

SWOT Satellite Altimetry Observations and Source Model for the Tsunami from the 2025 M 8.8 Kamchatka Earthquake



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Abstract

On 29 July 2025, an M_w 8.8 earthquake struck off Kamchatka, Russia, generating a Pacific-wide tsunami and marking the largest earthquake since the launch of the surface water and ocean topography (SWOT) satellite in 2022. We analyze tsunami observations from SWOT together with three nearby deep-ocean assessment and reporting of tsunamis (DART) buoys to resolve the source of the event. SWOT provided the first high-resolution spaceborne track of a great subduction-zone tsunami, capturing waveforms that reveal complex propagation, dispersion, and scattering. Inversion of the DART time series using Gaussian unit sources shows that the rupture extended ~ 400 km along strike, with peak uplift of ~ 4 m, significantly different from the published finite-fault model. A blended source that combines the DART-inverted uplift with subsidence from the seismic-geodetic model best matches both datasets and reproduces the SWOT observations. Comparison with reconstructions of the 1952 M_w 9.0 Kamchatka earthquake indicates that the 2025 rupture likely reactivated significant portions of the megathrust that broke in 1952 but occurred farther down-dip and with little to no near-trench slip, consistent with its smaller tsunami impact. These findings highlight the hazard implications of short recurrence intervals of great earthquakes and show how rupture style governs tsunami severity. They also demonstrate the value of satellite altimetry for improving tsunami source characterization, post-event forecasting, and understanding of hydrodynamic processes.

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Supplemental Material

Overview and Impacts of the Event

On 29 July 2025, an M 8.8 earthquake struck off the coast of the Kamchatka Peninsula (Fig. 1), marking the sixth largest earthquake ever recorded globally since 1900 (Wirth *et al.*, 2022). The rupture occurred along the Kuril–Kamchatka subduction zone, where the Pacific plate dives beneath the North American plate at ~ 8 cm/yr (Prytkov *et al.*, 2017), one of the fastest convergence rates on Earth (Argus *et al.*, 2011), and where cold, dense oceanic lithosphere is driven steeply into the mantle (Koulakov *et al.*, 2011). This highly coupled plate interface (Bürgmann *et al.*, 2005; Prytkov *et al.*, 2017) has produced numerous great megathrust ruptures, making it one of the most seismically and tsunamigenic active margins in the world. The 1952 M 9.0 event (Hutchinson, 1954; Johnson and Satake, 1999; MacInnes *et al.*,

2010), produced one of the largest recorded Pacific tsunamis (Kaistrenko and Sedaeva, 2001). That event was pivotal in advancing tsunami science and modern warning systems, laying the groundwork for the international monitoring and

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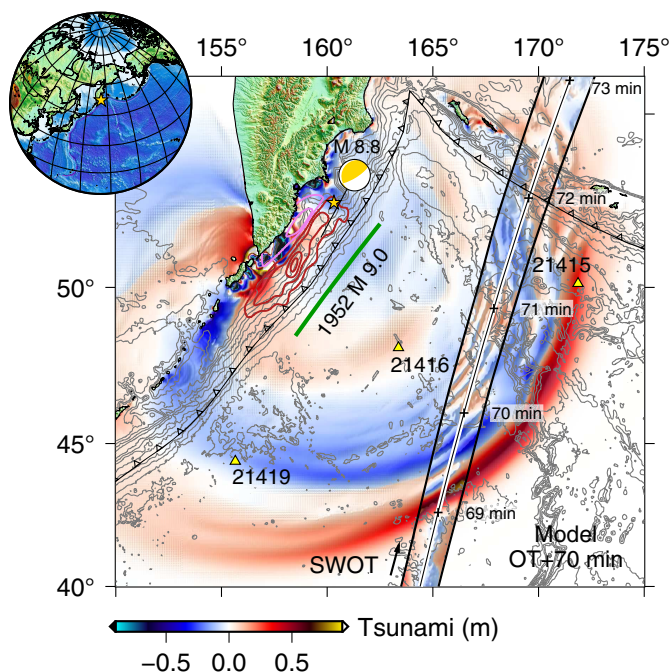


Figure 1. Regional context for the **M** 8.8 Kamchatka, Russia, earthquake and tsunami. The star is the event hypocenter, and the focal mechanism is from the *W* phase solution, both produced by the U.S. Geological Survey (USGS Earthquake Hazards Program, 2017). The green thick line is the modeled source extent for the 1952 **M** 9.0 earthquake from (MacInnes *et al.*, 2010). Color mapping shows the sea-surface height from the tsunami model output at 70 min after origin time (OT). Surface water and ocean topography (SWOT)-derived sea-surface height measured on 30 July 2025 (00:35–00:39 UTC) is superimposed, and the satellite's flight direction is shown by the arrow. Crosses indicate the satellite's position at different times after the earthquake origin. The best-fitting initial sea-surface condition is shown in contours spaced 1 m apart; maroon contours represent uplift, and pink contours are subsidence. The locations of the three ocean assessment and reporting of tsunamis (DART) buoys (yellow triangles) used for inversion are shown as well. Bathymetry contours at 1000 m intervals are shown in light gray.

communication networks that responded to the 2025 tsunami. The 2025 earthquake generated a Pacific-wide tsunami, detected by tide gauges and deep-ocean instruments, prompting warnings, evacuations, and emergency responses across the Pacific Rim.

