Ray-Tracing of Finite Tsunami Sources

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Background: Ray-Tracing

Energy propagation has long been modeled using rays. In this approach ("Ray-Tracing"), the energy leaving a source is assumed to propagate in the form of rays, or hypothetical lines perpendicular to the wavefront. As a result of the Snell's law, these rays twist and turn, controlled by variations in their velocity throughout an environment.

The energy from earthquakes and tsunamis has been studied as bundles of rays propagating, respectively, in the Earth's interior and the oceans (e.g. Crotwell *et al*, 1999; Woods & Okal, 1987).

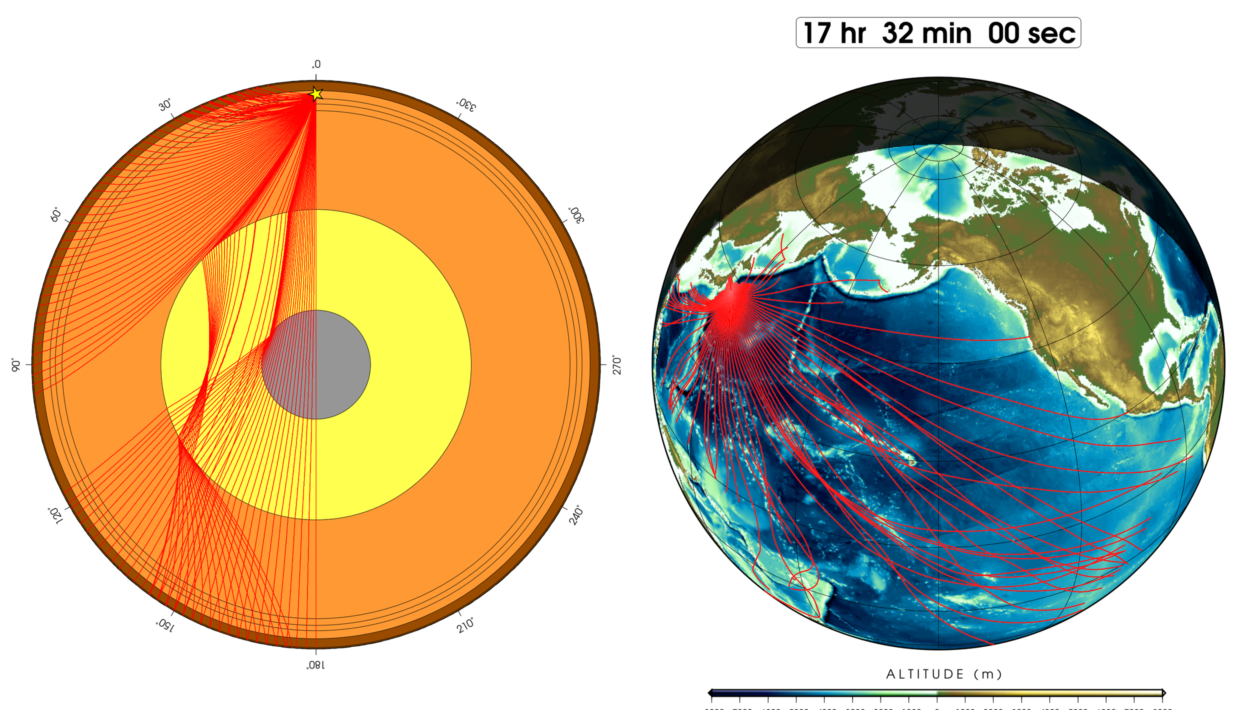

Figure 1: (*Left*) Seismic rays from a point earthquake source through the Earth's layers (Taup; Crotwell, *et al* (1999)); ((*Right)* Tsunami rays from a point source at the epicenter of Japan 2011 large earthquake, traveling through the Pacific ocean.

> **Rays propagate from a point-source and thus, all the information regarding the source size is discarded.**

> **Hydrodynamic Simulations are Time-Consuming.**
> **Ray-Tracing is FASTER!** ⟵ **Much Fewer Points!**

Method: Sampling the Tsunami Source

1. Calculate the initial *static* deformation.
2. Use available bathymetry grids for a region to **sample** the deformation source.
3. Propagate tsunami rays from individual source points considering their polarities (Up or Down).
4. Calculate ray density (ray points per unit area) in the grid, as a measure of tsunami amplitude.

