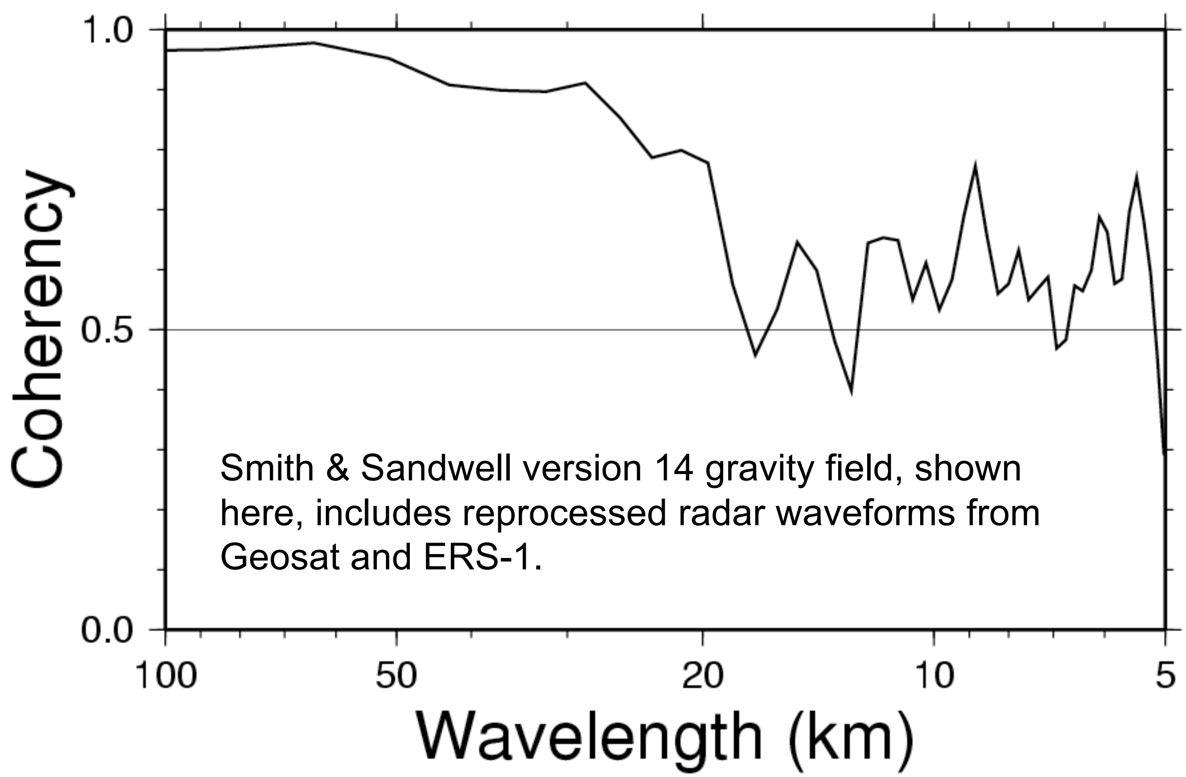
•Smith would like to have feedback from NGA in the form of scales resolved (error versus wavelength), not just point value assessments.

Long term:

•Help to fund a new delay-Doppler altimeter mission.

Current precision & resolution

Existing altimeter data resolve the gravity field to 20 km wavelengths; 1σ error ~1 a.s. or ~4 mGal.