In this article, we present a new set of observations of the 2025 tsunami from the surface water and ocean topography (SWOT) satellite altimeter (Morrow *et al.*, 2019), offering an unprecedentedly dense space-based measurement of tsunami propagation at high resolution; this event is the largest magnitude recorded since the launch of SWOT in 2022. We compare observations from SWOT and deep-ocean pressure

gauges from the deep-ocean assessment and reporting of tsunamis (DART) buoy system to assess their consistency and potential for rapid hazard characterization, and for understanding tsunami hydrodynamics. Using DART observations, we invert for the tsunami source and compare the resulting seafloor deformation model against available coseismic slip inversions derived from seismic and geodetic data. We show that the **M** 8.8 source must extend farther to the south, totaling a rupture length of ~ 400 km, significantly longer than currently available slip models, which suggest a rupture length of only ~ 300 km. In addition, we compare the tsunami source to those produced by MacInnes *et al.* (2010) for the 1952 **M** 9.0 earthquake to understand whether the 2025 event represents the re-rupturing of that portion of the megathrust.

The opportunity to capture dense, high-resolution altimetry observations of a major tsunami alongside independent source inversions is rare, providing unique insights into tsunami propagation, source characterization, and the role of satellites in operational warning systems, rapid response, and source analysis.

Tsunami Observations, Processing, and Modeling Methodology

DART buoys

The DART system (Fig. 1) is a global National Oceanic and Atmospheric Administration (NOAA)-led network of real-time tsunami monitoring stations. Each DART consists of a seafloor bottom pressure recorder (BPR) and a surface buoy. The BPR continuously measures the water column pressure at sub-centimeter resolution, sensitive enough to detect millimeter-scale tsunami waves. Data are sent acoustically to the surface buoy, and then via satellite to shore, normally transmitted every 15 min, but automatically switches to “event mode” (60 s or 15 s) when anomalous pressure signals are detected. For the 2025 Kamchatka tsunami, multiple DARTs recorded the wave's propagation. We focus on three sites (Fig. 1) near the tsunami source, with observations lightly processed, interpolated to 15 s, and high-pass filtered (2 hr corner) to remove the tides. These postprocessed data are used to perform a tsunami source inversion, estimating the seafloor deformation that best explains the recorded waveforms.

Satellite altimetry observations from SWOT

We leverage sea surface height (SSH) data from the SWOT satellite program (National Aeronautics and Space Administration [NASA]/Centre National d'Études Spatiales [CNES]

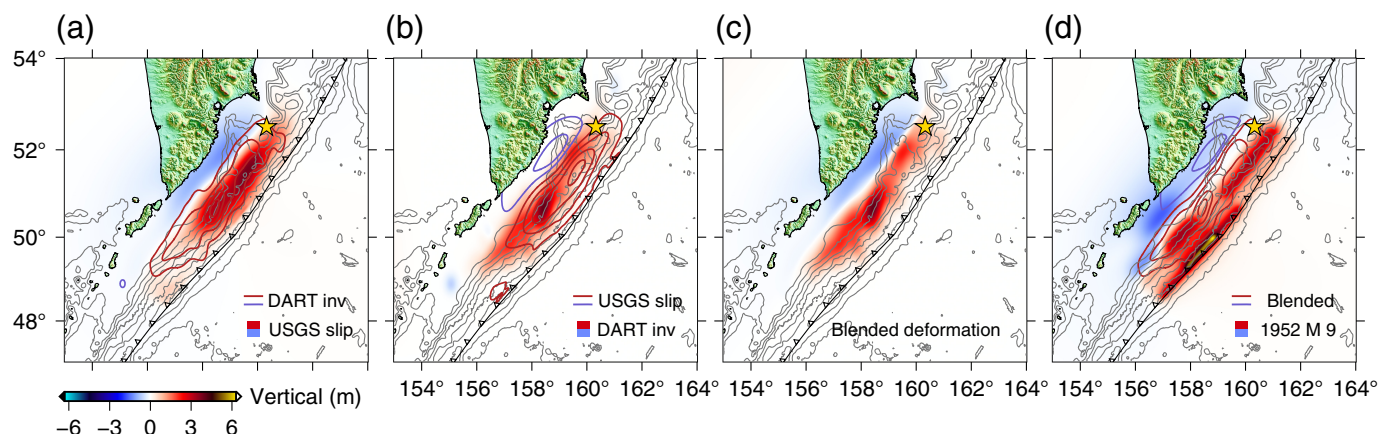


Figure 2. (a) Vertical coseismic deformation from the USGS version 3 finite-fault model in solid colors compared to our best-fitting inversion from DART data shown in contours. Bathymetry shown as 1000 m contours in light gray. (b) Same as (a), but the inversion is in solid colors and the USGS model in contours. (c) Blended model consisting of the uplift from (b) with the subsidence from (a). (d) Comparison between the blended model of (c) and the deformation from the JASmod7 slip model for the 1952 *M* 9 earthquake from [MacInnes et al. \(2010\)](#).

collaboration, [Morrow et al., 2019](#)), which captured unprecedented details of the tsunami from the *M* 8.8 Kamchatka earthquake. We employ the SWOT track from ascending pass number 267 of cycle 36 (Fig. 1).

