UNESCO/IOC – NOAA ITIC Training Program - International (ITP-Intl)
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# Tsunami Travel Time Forecasting Methods and Uncertainties

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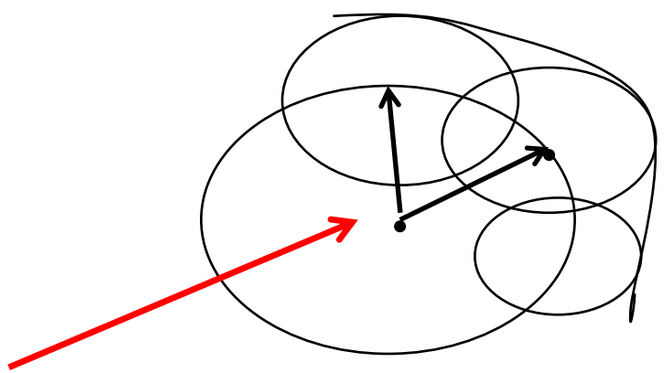
# 1. Computation of Tsunami Travel Time (TTT)

- For tsunami warning purposes, important to know expected/estimated tsunami arrival times (ETAs), which are included in tsunami bulletins.

- Computation of ETAs based on Huygens Principle:
  Every point on wave front of a point source is also a point source.
  Tsunami travel time dt=dx/C
  where C= $\sqrt{gh}$, $(wave\ speed)$.  h is water depth, *g* is gravitational acceleration




- Point source (or epicenter of earthquake)
  Travel time from epicenter to coastal point:  shortest possible time of all possible paths from epicenter to coastal point

Figure A1 shows the central node and all neighboring nodes considered when calculating incremental travel times. The central node represents one of the grid nodes that currently lie on the tsunami front (at time 0 this is typically a single node at the epicenter). From there we calculate travel times to 64 of the 92 nodes shown; these lie on 9 concentric circles. Nodes in black do not need to be calculated since the incremental travel time to these nodes cannot be shorter than some of the other nodes along the same radii (increments cannot be negative).

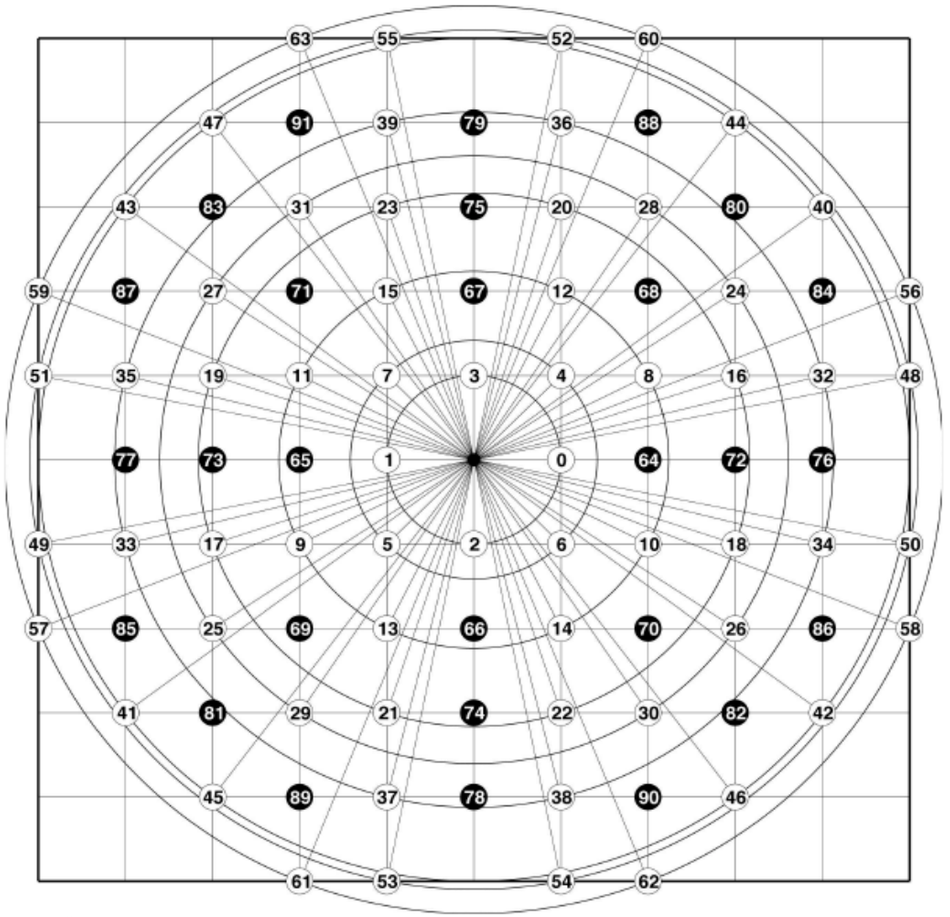



**Fig. A1.** We estimate how slowness varies linearly along radial lines to the nodes numbered 0–64. We sort all the possible travel times and pick the shortest; this gives us the next point on the wave front. Remaining travel times will be augmented with the next 64 travel times and again sorting will return the shortest time. This process repeats until we reach all the nodes.

**Numerical implementation is done via searching for shortest possible travel time at each node of given grid/resolution.**

**Wessel, 2011, TTT software development kit.**

# GEOWARE TTT software

- Epicenter of the earthquake (EQ) is assumed to be the location of the initial point source. If the epicenter of the earthquake is on land, the nearest ocean point is assumed to be the initial point source.
- The estimated tsunami arrival times (ETA) listed in PTWC's bulletins are computed in real-time using the GEOWARE TTT (tsunami travel time) software http://www.geoware-online.com/tsunami.html) with the GEBCO 30-arc-second bathymetry (http://www.gebco.net).
- For speed of computation, a lower resolution is usually used (such as 5 or 10 arc-minute grid). The computation typically takes a few seconds at 10-min arc-min. resolution for the Pacific basin.

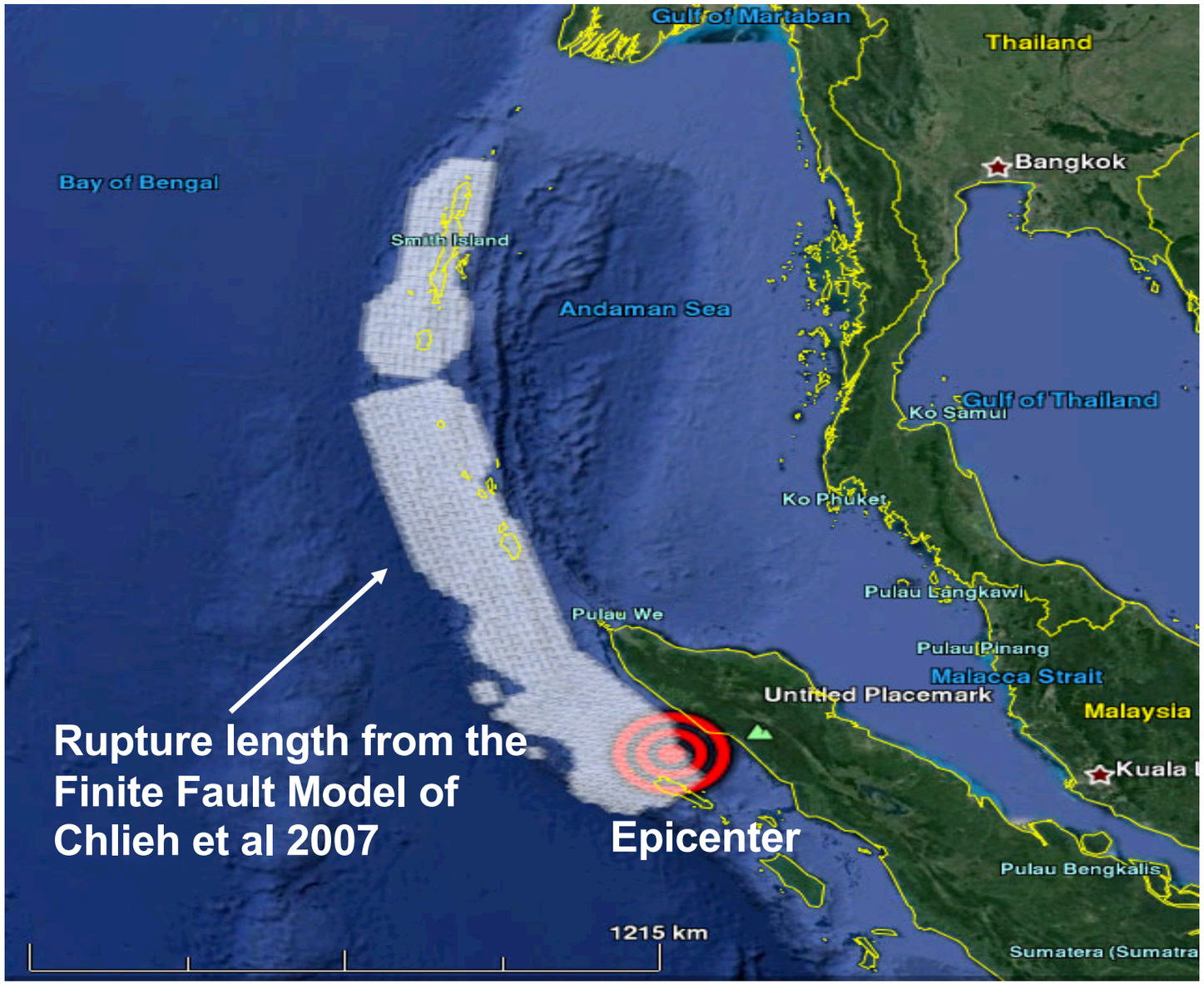
*Reference: Wessel, P. (2009), Pure and Applied Geophysics*

# Limitations/Uncertainties of ETA computations

- If bathymetry data is of low quality, travel time can be off, especially in shallow water.
- Tsunami source is not a point source - actual tsunami arrival time could be much sooner than computed (e.g., Sumatra 2004). Although finite source can be used in tsunami travel time software, option is currently not used at PTWC.
- Actual tsunami arrival can also be later than predicted.
  Research showed that elasticity of seafloor and compressibility of seawater also affect tsunami speed (e.g., Tsai et al 2013, Watada et al. 2014, Wang 2015).
- Tsunami arrival time does not mean time of maximum wave height.
  Actual maximum wave height can occur much later or sooner.
- Tsunami travel time can also be computed from tsunami forecast models (slower than optical method). Uncertainties still exist. Sometimes models can generate absurd tsunami travel times (e.g., intersecting travel time contours, later arrival contours inside closed contours of early arrivals—physically impossible).