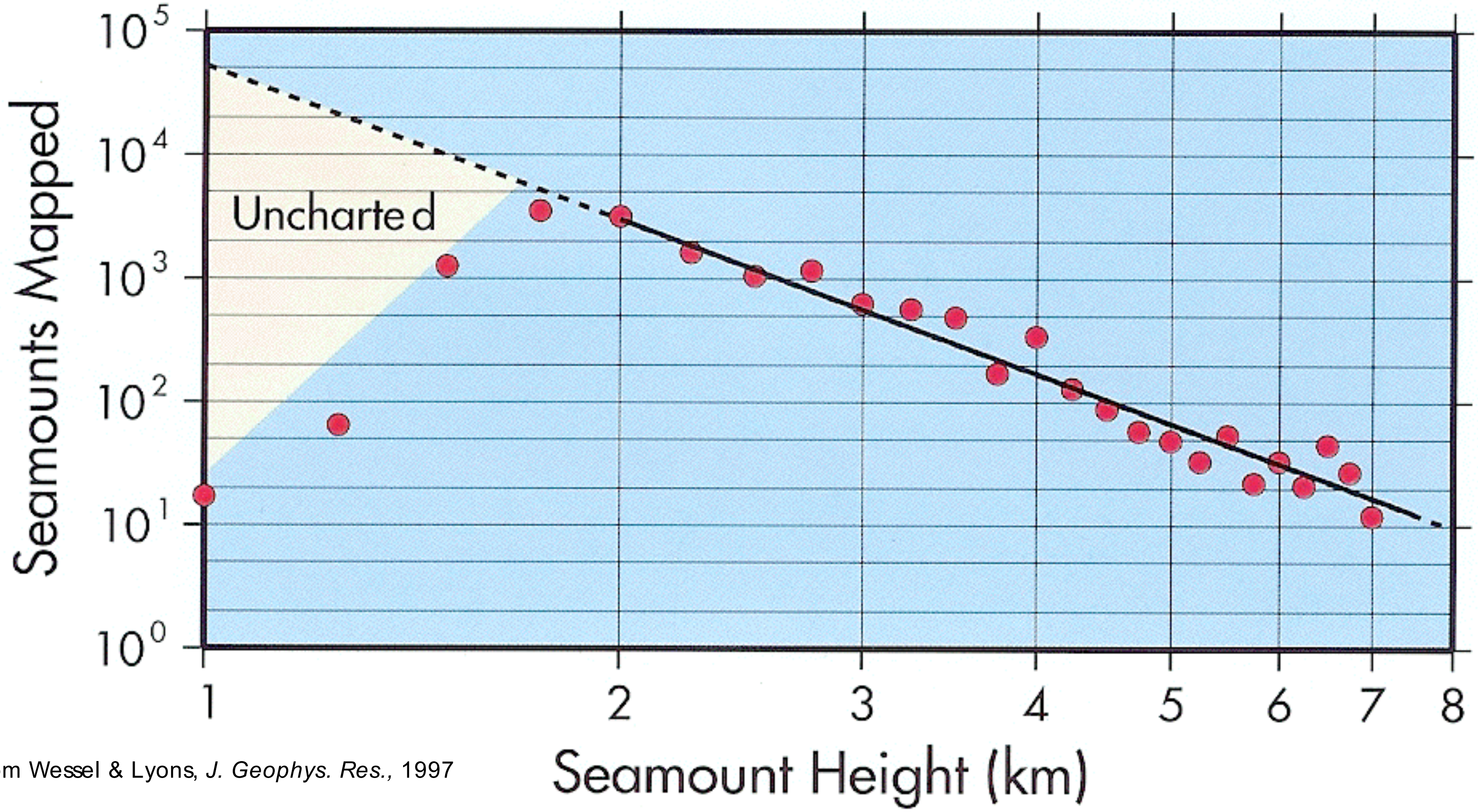
Enough for VD compensation in vehicles faster than SSBNs? (8 knots x Schuler period = 20 km.)

Not good enough for finding more seamounts, or for Trident VD comp.