SWOT provides an ~120 km-wide swath of SSH measurements. In this study, we rely on the latest release (v.2.0.1) of level-3 SWOT data, namely the SWOT_L3_SSH “Basic” (2-km resolution) product, derived from the L3 SWOT Ka-band Radar Interferometer, KaRIn, low-rate ocean data products provided by NASA/Jet Propulsion Laboratory and CNES ([AVISO/DUACS, 2023](#)). Level-3 processing removes SWOT’s systematic errors (mainly roll/phase) and excludes data flagged for atmospheric perturbations, and it has been extensively validated (e.g., [Dibarbouré et al., 2025](#)). Particularly, we used the denoised sea level anomaly, where the denoising process is performed using a complex convolutional neural network-based algorithm with a U-net architecture, reducing high-frequency noise while preserving coherent geophysical signals ([Tréboutte et al., 2023](#)). We also used the SWOT-Nadir altimeter data, located at the center of the track, for complementary analysis. Although the tsunami signal is much larger than the typical mesoscale variability that SWOT is designed to observe, the instrument’s spatial resolution is sufficient to resolve features at 10–100 km scales, including the observed dispersion ([Tranchant et al., 2025](#); [Wang et al., 2025](#)).

Earthquake sources and crustal deformation

For the 2025 Kamchatka earthquake, we use the U.S. Geological Survey (USGS) finite-fault Version 3 source model ([U.S. Geological Survey \[USGS\] Earthquake Hazards Program, 2017](#)), which combines teleseismic body and surface waves together with Interferometric Synthetic Aperture Radar (InSAR)-derived surface displacements ([Goldberg et al., 2022](#)). The combined dataset improves resolution of the slip distribution by leveraging

the complementary strengths of seismic and geodetic observations: teleseismic waveforms constrain the rupture timing and overall moment release, whereas InSAR provides high-spatial-resolution constraints on the near-field deformation pattern. The USGS V.3 model represents the rupture on a discretized planar fault consistent with the Kuril–Kamchatka subduction interface geometry, with subfault slip, rake, rupture time, and rise time estimated by simulated annealing optimization.

To model the seafloor deformation associated with the rupture, we compute displacements assuming an elastic layered half-space representation of the Earth, parameterized with LITHO1.0 crust over a preliminary reference Earth model mantle ([Pasyanos et al., 2014](#)), accounting for realistic variations in seismic velocities and elastic moduli. The resulting vertical deformation (Fig. 2a,b) serves as the initial condition for tsunami generation.

Direct inversion of DART buoys for the tsunami source

Because there are discrepancies (discussed later) between the predicted tsunami from the USGS source model and the DART observations, we produced our own tsunami source estimate (Fig. 2b,c). We inverted deep-ocean tsunami records from three DART buoys, 21415, 21416, and 21419 (Figs. 1 and 3), to estimate the initial sea-surface displacement of the 2025

Kamchatka event. The inversion follows a “Gaussian lump” parameterization (e.g., [Lin *et al.*, 2020](#); [Wang *et al.*, 2023](#); [Santallanes *et al.*, 2025](#)), in which the initial water surface is represented as a sum of localized Gaussian-shaped perturbations. Each Gaussian has a standard deviation of 15 km and is centered on a grid with 0.3° spacing in both latitude and longitude. This formulation allows for a smooth, spatially compact representation of the source while limiting the number of free parameters. A key advantage of this approach is that it makes no assumptions about the earthquake source geometry, rake, or slip distribution, allowing the tsunami data alone to determine the spatial pattern of initial displacement. The approach assumes linearity, and, although GeoClaw solves the fully nonlinear shallow-water equations (SWEs), for the small-amplitude, first-wavelength tsunami signals used in the inversion, the solution is well approximated by the linearized equations. Previous studies have shown that the error introduced by this is modest to negligible ([Melgar and Bock, 2013](#)).

The inversion domain surrounds the USGS V.3 finite-fault source, ensuring the solution is physically consistent with independent seismic and geodetic constraints while allowing for the exploration of deviations in source location or extent. To compute the tsunami Green’s functions for each Gaussian basis element, we used GeoClaw ([Clawpack Development Team, 2024](#))—a finite-volume numerical model that solves the nonlinear SWEs for wave propagation and inundation. For each Gaussian, an initial sea-surface displacement was prescribed and propagated through the model to each DART location, producing unit-amplitude synthetic waveforms. The tsunami wavefield at the buoys is then represented as a linear combination of these precomputed Green’s functions, with the inversion solving for the optimal coefficients of each Gaussian.

DART time series were band-pass filtered between 2 min and 2 hr to isolate as much as possible the tsunami band and suppress both high-frequency noise and long-period background signals (e.g., tides, infragravity waves). Rayleigh waves from the earthquake contaminate the earliest part of the DART pressure records. These surface waves generate vertical accelerations recorded as pressure fluctuations in the water column. To mitigate this effect and ensure linearity in the inversion, we manually picked the first clear wavelength of the tsunami signal for each buoy (yellow-shaded regions in [Fig. 3a](#)) and limited the inversion to that time window. This choice is motivated by the fact that, while tsunami propagation is inherently nonlinear, a linear Green’s function-based inversion can be valid when modeling is restricted to only the initial portion of the wavetrain before

significant nonlinear interactions and dispersion occur ([Melgar and Bock, 2013](#); [Gusman *et al.*, 2016](#)).