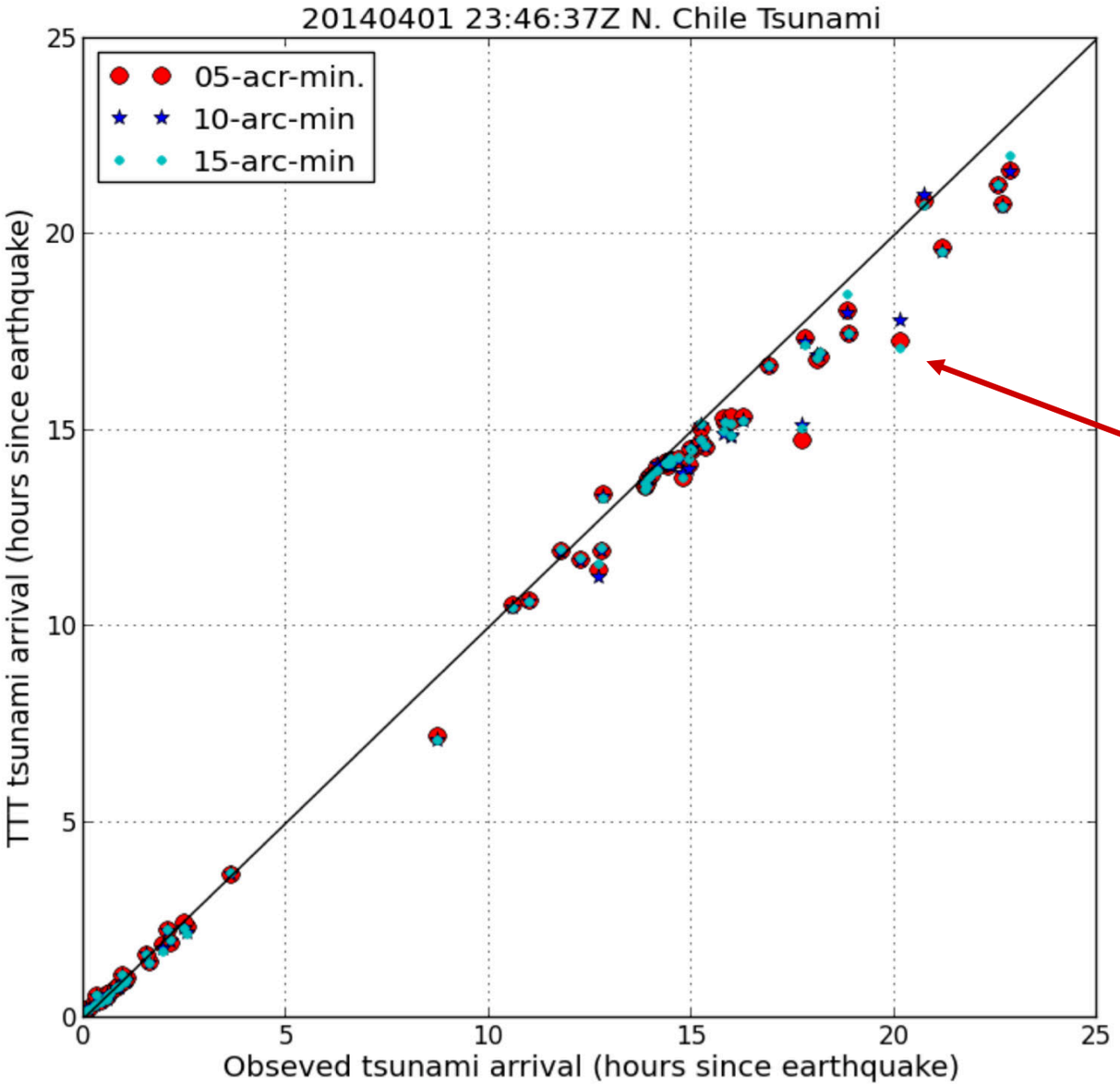
**It is difficult to come up with a robust/consistent definition of tsunami arrival time from tsunami wave forms (usually visual pick is the best)**

# 2004 Sumatra Tsunami




- Rupture length ~1300km
- Rupture lasted about 8 min. (Ishii et al, 2005)

- Using epicenter (red target) as point source for ETA computation would result in tsunami arrivals up to 2 hours late.