Increase seamount detection 17x

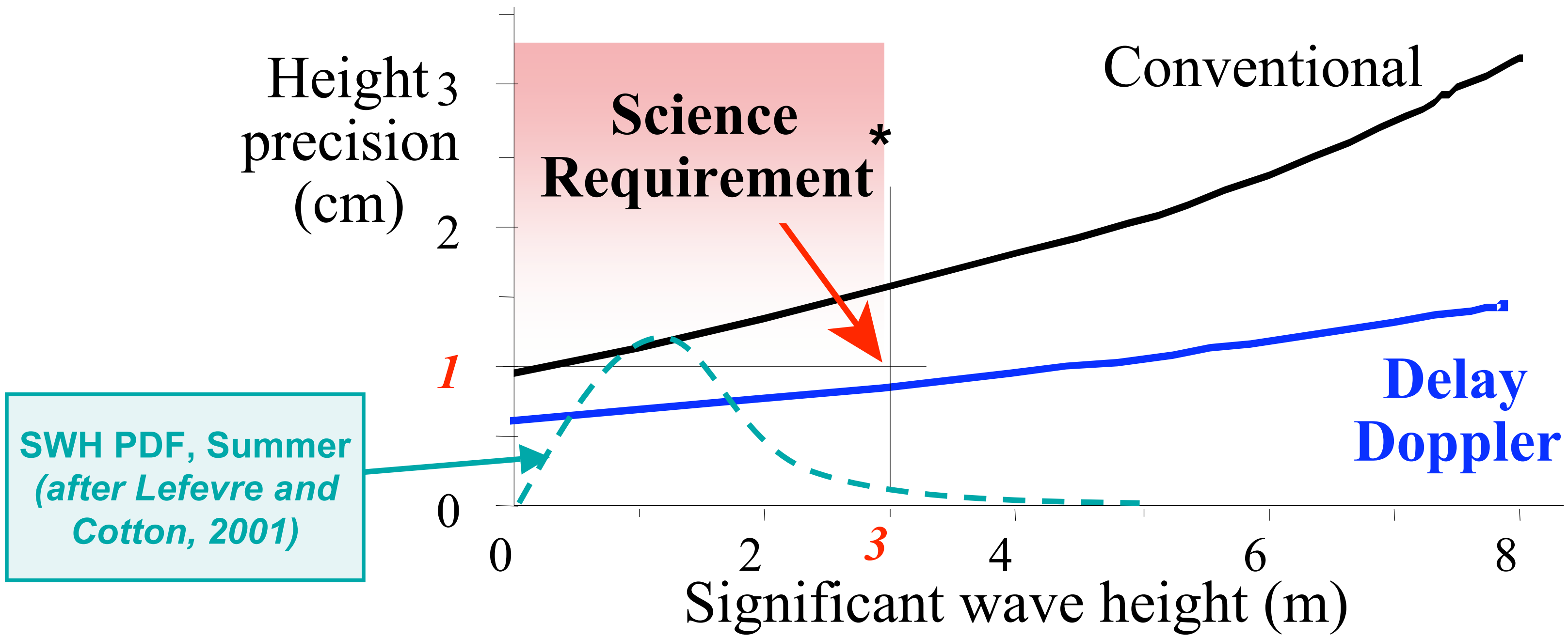
Probably 50,000 seamounts 1 km tall remain undetected.

A 2x better altimeter might find 17x more seamounts.



From Wessel & Lyons, *J. Geophys. Res.*, 1997

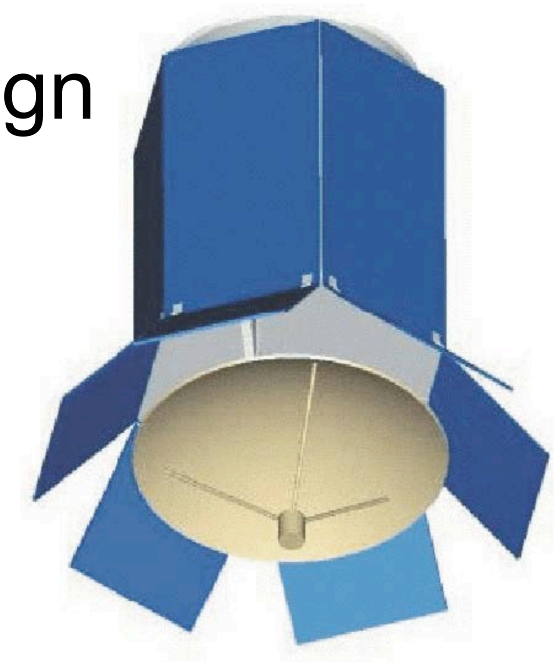
A 2x better altimeter: delay-Doppler



ABYSS proposal: Use d-D altimeter to achieve 1.8 μrad @ 6 km half-wavelength in sea state of 3 m SWH. Collect 4 x redundant data (6 year mission) for 1 μrad final error.