The resulting inversion ([Fig. 2a,b](#)) yields an initial sea-surface displacement field derived directly from tsunami observations, which we compare to the deformation predicted by the USGS V.3 finite-fault model to evaluate consistency and identify possible differences in source characteristics.

Hydrodynamic modeling to match SWOT observations

Using GeoClaw and our preferred initial condition model ([Fig. 2](#)), we propagate the tsunami across the open ocean at high resolution using the Shuttle Radar Topography Mission 15+ global bathymetry data set ([Tozer *et al.*, 2019](#)). During its ascending pass, SWOT travels south to north along its polar orbit, it samples the tsunami at different times; it is not a single snapshot at a fixed moment. Thus, to create a synthetic SWOT track, we extract tsunami amplitudes from our simulations at the coordinates of each SWOT pixel at the appropriate time. To do so, we generate output at over 60,000 synthetic tide gauges and interpolate them to create a consistent synthetic product ([Figs. 1](#) and [3c,d](#)). In addition, to try to reproduce as much of the wavefield captured by SWOT as possible, we included dispersive wave dynamics from the Boussinesq-type solvers recently implemented in GeoClaw ([Berger and LeVeque, 2023](#)). These are based on the Serre–Green–Naghdi equations, a depth-averaged dispersive system that extends the standard SWE by including higher-order derivative terms. Adaptive mesh refinement is maintained by interpolating dispersive correction terms across refinement levels. This hybrid approach allows GeoClaw to capture dispersion during tsunami propagation while maintaining computational efficiency and stability near shore. For both the inversion and the set of forward simulations described in this section, we assume an instantaneous seafloor deformation (static source), neglecting finite-duration rupture kinematics. Previous work indicates that, at the distances and for the first-arriving wave considered here, the impact of rupture kinematics on deep-water tsunami amplitudes is modest to negligible (e.g., [Williamson *et al.*, 2019](#); [Melgar, 2025](#)).

Results and Discussion

Tsunami source

The best-available slip model for the event is the USGS V.3 finite fault from joint teleseismic and InSAR inversion. When we use it to initialize a hydrodynamic model ([Fig. 2a](#)) and compare it to DART observations ([Fig. 3b](#)), it shows predicted

