The Kamchatka Earthquake of 2025, M8.8: Results from Regional Data Processing

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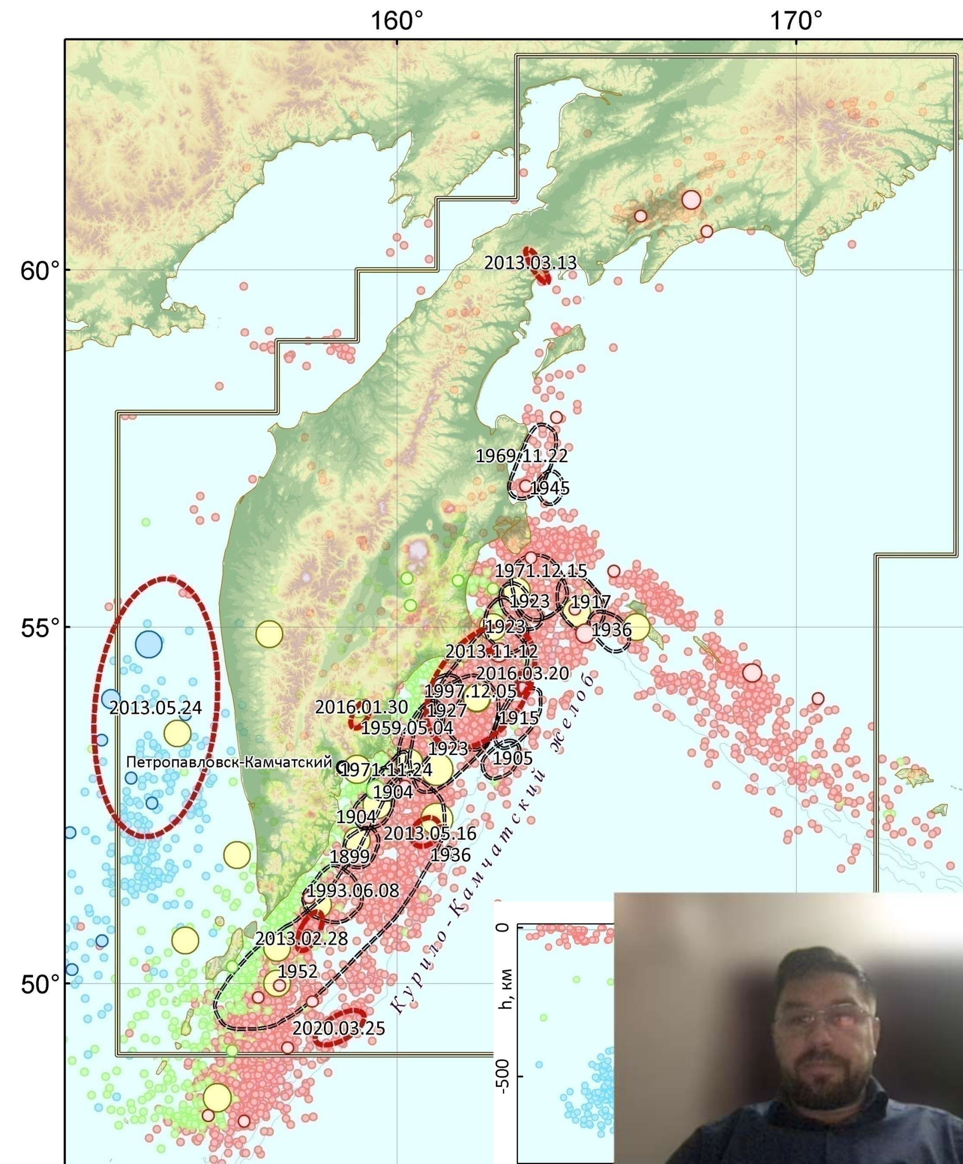
Plan of presentation

- Systems of observations in Kamchatka
- Tsunami warning system
- Earthquake prediction system and expert support of Government Authorities
- Warning system response from Mega-Earthquake
- Earthquake Processing
- Consequences



Seismic Subsystem of Tsunami Warning System in Far East, Russia

Seismic subsystem of Tsunami Warning System, created in 2010, includes:

- 11 specialized seismic stations, including 5 basic stations (micro-arrays)
- 16 strong motion stations
- 3 processing centers
- System of data collection, storage and processing.

The Tsunami Warning System (TWS) is underequipped by modern standards. Its operational functionality is maintained through its integration with regional seismic monitoring networks, specifically the seismological observation system in Kamchatka.