Note d-D altimeter meets NGA-USAF VD precision goal without redundant mapping; 1.8 μrad = 0.375 arc-sec.

ABYSS-Lite d-D mission design

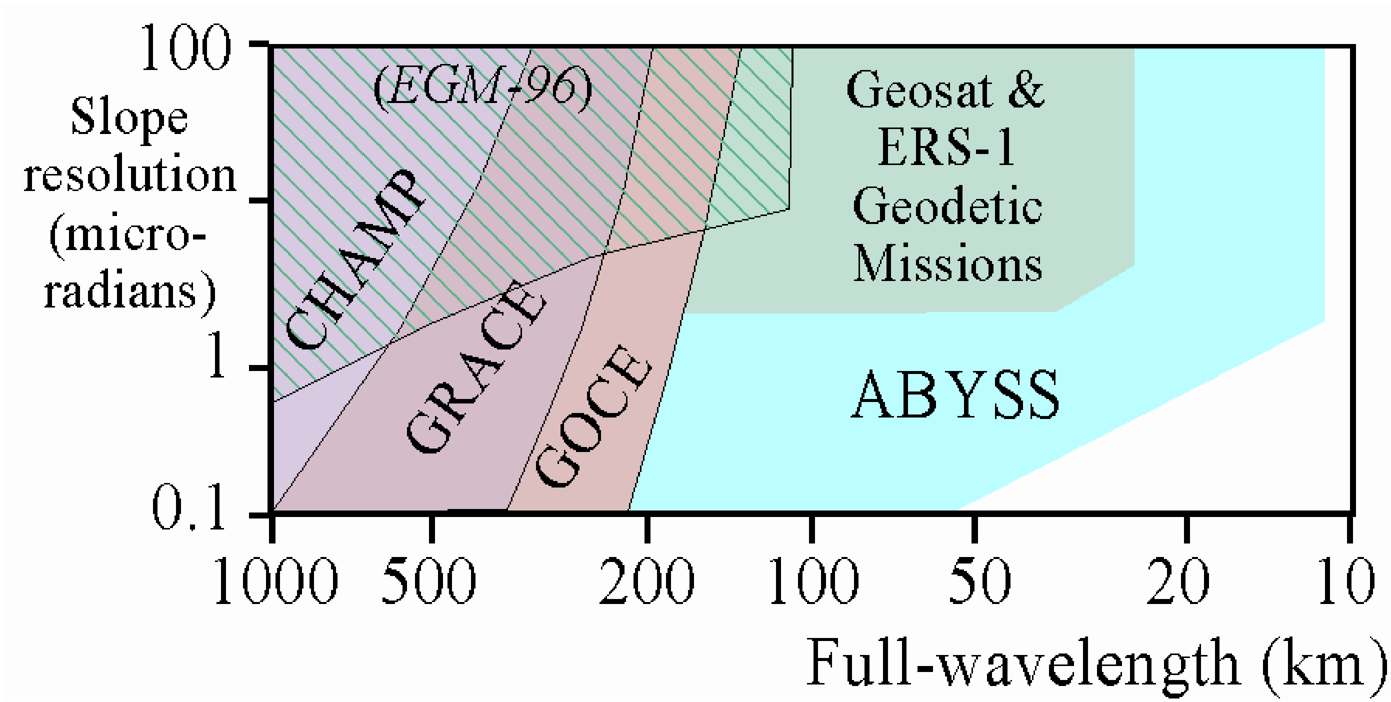


Target cost*: less than $60 M

Radar mass (kG)	~ 28
Spacecraft mass (kG)	148
Antenna diameter (m)	1.0
Science data rate (Kb/s)	25 (average)
Radar power (W)	< 75 (fixed solar arrays)
D/L data rate (Mb/s)	4 (two days of data, 10 min)
Navigation	Star-trackers & GPS
Attitude control	Pitch wheel and torque rods
Launch	Pegasus (60 degrees#)