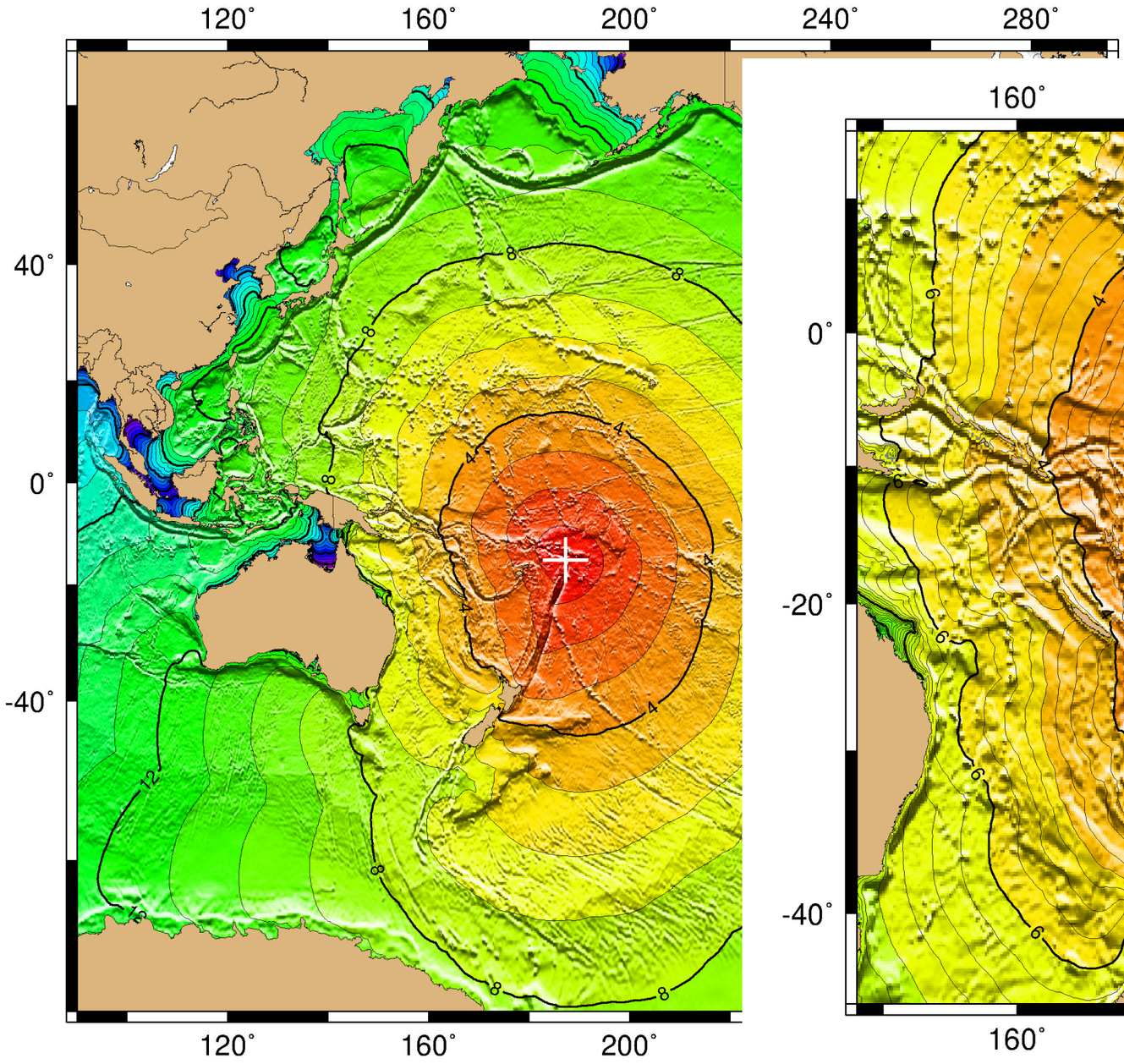

**2014 Chile Tsunami**
**Computed ETAs vs. Observed (measured from coastal sea. level records).**

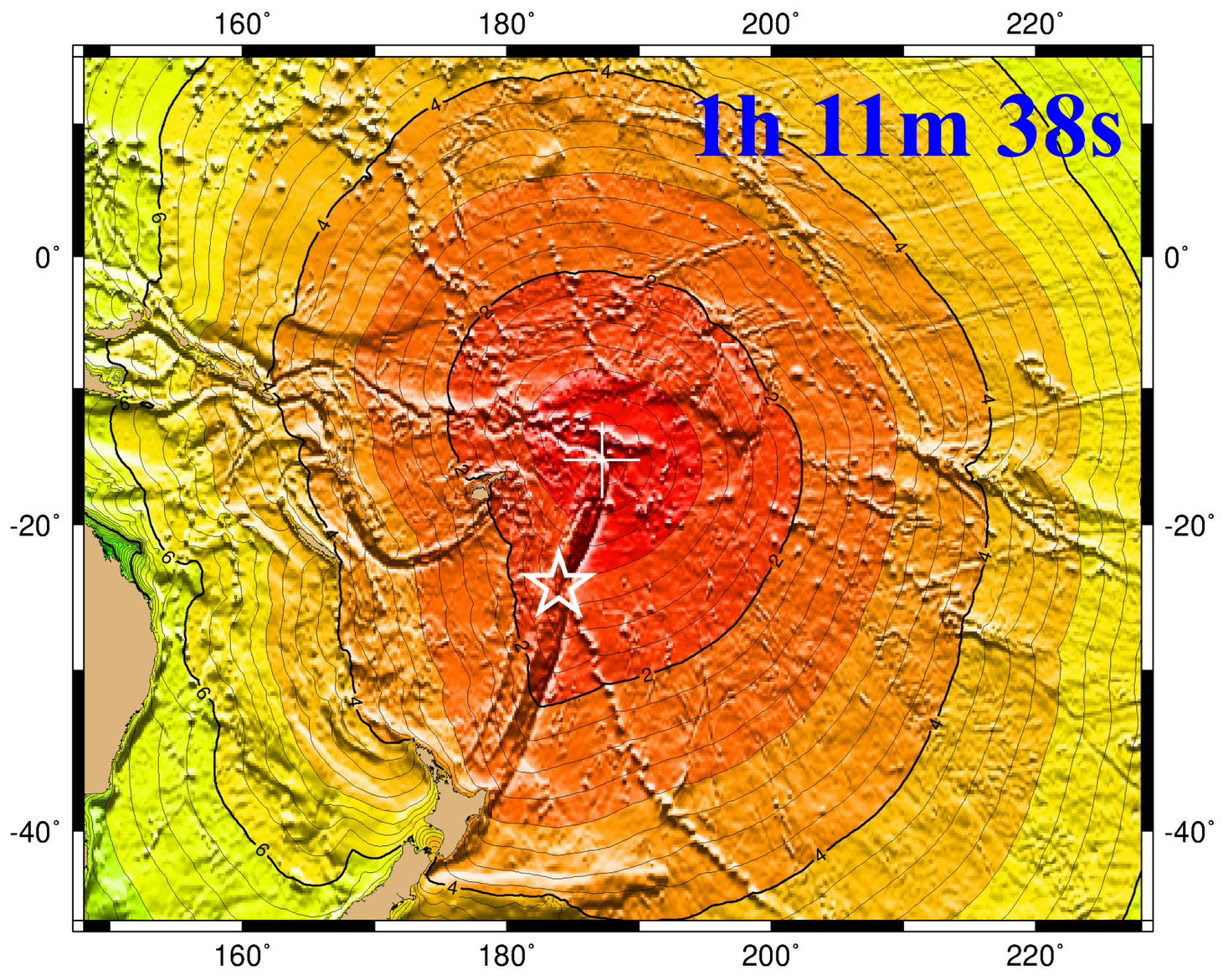
**There is not much sensitivity between 5, 10, 15 arc-min. resolutions.**

**Actual tsunami arrival can be two hours later than predicted.**

**Possible reason:**
**Path of minimum travel time does necessarily contain much wave energy (thus might not be observable).**

# Travel time - Point source

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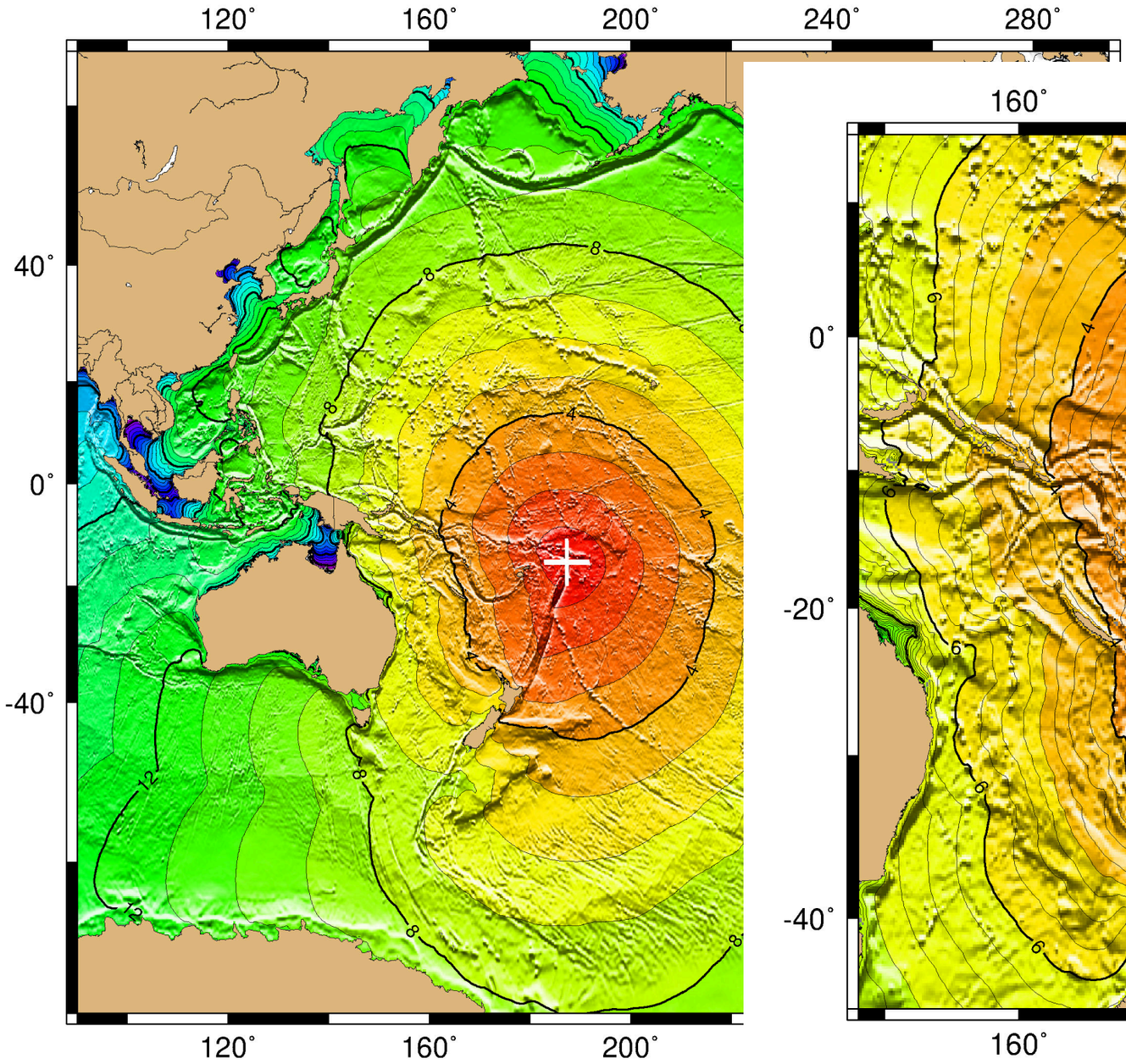
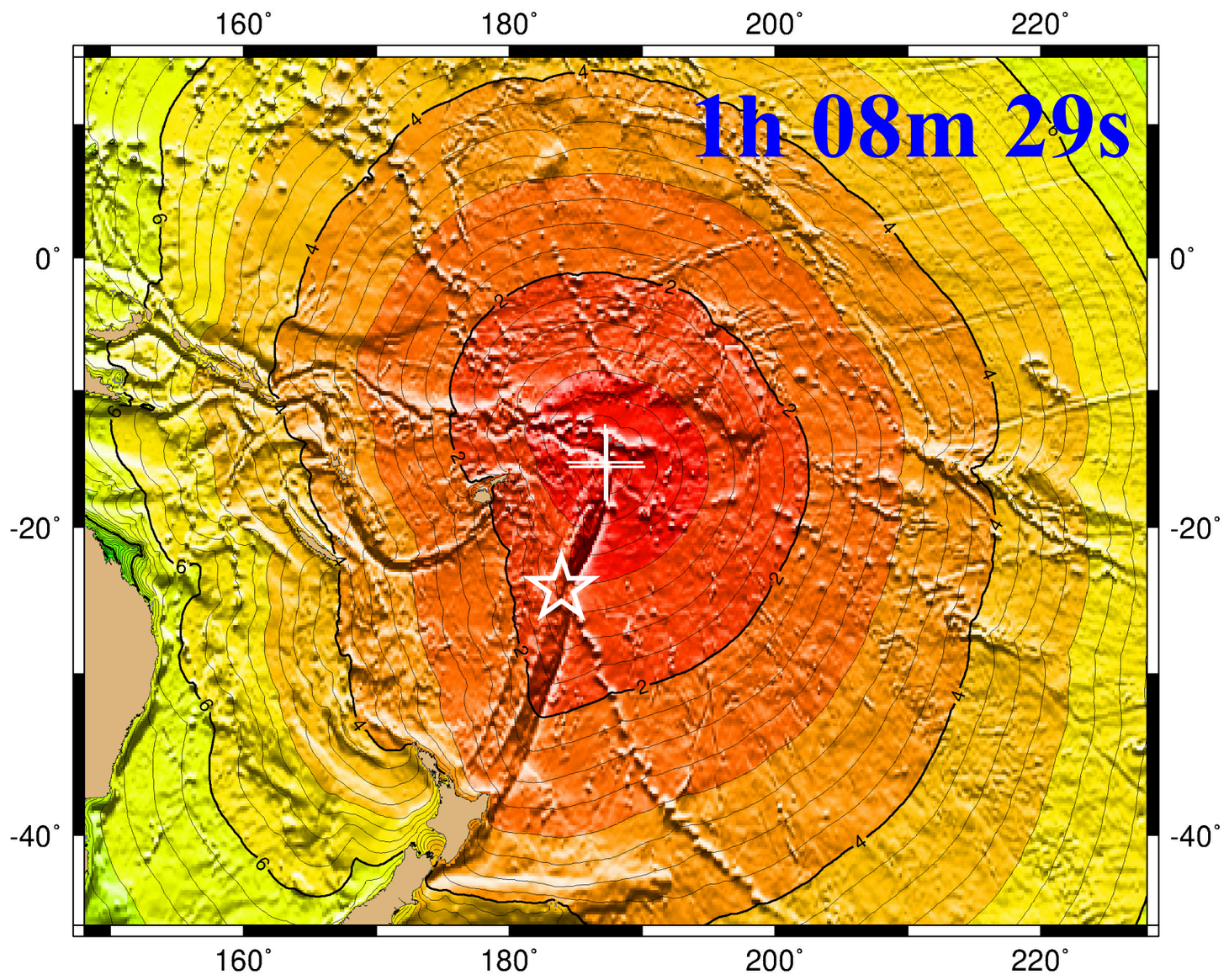
GMT 2019 Oct 11 08:05:57 TSUNAMI TRAVEL TIMES USING POINT SOURCE (EPICENTER), ● = Past EQ, ▲ = Coastal Gauge, ▼ = Deep-ocean Gauge