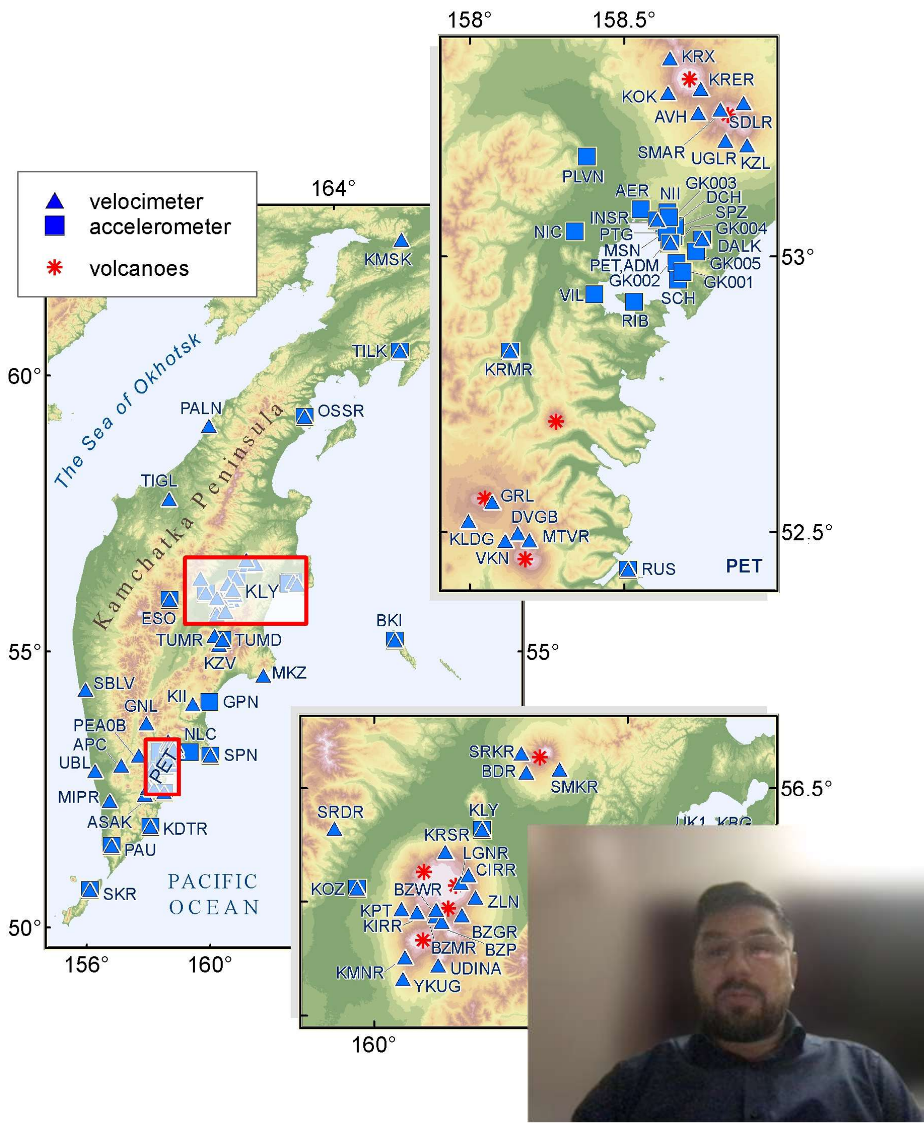
Seismic network in Kamchatka

Currently, 85 seismic stations are operational in Kamchatka.

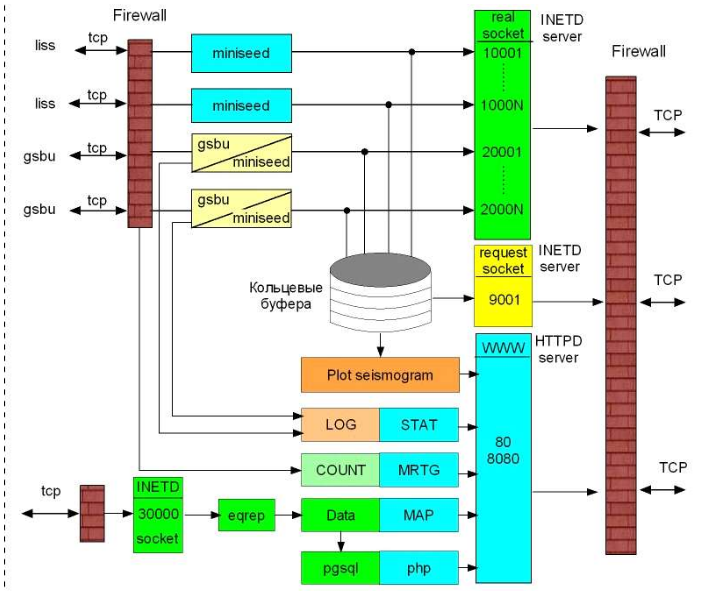
Equipped with both short-period and broadband velocimeters, Kamchatka's seismic stations provide reliable recording of seismic signals across a broad frequency and dynamic range. They enable the identification of earthquakes throughout the whole Kamchatka region with a magnitude of ML ≥ 3.