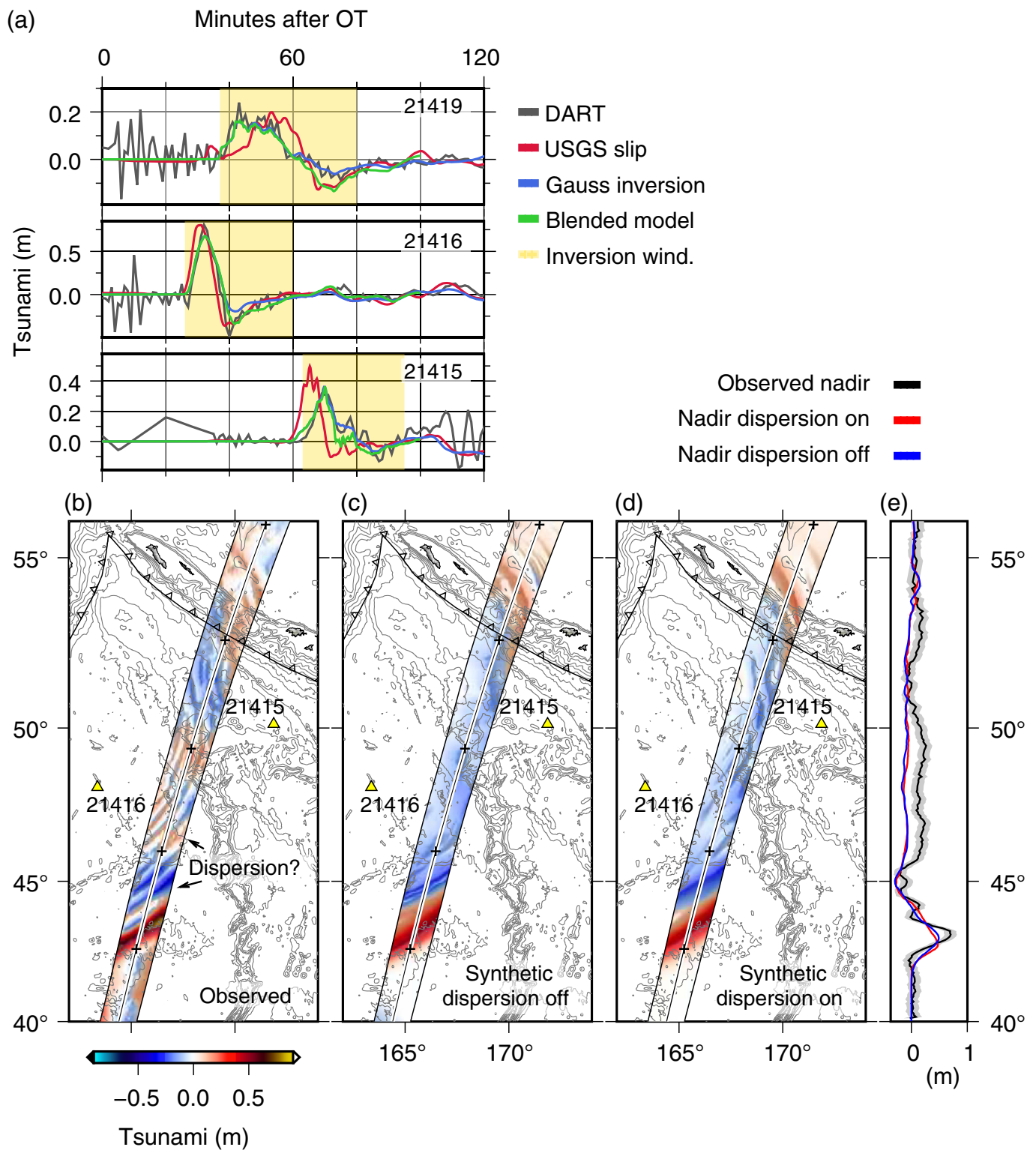


Figure 3. (a) Fits to the DART observations (all locations in Fig. 1) from the USGS V.3 slip model, our best-fitting Gaussian inversion, and the blended model. The yellow-shaded regions indicate the portions of the waveform used for inversion. (b) SWOT observations of sea-surface height. Locations of DART buoys are shown in yellow triangles. The crosses are spaced 1 min apart as in Figure 1. Bathymetry contours at 1000 m spacing are shown in

light gray. (c) Same as in (b) but showing the synthetic SWOT track resulting from the blended model in Figure 2, and (d) is the synthetic track with dispersive wave dynamics. (e) Comparison of the observed and synthetic sea-surface height anomalies along the satellite's near-nadir. The gray-shaded regions indicate the one-sigma uncertainty in the observations.

waveforms arriving 3 and 10 min early at DARTs 21415 and 21416, respectively, and 12 min late at 21419. These are major discrepancies.

Meanwhile, the Gaussian lump inversion corrects these large timing issues with ease. It is significantly different than the USGS source, it has much larger uplift in the southern 200 km and suggests that the extent of the earthquake is at least 400 km with a peak uplift of ~ 4 m at 51° N. There are some similarities, though, with both the USGS V.3 and Gaussian models showing a similar “down-dip” extent, the rupture terminates ~ 300 km landward of the trench.

However, unlike the USGS V.3 model, the Gaussian inversion has almost no subsidence, as would be expected for a pure thrust earthquake, underestimating the negative pulse at 40 min after origin time (OT) at DART 21416. The USGS V.3 model, despite its timing issues at all buoys, does a better job of replicating the amplitude of this negative pulse. For this reason, we produced a “blended” model (Fig. 2c), which retains the positive/uplift portion of the Gaussian inversion and combines it with the negative/subsidence portion of the USGS V.3 model. When we run the hydrodynamic propagation, we find that this blended source fits all three DART buoys to a similar degree as the Gaussian inversion (Fig. 3a), with the added benefit of producing a more significant negative pulse at 21416. For this reason, we consider the blended model our “preferred” tsunami source.

Does 2025 re-rupture the portion of the megathrust involved in the 1952 M 9 event?

The 2025 earthquake likely re-ruptures significant portions of the megathrust that ruptured in 1952, likely limited to the down-dip portions of it. To establish this, we studied the results of MacInnes *et al.* (2010), who combined historical observations with 31 new tsunami-deposit surveys along Kamchatka and the northern Kuril Islands to reconstruct near-field runup from the 1952 earthquake. They implemented the NOAA-MOST model with different hypothetical slip distributions to simulate tsunamis and compare results against the expanded dataset. Their results showed that the best fits required concentrated, near-trench high-slip patches off southern Kamchatka and the northern Kurils, indicating heterogeneous rupture with significant slip extending closer to the trench than previously inferred. In Figure 2d, we calculated the uplift/subsidence from the best-fitting slip model from that work, labeled JASmod7 by the authors, against our preferred 2025 model. The along-strike extent is nearly identical; however, the deformation from the