# Travel Time - Two sources

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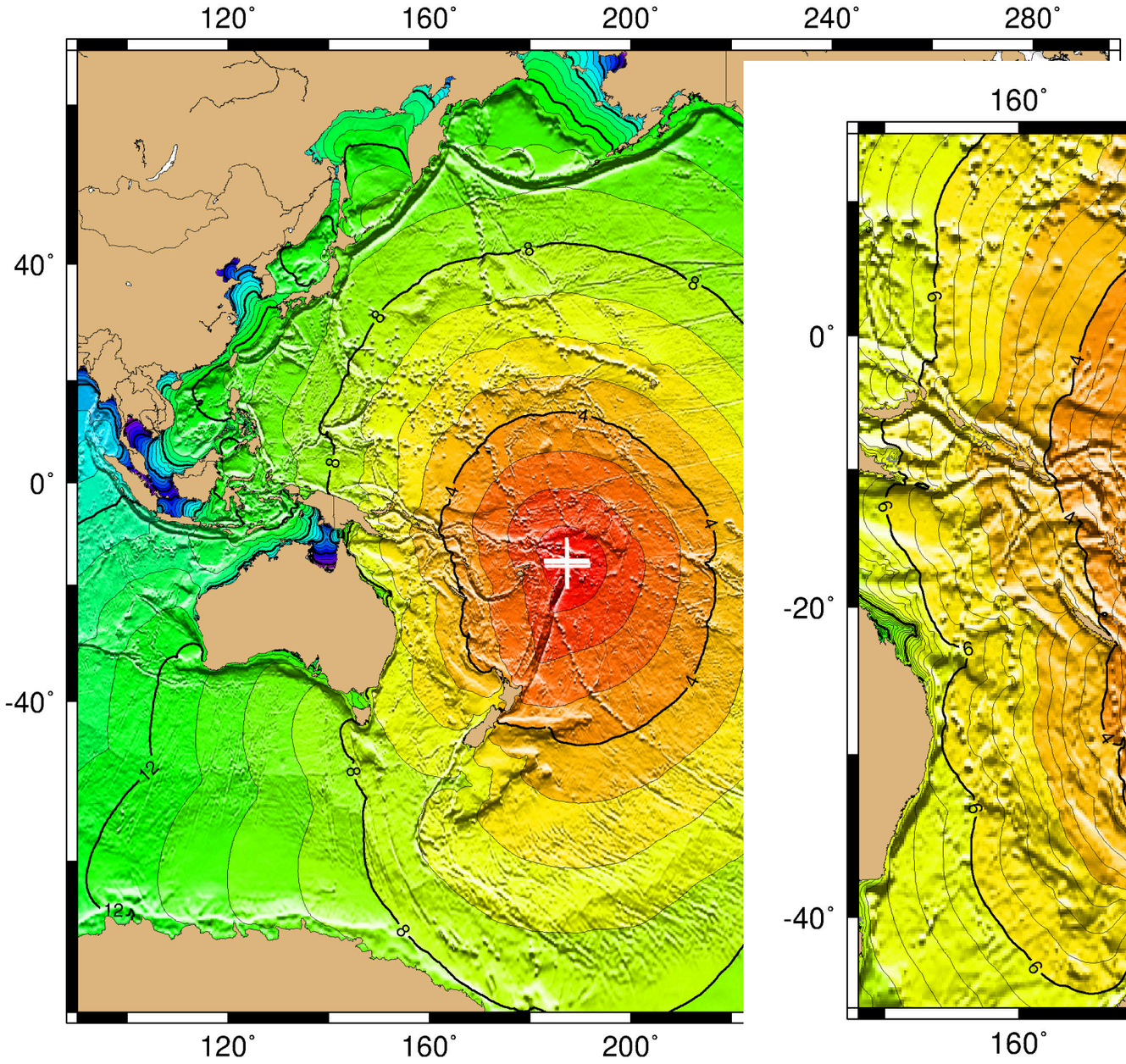
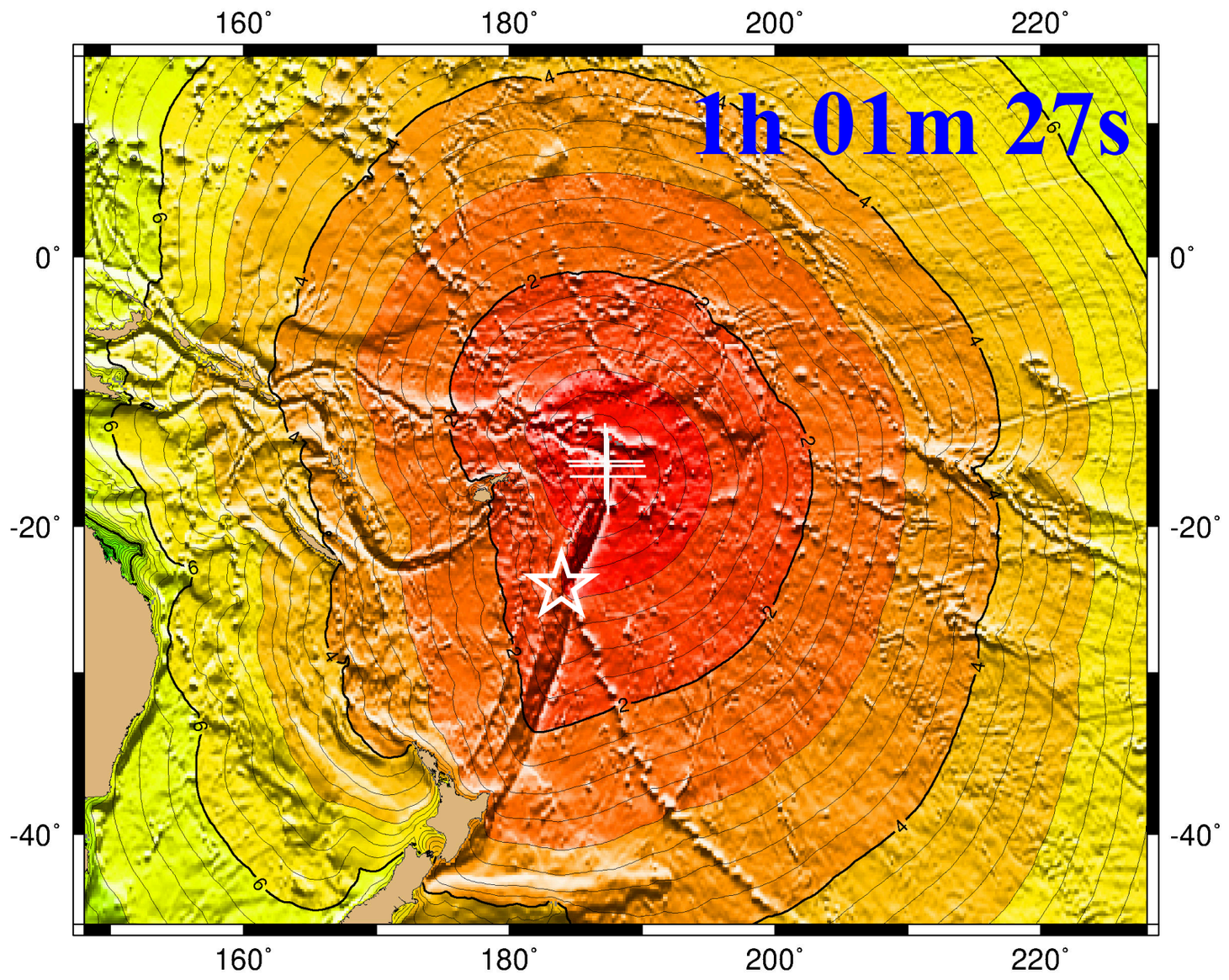
# Travel Time - Three sources