For events in the Avacha Bay: ML ≥ 2.6; for the Avacha volcanic group – ML ≥ 0.9; and for the Klyuchevskaya volcanic group – ML ≥ 1.6.

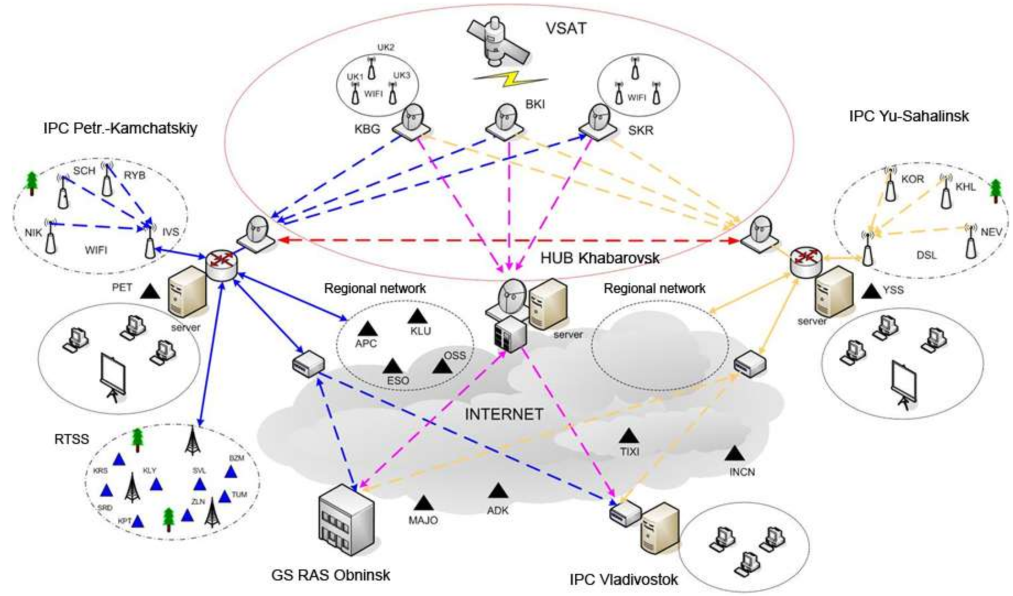
A strong-motion network (accelerometers), concentrated on the eastern coast of Kamchatka and in the Petropavlovsk-Kamchatsky area, ensures the distortion-free recording of the most intense ground motions.



Data collection



Logical structure of the seismic data acquisition server



The data acquisition system relies on satellite communication channels, dedicated optical and telepho
specialized radio-Ethernet networks
communications in the 5.3 GHz range

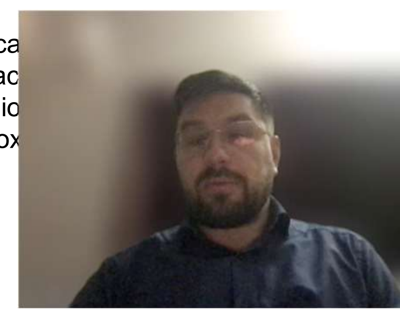
Typical Seismic station in Kamchatka

Challenges of Installing Observation Stations in Kamchatka

- **Heavy snow cover:** Powerful snow accumulation
- **Extreme winds:** Severe wind conditions / Hurricane-force winds
- **Extreme inaccessibility:** The sites are remote and inaccessible, making it impossible to reach and perform maintenance without specialized transport or a helicopter.