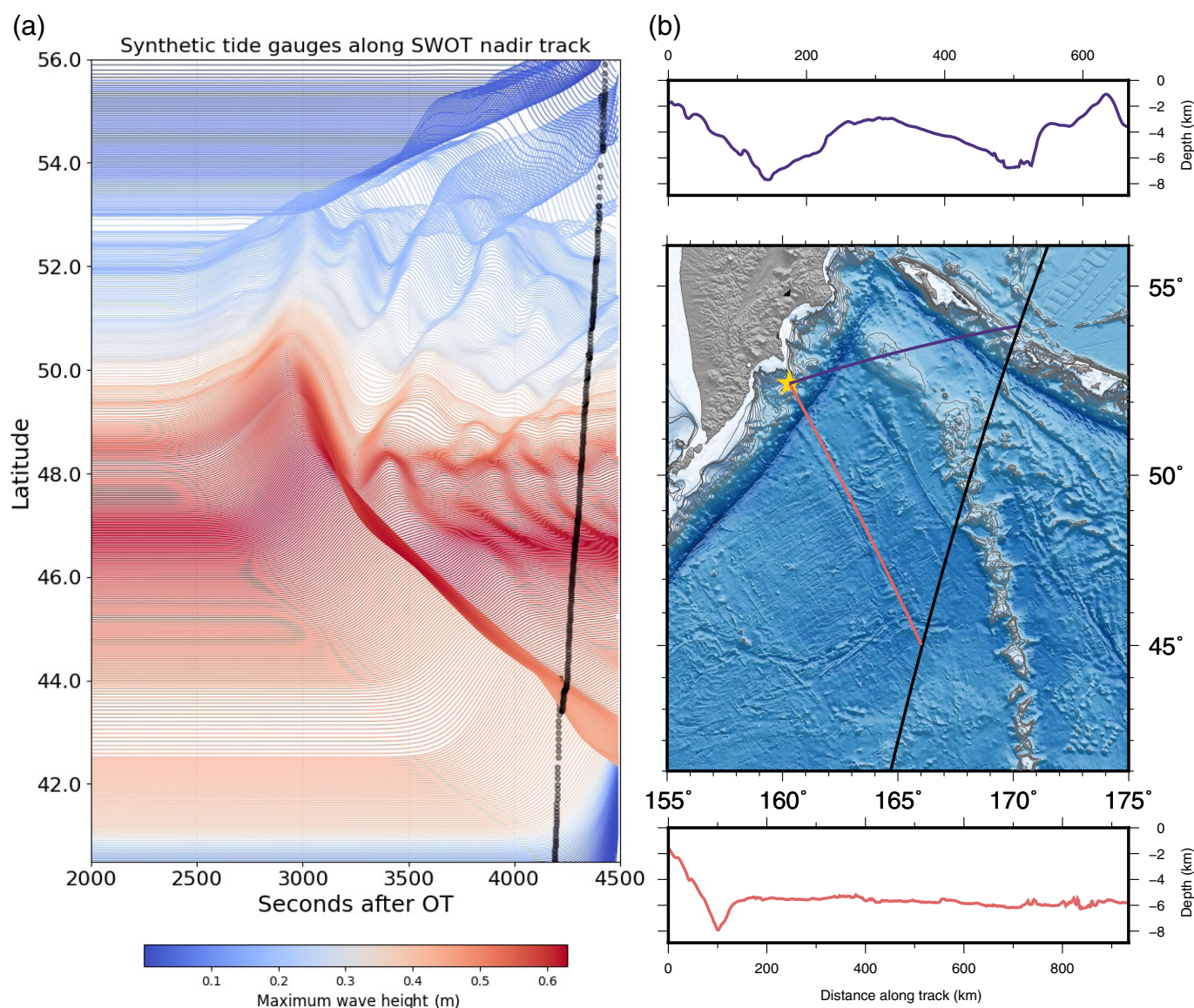
2025 earthquake is located farther down-dip than in 1952 and involves no near-trench slip. This is consistent with 1952 having a much more damaging tsunami. Tantalizingly, our peak uplift lies between two high uplift patches from the 1952 earthquake. The large slip regions from JASmod7 from MacInnes *et al.* (2010) have 9–15 m of slip. At a convergence rate of 8 cm/yr, only 5–6 m of slip could have reaccumulated since the 1952 rupture, so our results are a strong suggestion that the 1952 earthquake did not release the entirety of the available slip budget and that some residual slip was left behind and used by the 2025 rupture.

Understanding the observations from SWOT and implications for hydrodynamics

The use of satellite-derived observations of sea-surface heights for tsunamis has been limited by the spatial resolution of the traditional altimetry satellites. The ocean signal from the 2004 M 9.1 Sumatra event was retrieved from Jason-1 and ENVISAT tracks; however, the data processing for this was not trivial and the signal-to-noise ratio was low despite the very large magnitude (Song *et al.*, 2005). The new generation SWOT satellite has greatly improved those capabilities, including additional bands, revealing intriguing details of the tsunami. Figure 3b clearly shows the tsunami front (about 43° N) and how the tsunami main beam propagates southeast, whereas the SWOT ascending trajectory is toward the north-northeast. Previous to this event, two other examples were captured by SWOT: the landslide induces Dickson fjord tsunami (Monahan *et al.*, 2025) and Loyalty Islands M 7.7 event (Roger *et al.*, 2025), both showing complex dispersive modes that challenge numerical models.

Figure 4a shows the time history of the tsunami-wave amplitude along the synthetic nadir track (the center of the SWOT track) from our simulation with dispersion. Waveforms transition from nearly undisrupted ($<46^\circ$ N), to undisrupted with dispersion (46° – 49° N), and highly disrupted at higher latitudes ($>50^\circ$ N), in which complex bathymetry scatters the tsunami, splitting the wavefront into multiple pulses. This representation shows the complex propagation of the tsunami across the Pacific. The SWOT observations similarly show a high-amplitude wavefront followed by multiple lower-amplitude wavefronts.

Somewhat surprisingly, dispersion is important to explain features in the SWOT track behind the main tsunami front. For tsunamis generated by large subduction earthquakes, the dominant wavelengths are so much greater than the ocean



depth that, in this long-wave regime, the SWE typically provide an accurate-enough description of the tsunami; dispersive effects are usually considered minimal (Glimsdal *et al.*, 2013). However, we observed that the wavetrain behind the main front (Fig. 3b) is not explained properly by the pure SWE solution (Fig. 3c). When dispersive terms are allowed (Fig. 3d), the comparison, while still not perfect, is much better. One likely explanation is that interactions between the tsunami, at its origin, with the complex bathymetry of the trench and continental slope, and with the near-source coastline, generate shorter-wavelength features which propagate out to the open ocean and require dispersion to be modeled correctly. Although enabling dispersion in the forward model improves