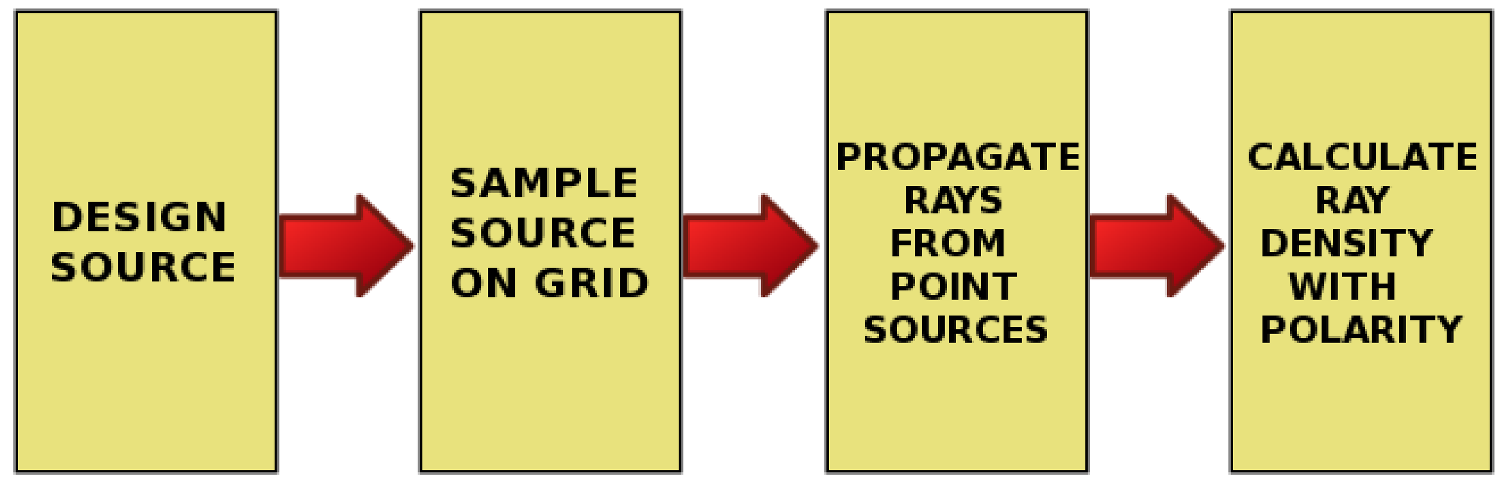

Figure 2: Tsunami ray-tracing process for finite sources used in this study.

Experiment 1: Simple Geometries

Cylinder | **Linear Fault**

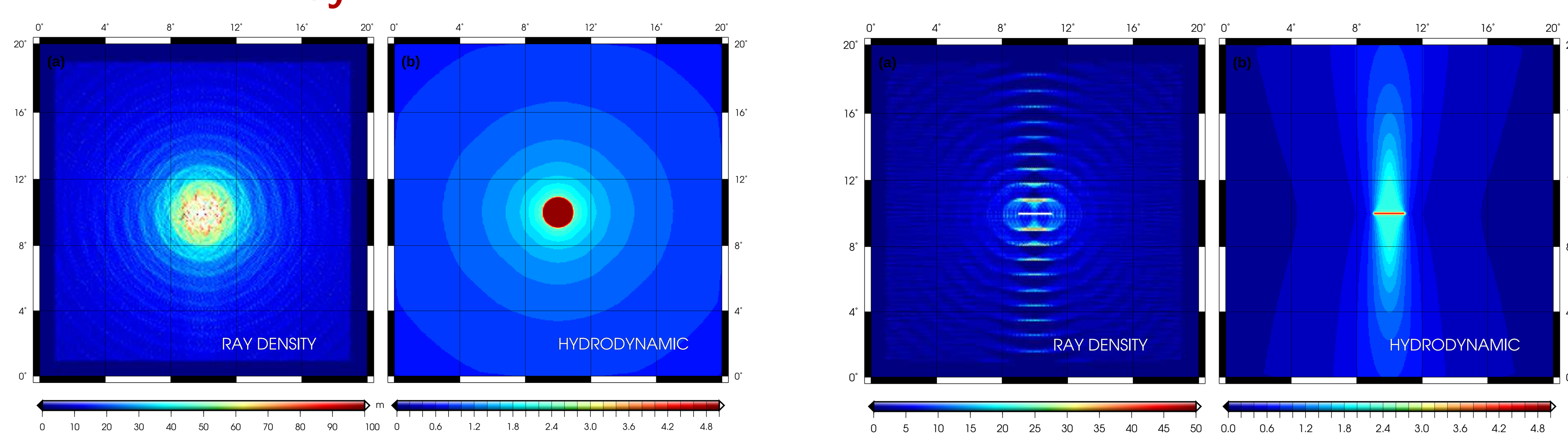

Figure 3: Comparison between ray-tracing and MOST (Titov *et al*, 2016) hydrodynamic simulations of maximum amplitudes from (*left*) a vertical cylinder, and (*right*) a linear fault.