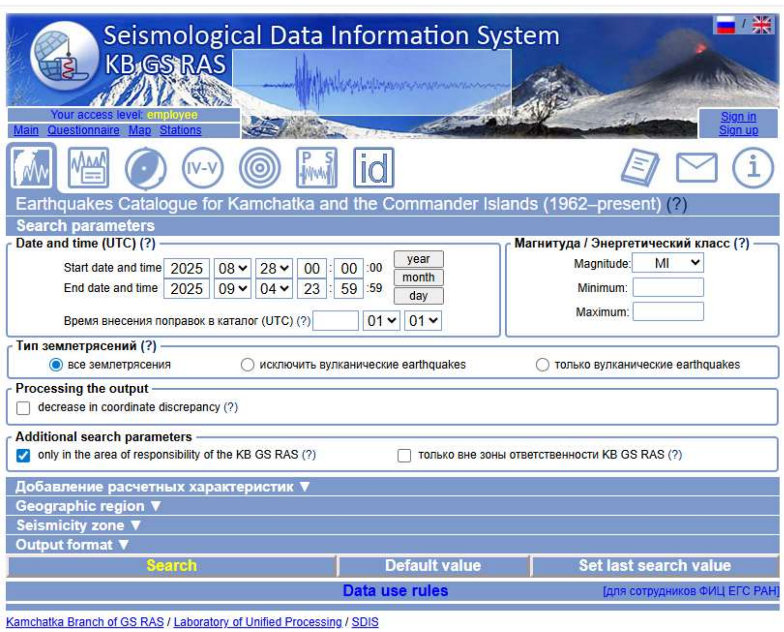
Typical Kamchatka volcanic province

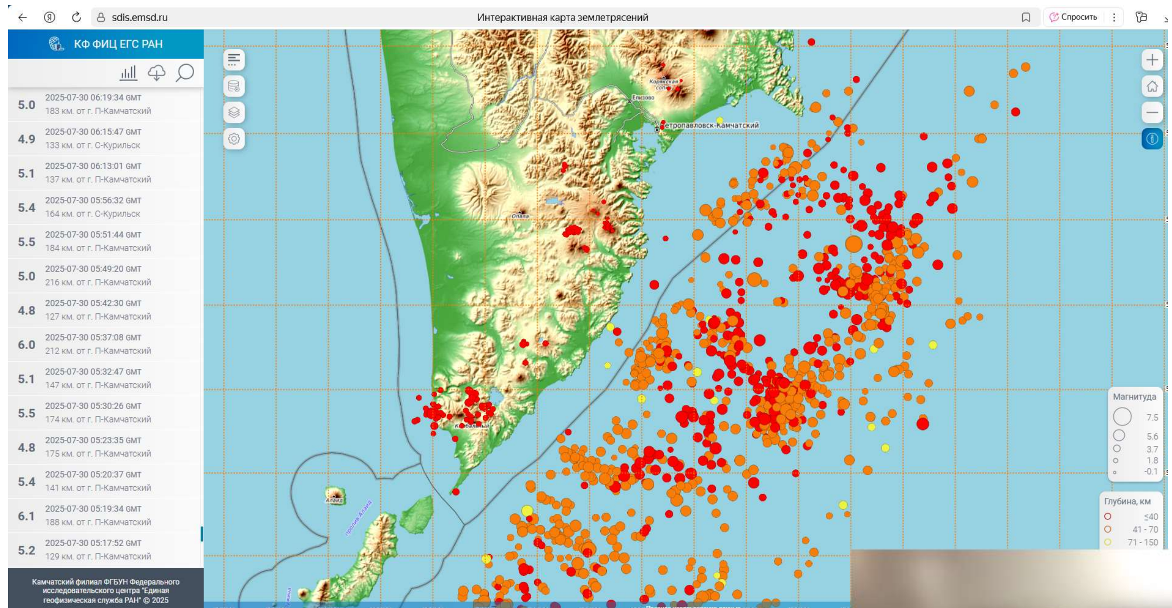
Example of a Nodal Infrastructure Station
The **"Yulia Kugaenko" Relay Station (code: YKUG)** is loca
the Tolbachik Dale, atop Mount Vysokaya. It ensures data ac
sector of the Northern Volcanic Group via a specialized radio
communication link in the 5.3 GHz range (a Wi-Fi link approx
Its composition includes:
A seismic station (broadband velocimeter)
A GNSS station
A video camera for monitoring volcanic activity

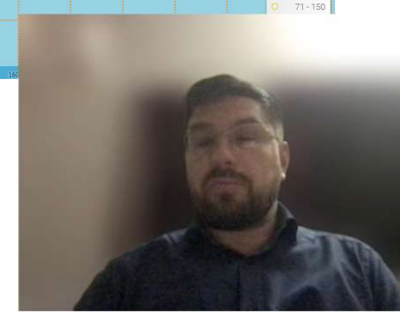


Database: data access

https://sdis.emsd.ru







Access to catalogues

Expert Decision Support System for Government Authorities (seismic and volcanic disasters)

Expert Support System Foundation

The foundation of the expert support system is the Kamchatka Branch of the Russian Expert Council for Earthquake Prediction.

Core Function: Systematizing the practice of earthquake forecasting and providing comprehensive predictive assessments.