Figure 4. (a) Time series of normalized synthetic tide gauges along the SWOT nadir track for the real SWOT pass (black dots) showing the waveforms of the propagating tsunami wave. The wave is undisturbed for the lower latitudes, 41°–47° N, and shows complex waveforms for higher latitudes. The band between 46° and 50° N shows the combination of pure propagation plus dispersive bands observed in SWOT. (b) Shuttle Radar Topography Mission (SRTM) 15+ high-resolution bathymetry showing the SWOT nadir track (black) and two representative trajectories (purple and peach), with their corresponding bathymetry shown in the same color above (purple) and below (peach).

the agreement with SWOT, the satellite still observes a more strongly dispersive wavetrain than our simulations. We attribute this mainly to the limited spatial resolution of our inversion,

which is constrained by only four buoys and a coarse parameterization, rather than to the use of nondispersive Green's functions for the inversion, which fit only the first, essentially nondispersive wavelength. Future multidata inversions with higher slip resolution are expected to recover more short-wavelength source structure and thereby generate a richer dispersive signal that better matches SWOT.

Implications for hazards

The 2025 Kamchatka earthquake underscores the continuing hazard posed by great megathrust ruptures along the Kuril–Kamchatka margin. Slightly smaller in magnitude than the 1952 M 9.0 earthquake, the M 8.8 event re-ruptured a large portion of the same segment, showing that this margin can generate “great” earthquakes on sub-century timescales. This recurrence in less than a century is a cautionary signal for seismic hazard models, which often assume centennial or longer recurrence intervals for the largest events. The implication is that strain release in 1952 was incomplete, with the 2025 rupture consuming residual slip that remained. This raises the prospect that even large ruptures may not exhaust the seismic potential of a megathrust, leaving behind hazardous asperities capable of generating future great events. Similar behavior has been suggested for other subduction zones that produce large earthquakes (e.g., Yamazaki *et al.*, 2025).

From a tsunami hazard perspective, the comparison of 2025 and 1952 (Fig. 5) is particularly striking. The 1952 rupture included significant shallow, near-trench slip that generated a catastrophic trans-Pacific tsunami; the 2025 event ruptured further down-dip and produced a smaller, although still ocean-basin-wide, tsunami. The difference highlights how the tsunami hazard is not dictated by magnitude alone but by the details of the depth distribution of slip. The 1952 event devastated Pacific coastlines with runups exceeding 15 m in Kamchatka and damaging waves across the Pacific Rim. In contrast, the 2025 tsunami, though widely observed, was less destructive. Still, the 2025 case shows that even without trench-breaking slip, an M 8.8 event can trigger mass coastal evacuations across multiple nations and impose major societal costs.

Together, these events emphasize two key points for hazard science and risk mitigation. First, recurrence of great earthquakes on sub-century timescales cannot be ruled out in fast-converging margins, which challenges overly simplistic views of the seismic cycle. Second, the tsunami hazard is highly sensitive to rupture style. Deep-slipping ruptures may produce relatively modest waves, but shallow trench-breaching ruptures remain the

primary concern for catastrophic transoceanic tsunamis. For communities around the Pacific, the lesson is clear: preparedness and warning systems must assume both recurrence and variability in rupture style because either outcome carries profound implications for regional and global tsunami risk.