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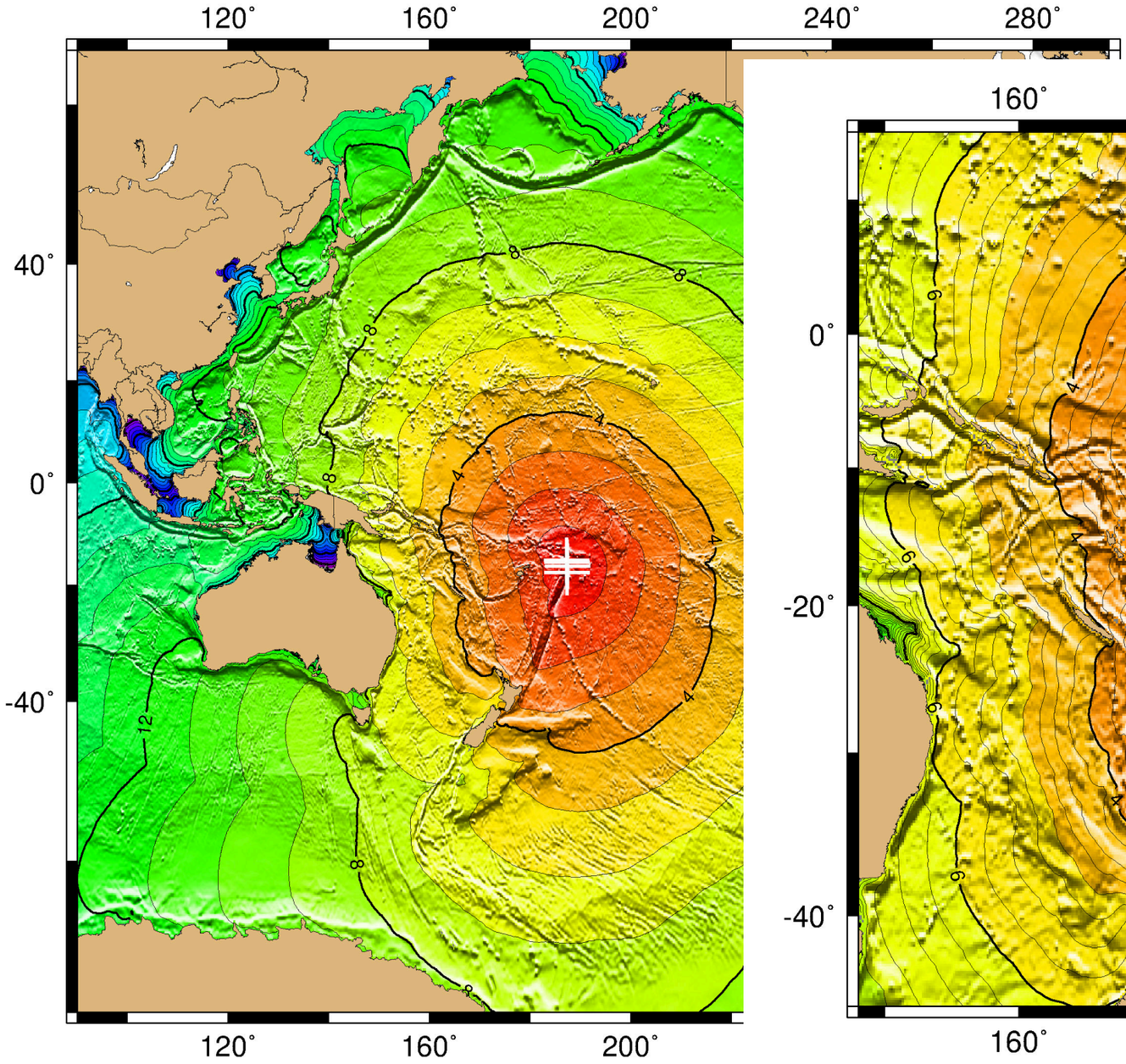
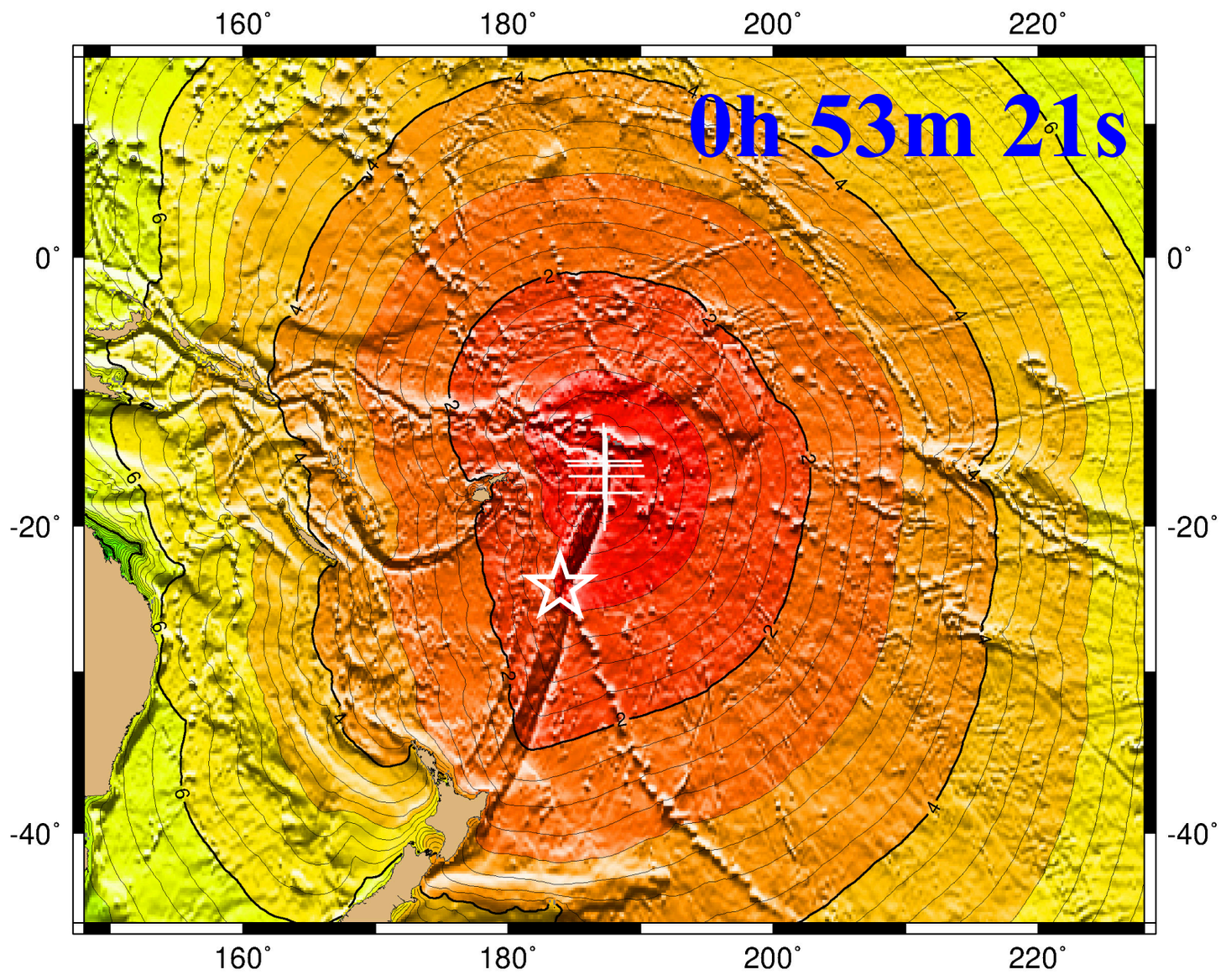
# Travel Time - Four sources