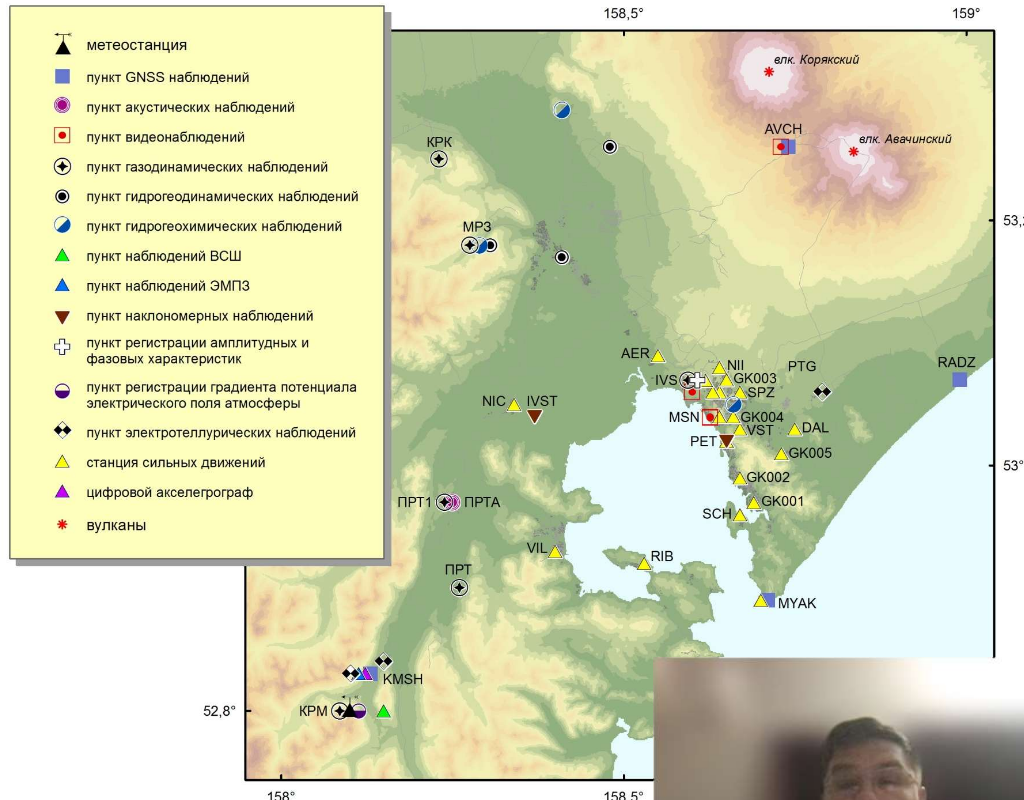
Our Direct Contribution

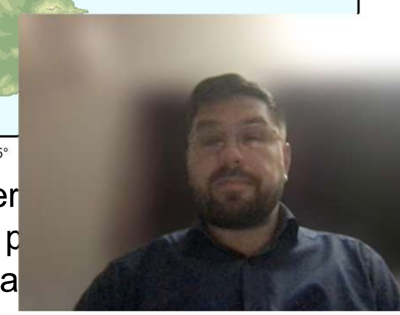
We directly maintain a network of approximately **40 geophysical observation stations** in Kamchatka, aimed at searching for earthquake precursors. The monitoring methods include:

- **Hydrogeochemical** monitoring
- **Hydrogeophysical** monitoring
- **Subsoil gas** monitoring
- **Infrasound** monitoring
- **Tiltmeter** observations
- **GNSS** observations

Primary Role in Emergency Management

However, as a definitive solution to the problem of earthquake prediction remains distant, the Council's most critical practical function has evolved into **supporting decision-making for the EMERCOM** during the development of an emergency. This involves generating and evaluating possible **scenario-based forecasts** for the situation's progression.