**Excluding reserves and launch vehicle* *#Additional cost of retrograde orbit TBD*

Altimetry required: GRACE won't help

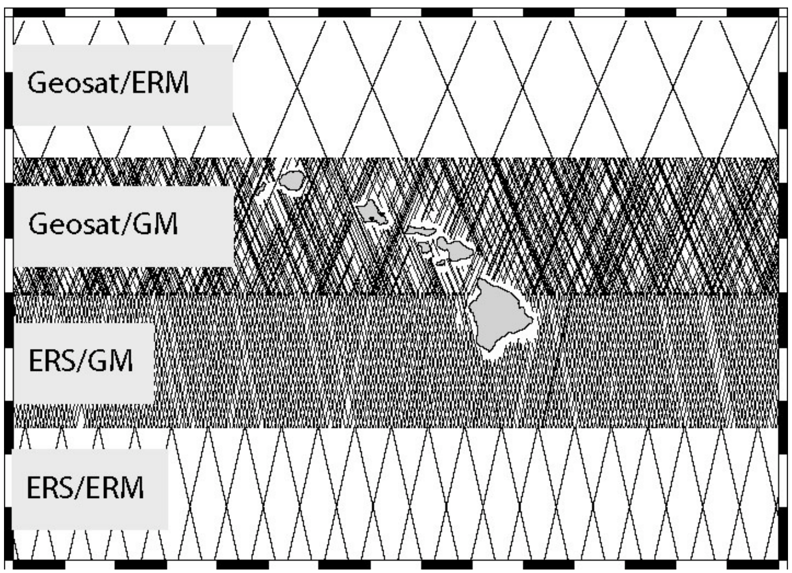


Altimetric sea surface slopes measure VD at sea level and so capture the full signal. Gravimetry in orbit (CHAMP, GRACE, GOCE) measures gravity at satellite altitude. Upward continuation that far wipes out the signal.

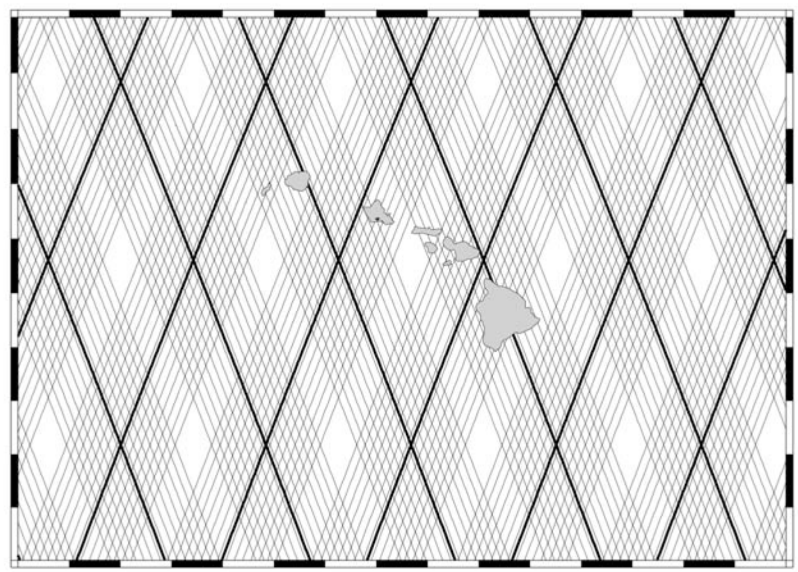
Wide-Swath Altimeter won't help

Track spacing 15 km (8 n.m.) at best, worse in "yaw steering mode", and leaves gaps.

Precision 2.7 μrad (0.6 arc-sec) after 4 years of averaging on 15 x 15 km (8 x 8 n.m.) grid, but resolves only to 30 km full-wavelength: no net improvement in spatial resolution over existing data



WSOA tracks (no yaw)