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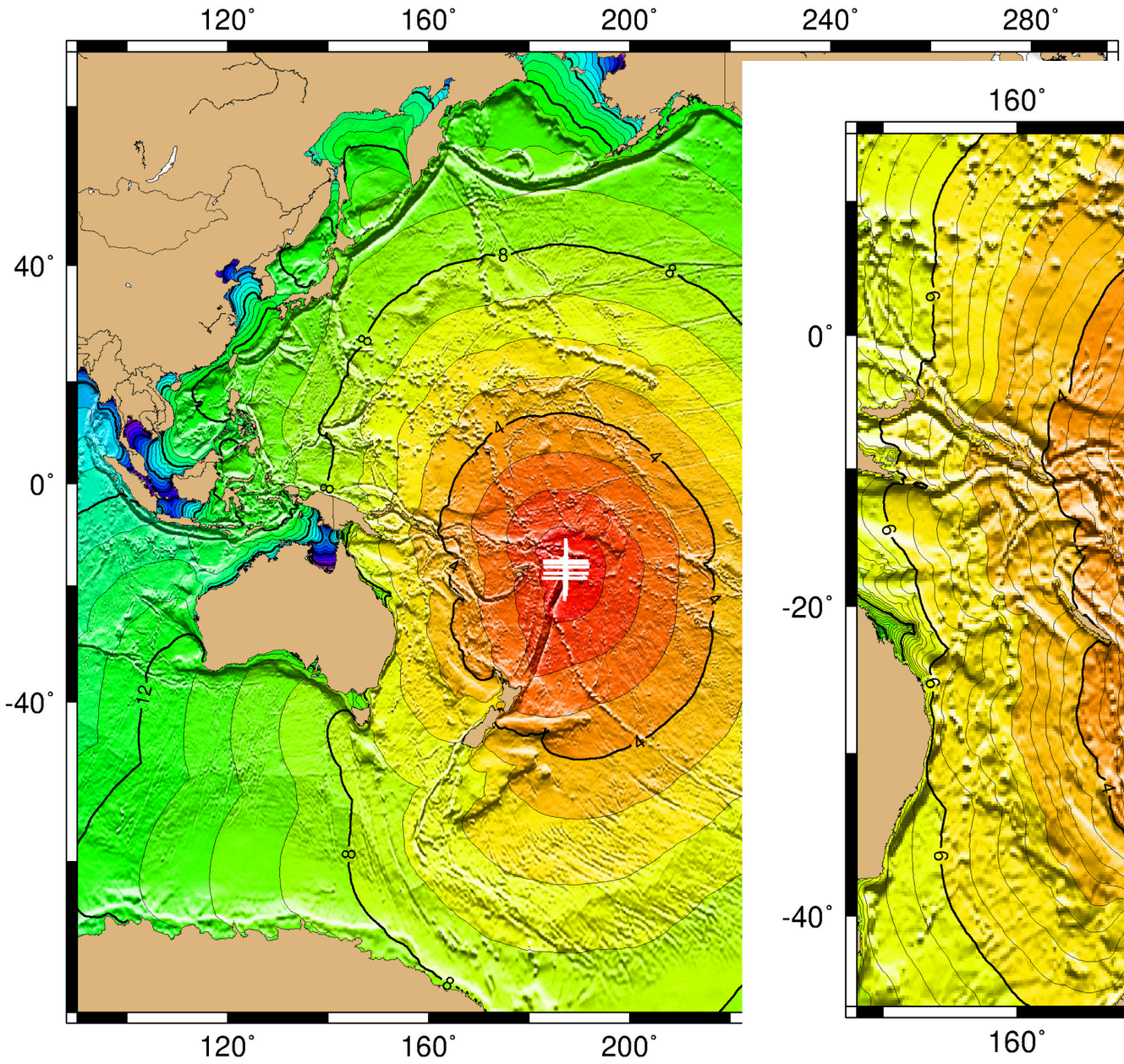
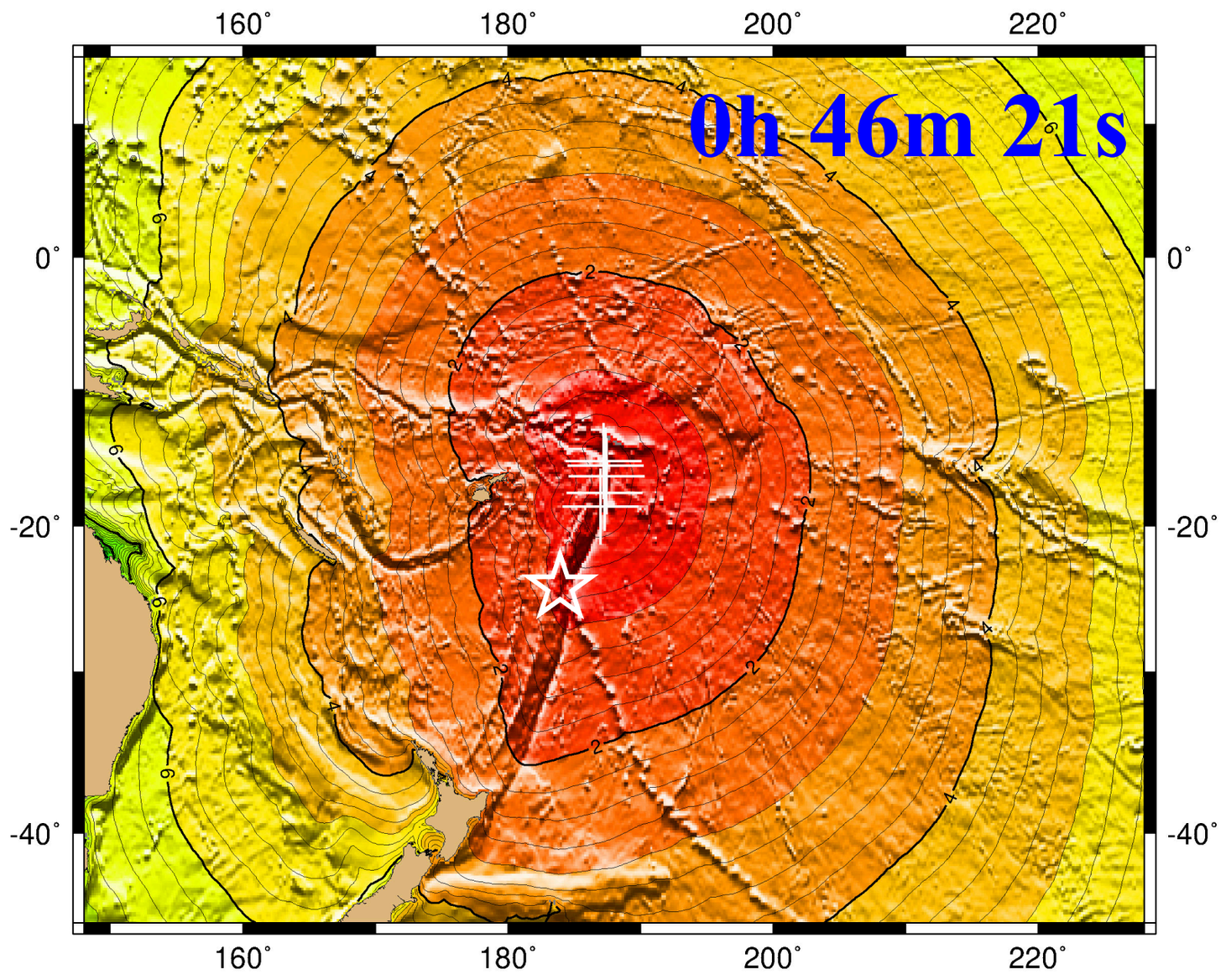
# Travel Time - Five sources

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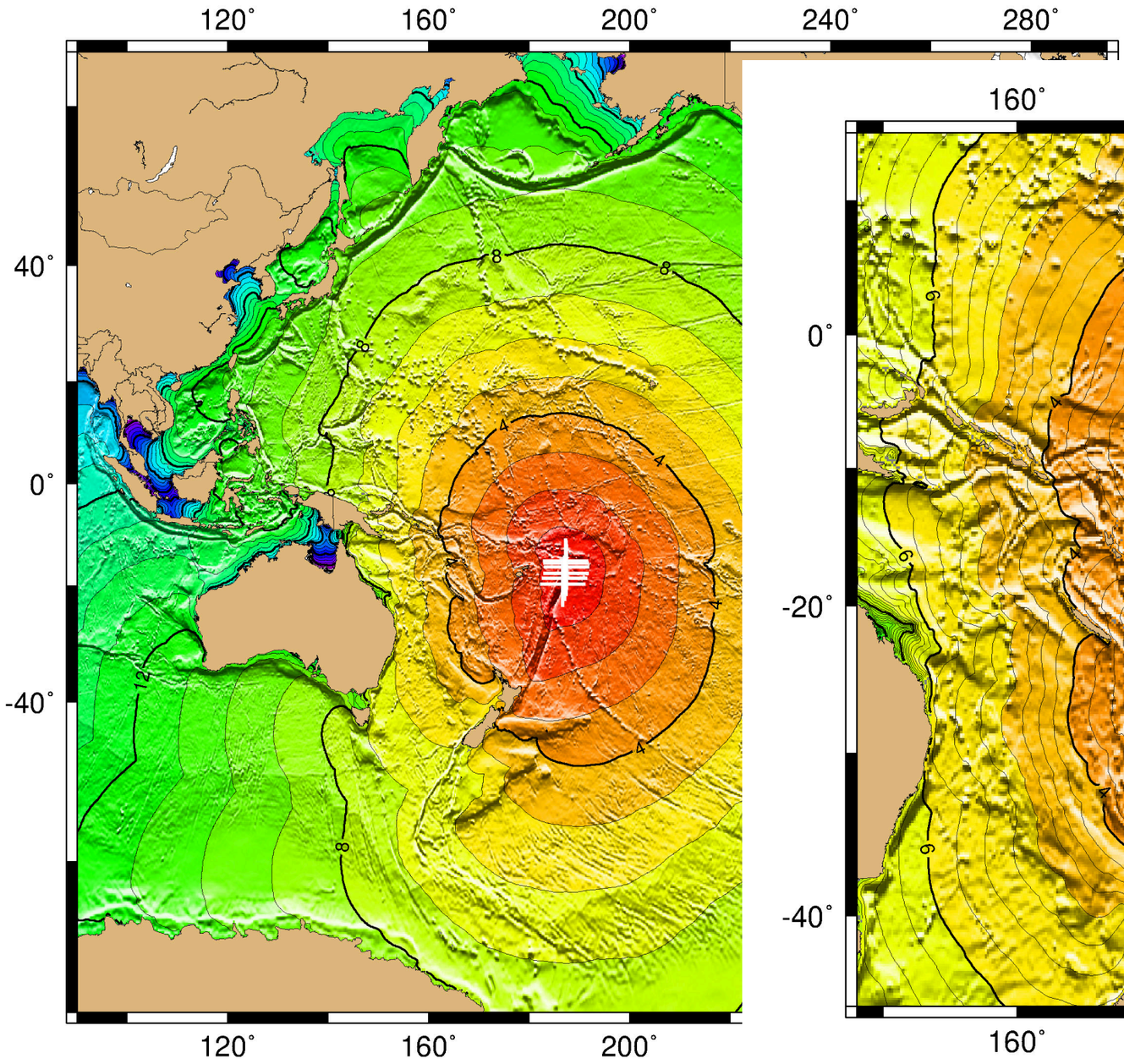
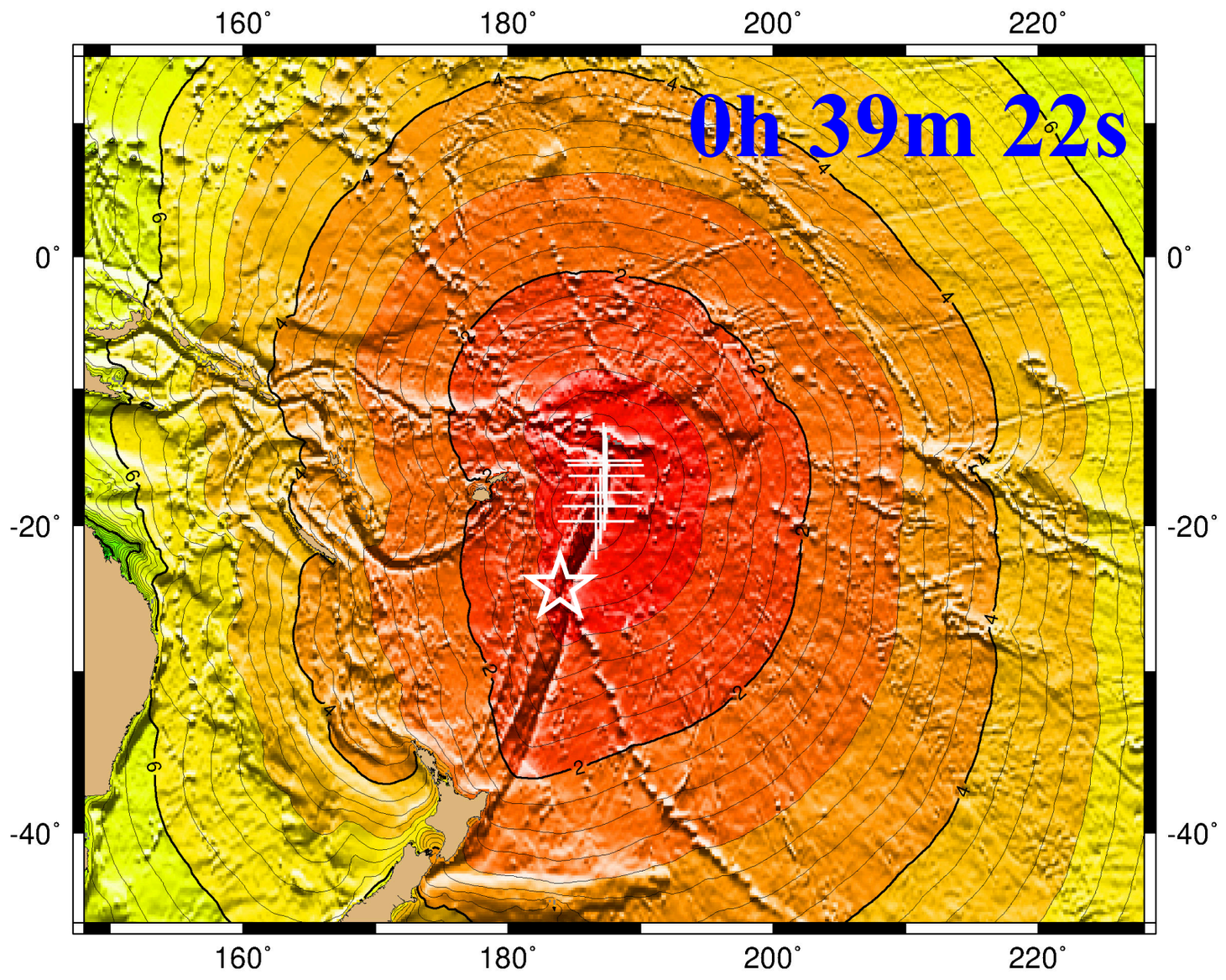
# Travel Time - Six sources