System of geophysical obser identification and earthquake p Petrropavlovsk-Ka

Seismic network condition at the Moment of the EQ

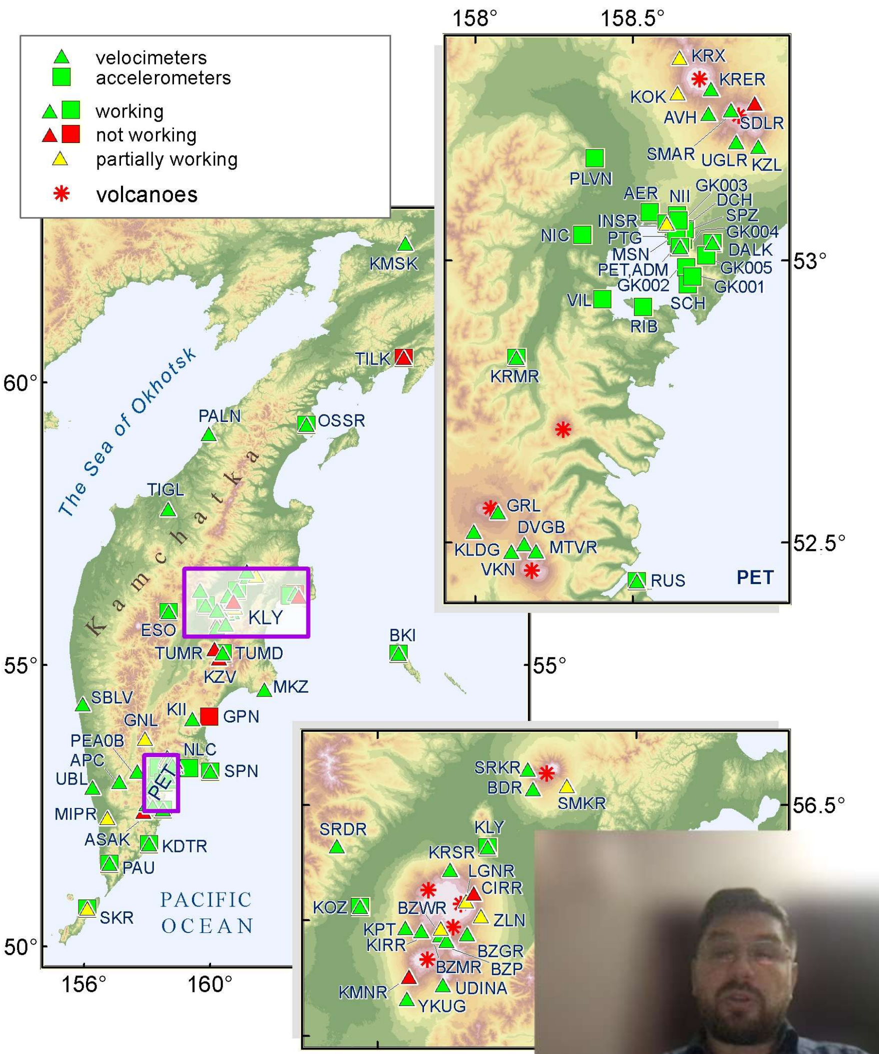
The Kamchatka network was fully operational at the time of the July 29th event, with only 11.5% of recording stations out of service.

As a result of the earthquake:

Velocimeters were overdriven at epicentral distances of up to 15 degrees. (For example, South Sakhalin stations and South Kuril station)

Thanks to the strong-motion accelerometer network, it was possible to promptly determine the earthquake's parameters for the purposes of the Express Reporting Service and the Tsunami Warning System.

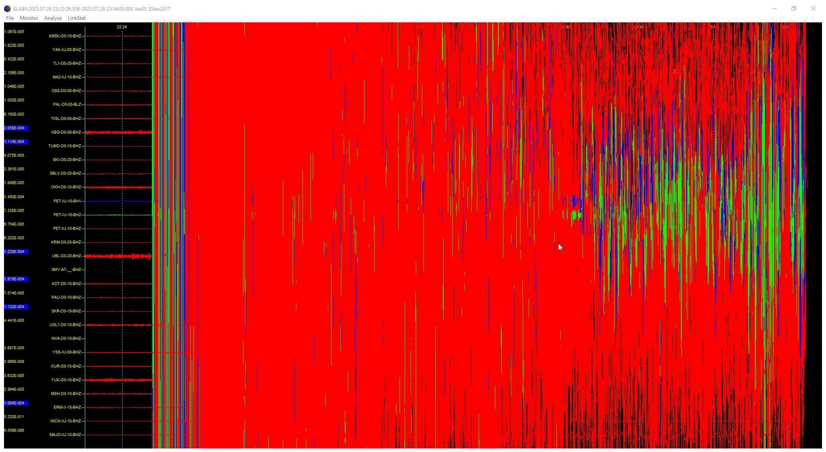
The communication channels demonstrated high reliability. Despite localized power outages, most of the data was successfully collected in real-time.