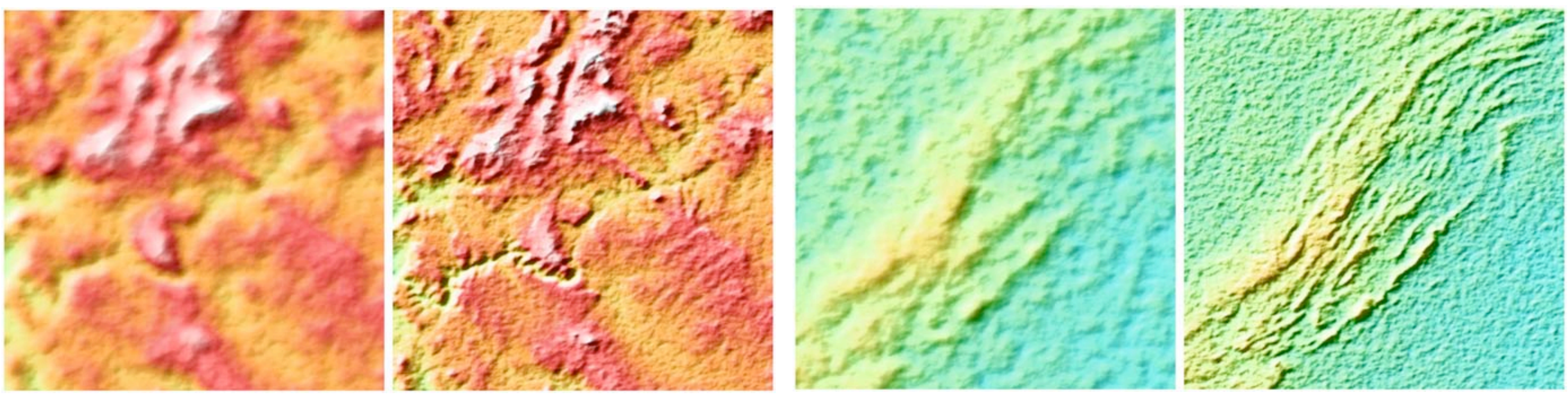


Cost perspective (in billions)

0.1 G$: A new delay-Doppler altimeter mission w/ 17-fold increase in number of seamounts mapped. Invaluable contribution to tsunami hazard mitigation.

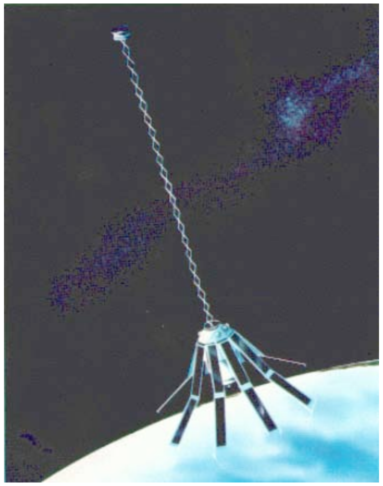
1 G$: The USS *San Francisco*

10 G$: A complete bathymetric survey of the oceans.
(M. J. Carron et al., *Int'l Hydr Rev*, 2(3), 49-55, 2001).

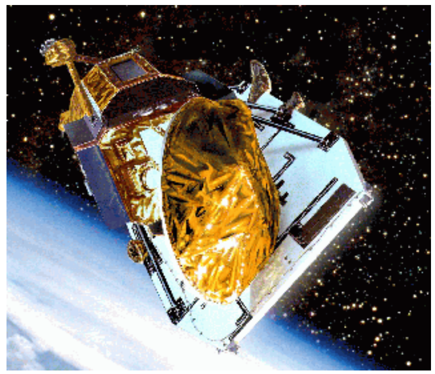


Expected improvement if Grand Canyon or Appalachia were ocean floor features mapped with existing altimetry and with a new delay-Doppler mission.

Navy altimeter satellites



Geosat (1985-89)



“GFO” (1998 to present)

(designed for 8 yrs)

A delay-Doppler mission should be next! NOAA, NGA, USN can share costs.

Would aid tsunami hazard assessment as well.

Bathymetry and tsunami hazard

June 10, 1996: M7.9 earthquake at Andreanov Island, AK, generated a tsunami 1 m high at Alaskan coast and less on other US coasts. Wave was large enough to lead researchers to conclude that:

- Energy doesn’t take direct path (warning times difficult)
- Most energetic arrival may not be first arrival (ditto)
- Two nearby coastal sites may receive very different amounts of energy (evacuation decisions difficult)

See animation of propagation at next slide.

A better ocean floor map will advance tsunami hazard forecasts as well as submarine navigation.