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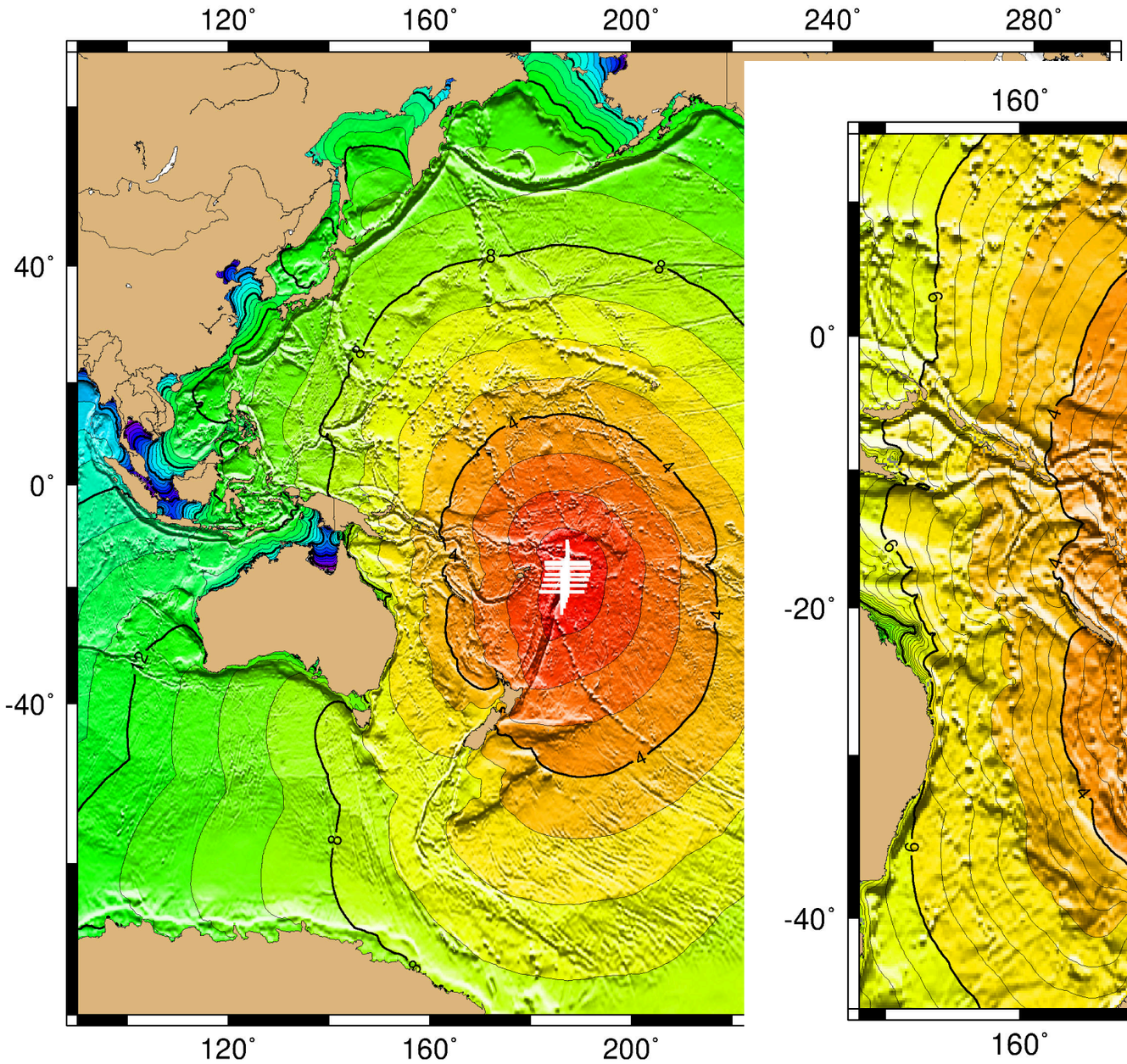
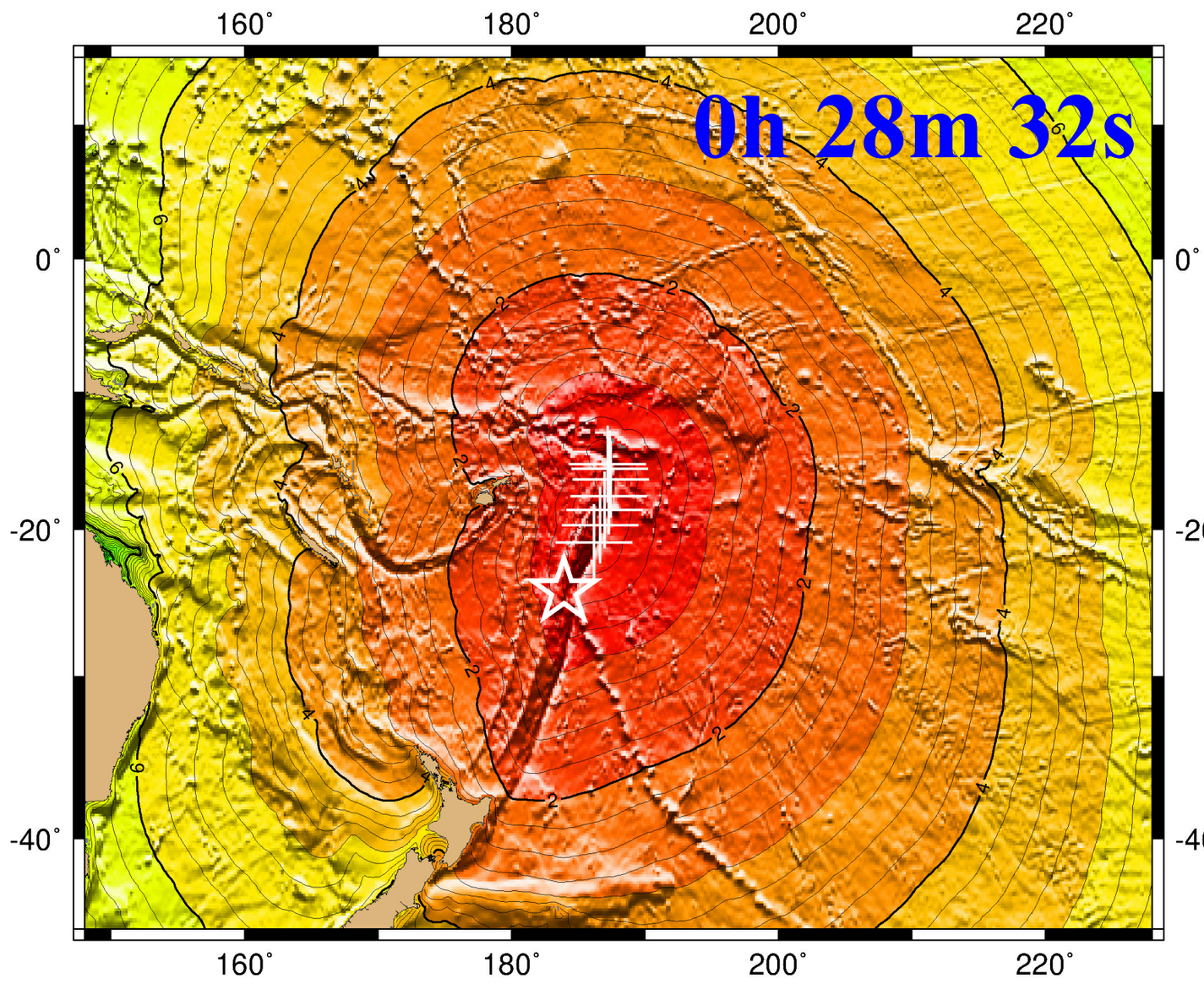
# Travel Time - Seven sources