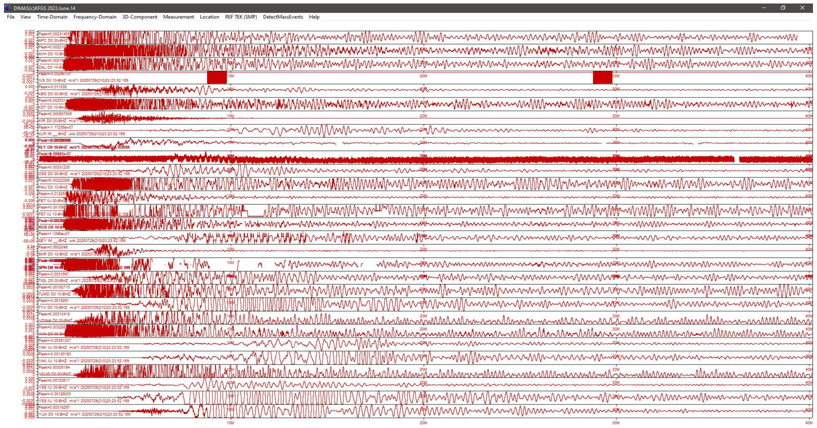
Seismic signals at the Moment of the EQ

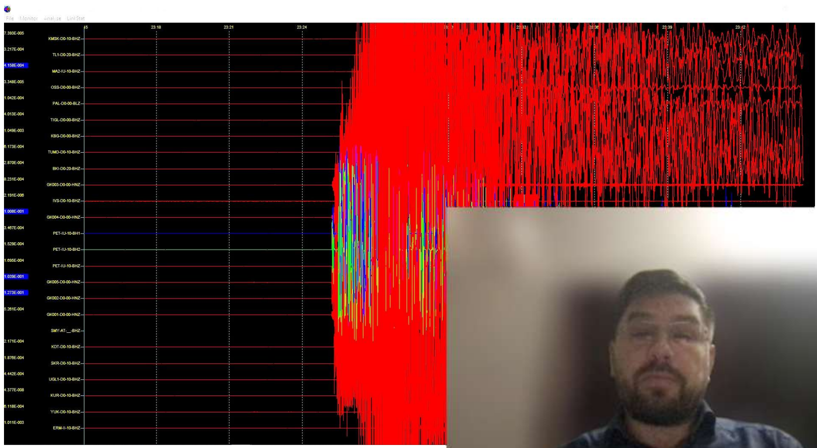
Velocimeters were overdriven at epicentral distances of up to 15 degrees. (For example, South Sakhalin stations and South Kuril station)

Tsunami Warning System had to operate only by accelerometers.



Real-time Display screenshot – overdriven velocimeters





Real-time Display screensh

Tsunami Warning System at the moment of EQ: Timeline

T+5 min: The initial earthquake parameters were determined within five minutes of the event's origin time. An unconditional tsunami alarm was declared for the entire Kamchatka coastline. The magnitude estimate, made before the rupture process was complete, was significantly underestimated.

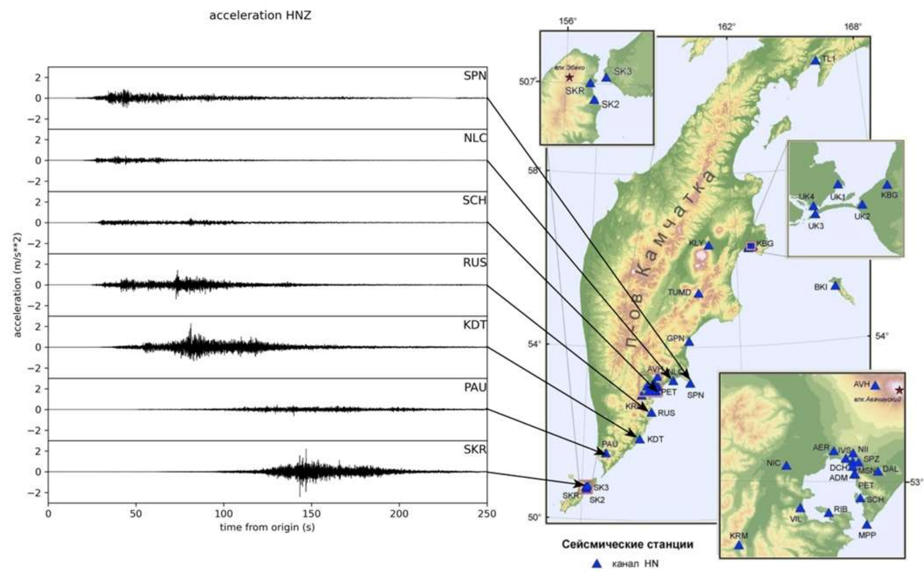
T+10 min: More realistic magnitude estimates became available (M ≈ 8).

T+15-20 min: The moment magnitude estimate was updated to Mw = 8.8 (as reported by the NEIC, many thanks to our colleagues).

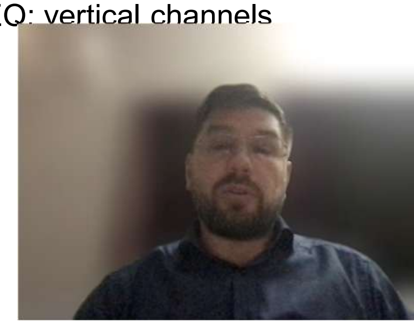
T+30-60 min: The initial seismic moment tensor solutions were released (by the NEIC, thanks again!).

T+10 hours: A seismic moment tensor solution was calculated using our own proprietary methodology.

Impact and Response Effectiveness: The decision to issue an unconditional tsunami alarm enabled the early evacuation of coastal areas. The port of Severo-Kurilsk sustained significant damage; however, there were no human fatalities. This early warning also ensured the safety of individuals located in remote, undeveloped coastal areas.