Future uses of satellite altimetry

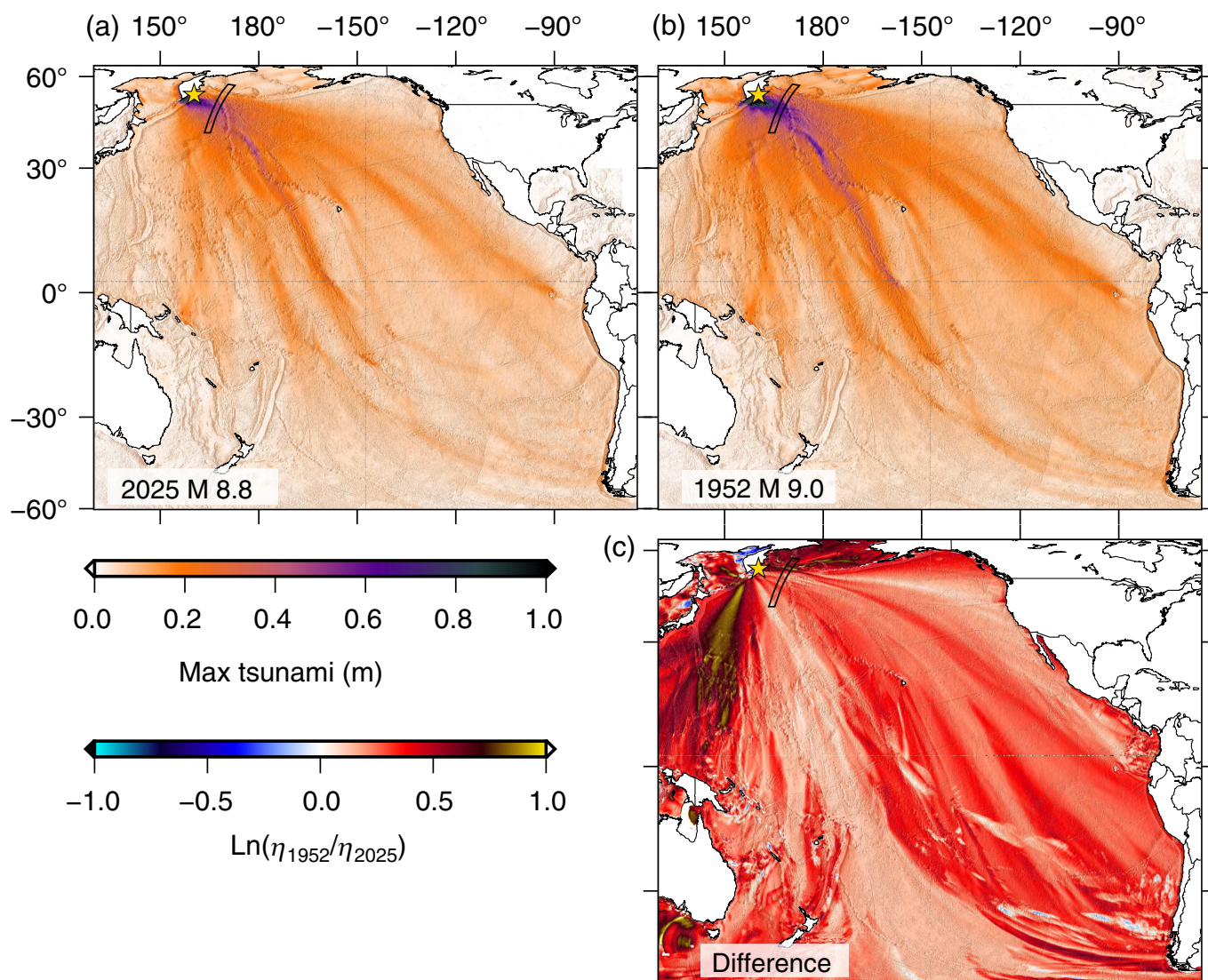
Satellite observations, particularly from the SWOT era, hold significant promise for advancing tsunami science. Although real-time/early warning remains limited by 5–10 day data latency, the 2025 Kamchatka event demonstrates the unique value of satellite altimetry for post-event analysis. The SWOT observations provided an unprecedented view of tsunami propagation, revealing the complexity of waveforms, including dispersion patterns at scales that traditional altimeters could not resolve.

These measurements provide a new tool to improve tsunami modeling and forecasting. Even if not real-time, SWOT-class altimetry can be assimilated into models soon after events to refine hazard assessments during response operations. Dense spatial sampling allows for a detailed study of tsunami hydrodynamics, including dispersion, scattering, and resonance effects, which greatly improves the physical understanding of tsunamis.

Although in situ validation in our study area is limited, the close agreement between SWOT and DART observations provides confidence in the robustness of satellite altimetry for tsunami applications. Future swath altimetry missions with 2D resolution, that reduce data latency or expand spatial coverage, could make space-based altimetry a critical complement to in-ocean and coastal monitoring systems, enhancing both operational response and scientific investigation of complex tsunami processes.

Conclusions

The 2025 M_w 8.8 Kamchatka earthquake and tsunami demonstrate both the hazard potential of repeated great ruptures and the scientific value of new observational tools. The event likely re-ruptured portions of the 1952 rupture zone, but with slip concentrated farther down-dip, producing a smaller tsunami despite its large magnitude. This underscores how rupture style, not magnitude alone, controls tsunami impact. SWOT altimetry provided the first dense spaceborne observations of a great tsunami's wavefield, validating source models against DART data and revealing complex propagation features, which are not completely resolved with current numerical models



and leave room for improving their skills based on a unique set of observations. These results highlight the need to consider both recurrence and variability in rupture behavior when assessing hazard and point to the emerging role of satellite altimetry in refining tsunami forecasts and advancing our physical understanding of tsunami dynamics.

Data and Resources

All data and modeling codes used are open source. Ocean assessment and reporting of tsunamis (DART) buoy data were available at <https://catalog.data.gov/dataset/deep-ocean-assessment-and-reporting-of-tsunamis-dart1>. Surface water and ocean topography (SWOT) altimetry data were available at <https://www.avisio.altimetry.fr/en/data/products/sea-surface-height-products/global/swot-l3-ocean-products.html>. Shuttle Radar Topography

Figure 5. (a) Maximum modeled tsunami amplitudes for the 2025 **M** 8.8 earthquake (η_{2025}). (b) Maximum modeled tsunami amplitudes for the 1952 **M** 9.0 earthquake (η_{1952}). (c) Difference shown as the natural log of the ratio of 1952 to 2025 amplitudes, such that +1 corresponds to the 1952 event being a factor of e larger and -1 the 2025 event being a factor of e (≈ 2.718) larger. In all panels, the yellow star is the event hypocenter, and the 2025 SWOT track is shown as well.

Mission (SRTM) 15+ bathymetry data were available at <https://portal.opentopography.org/raster?opentopoID=OTSRTM.122019.4326.1>. GeoClaw software data were available at <https://www.clawpack.org/geoclaw>. All websites were last accessed in August 2025. The supplemental material to this article includes an animation of the simulated tsunami wave heights generated by the 2025 **M** 8.8 earthquake and the SWOT ascending pass 70 min after the origin time.

Declaration of Competing Interests

The authors acknowledge that there are no conflicts of interest recorded.

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