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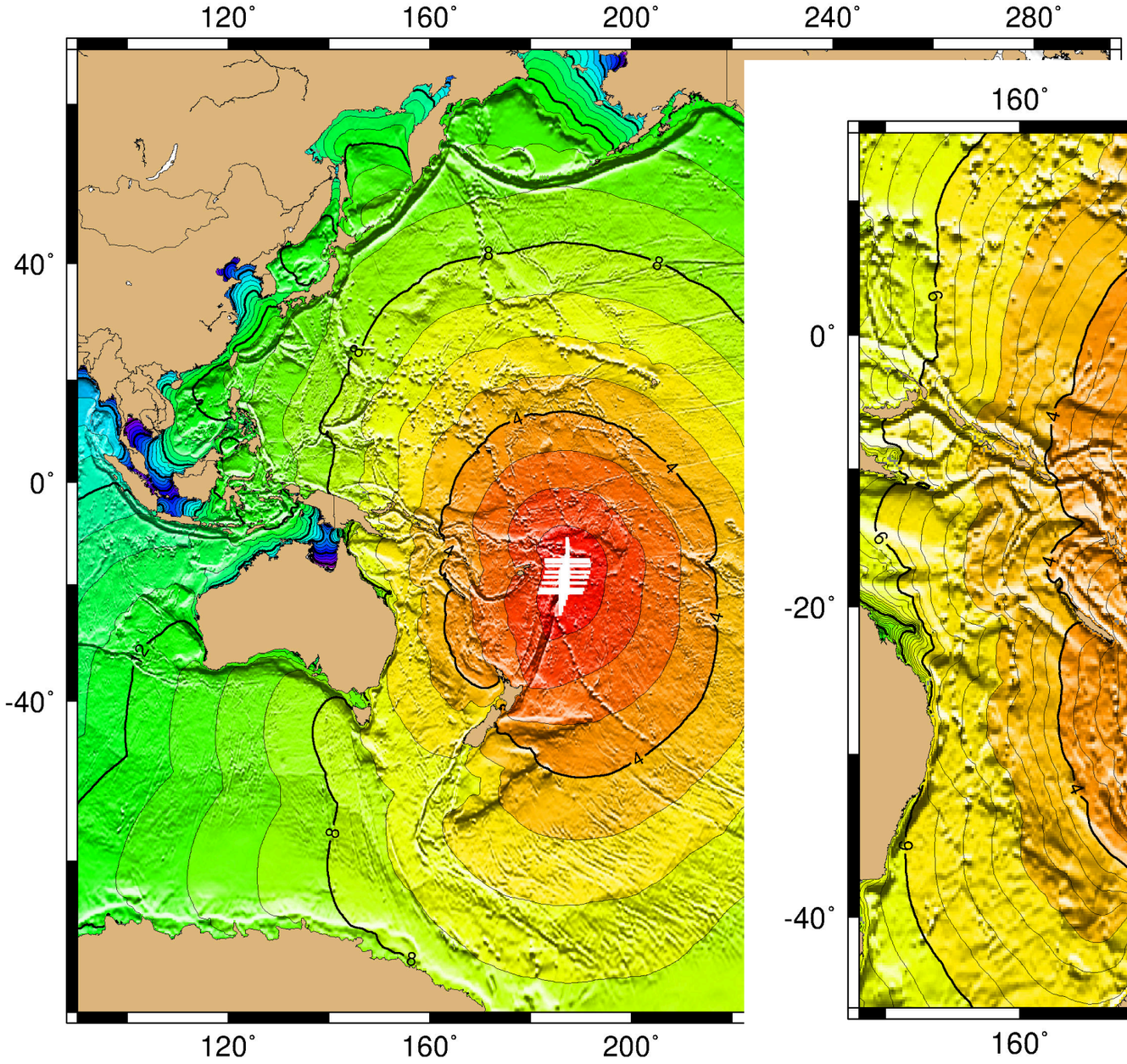
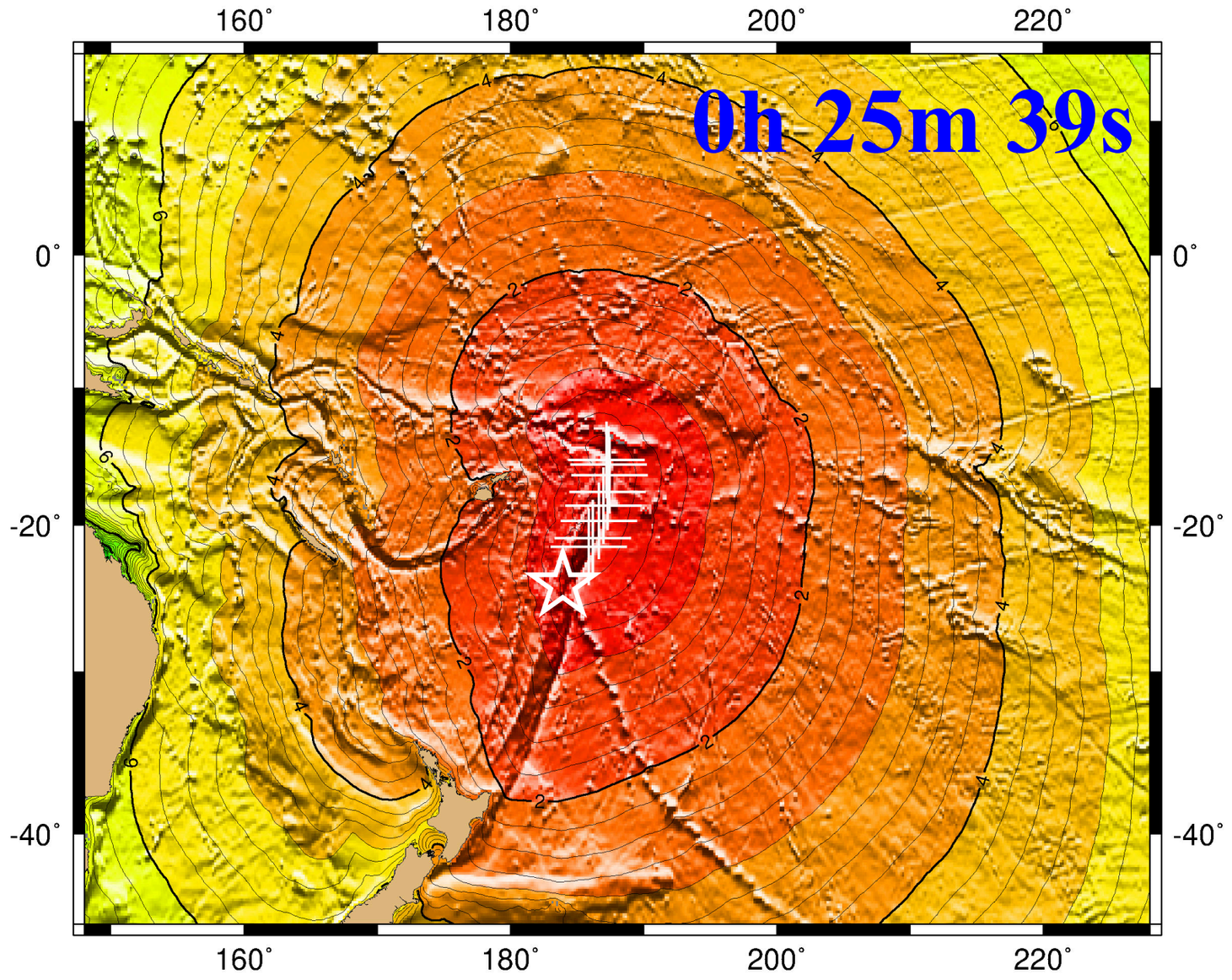
# Travel Time - Eight sources

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# Thank You

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