> **IMPORTANT:**
>
> **1. Relative tsunami amplitudes are preserved.**
>
> **2. Directivity is preserved.**
>
> **3. No information on absolute amplitude.**

Experiment 2: Complex Geometries

2011 Japan | **1945 Makran**

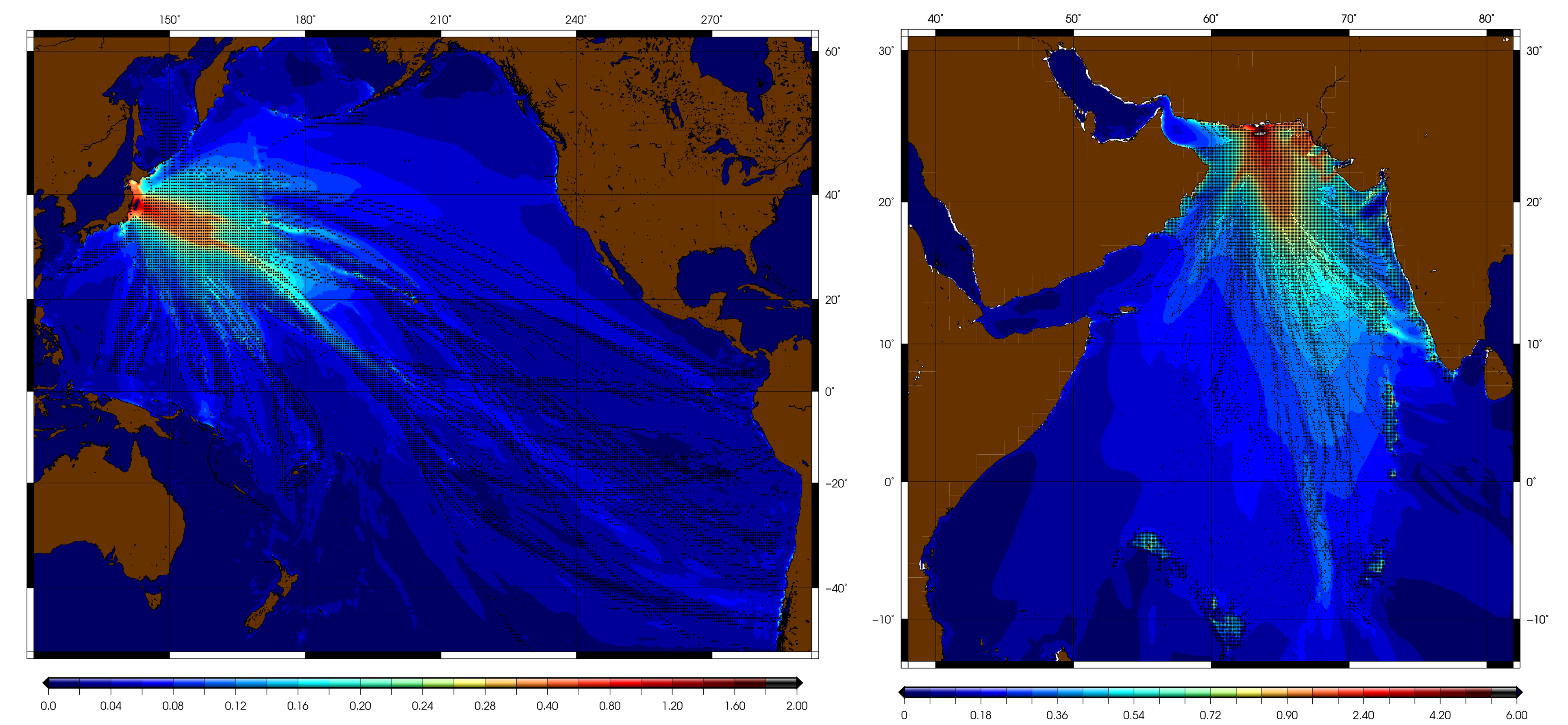

Figure 4: Ray-tracing of discretized static Okada sources (calculated using Mansinha & Smylie's (1971) method) for the (*left*) 2011 Japan, and (*right*) 1945 Makran earthquakes. Black dots represent arbitrary minimum ray densities superimposed over MOST hydrodynamic simulations (Titov *et al*, 2016).

TsuBox v2.0: Toolkit to Ray-Trace Tsunami Sources

TsuBox v2.0, developed at Northwestern University, is a ray-tracing software package for earthquakes, landslides, and polar tsunamis both as point and finite sources. Please scan the code below for more information!

Scan me

Conclusion

Our results show that while ray-tracing of tsunamis cannot fully replace hydrodynamic simulations, it can be used to obtain very fast estimates of tsunami propagation, especially in the far-field. Future studies on the effects of addition of effects such as attenuation and initial amplitudes will help to obtain more robust ray-tracing results.

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