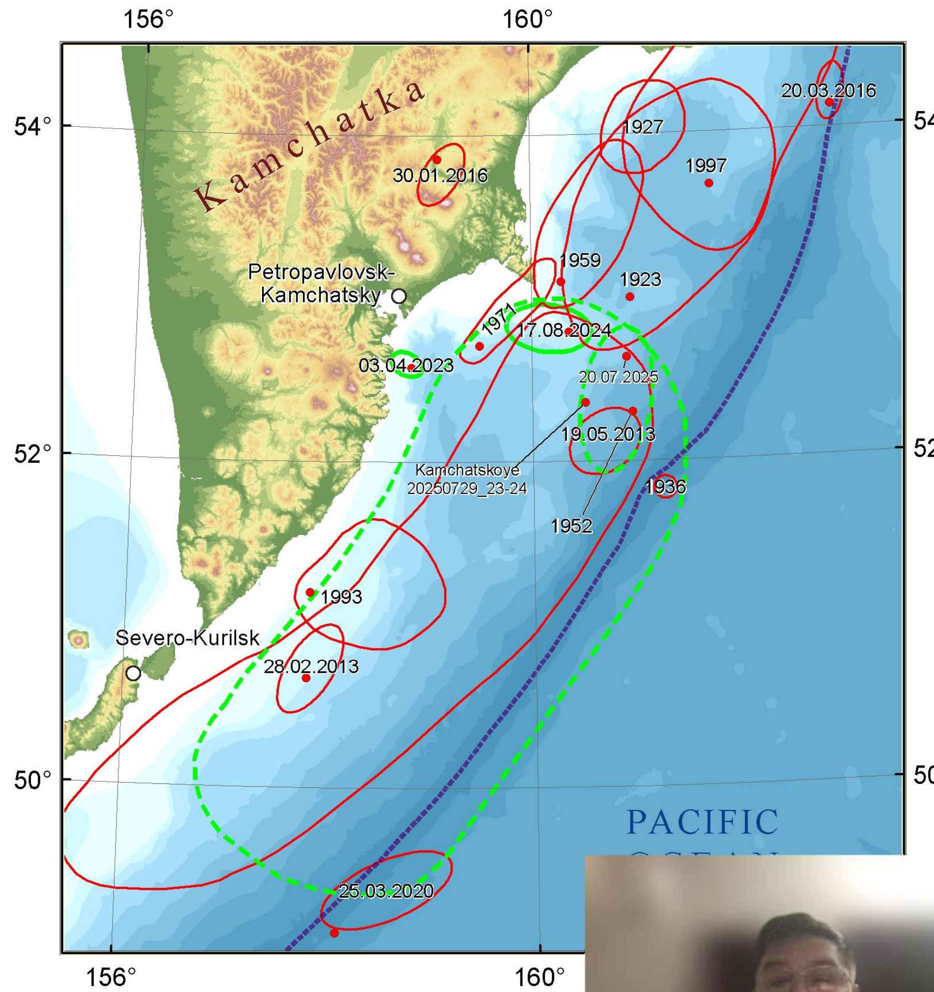


Strong motion records of EQ: vertical channels

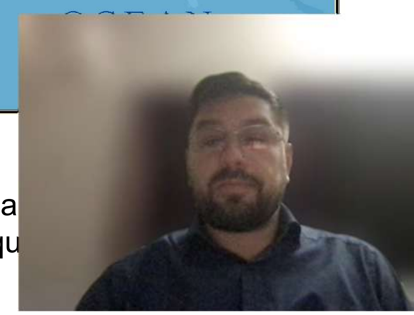


Strong Earthquakes of Southern Kamchatka Over the Last 100 Years: The Seismic History of the Region

1. **Comparison with the 1952 Event:**
   Many characteristics of the 2025 Kamchatka earthquake allow it to be directly compared to the great 1952 Kamchatka earthquake.
2. **«Foreshock» Sequence:**
   The Vilyuchinskoye (April 3, 2023), Shipunskoye-I (August 17, 2024), and Shipunskoye-II (July 20, 2025) earthquakes are likely genetically linked to the main event of July 29, 2025, and may be considered part of a single seismic process. This sequence began following a series of significant seismic quiescence periods in the Avacha Gulf and Southern Kamchatka.
3. **Rupture Zone Delineation (2025 vs. 1952):**
   2025 Earthquake: The rupture zone of the 2025 Kamchatka earthquake has been delineated based on all processed aftershocks (**upper-bound estimate**).
   1952 Earthquake: The rupture area of the 1952 earthquake was delineated based only on the strongest aftershocks recorded by the global seismic network at that time (**low reliability**).



Rupture zones of the strongest earthqua
the rupture zones of recent major earthqu

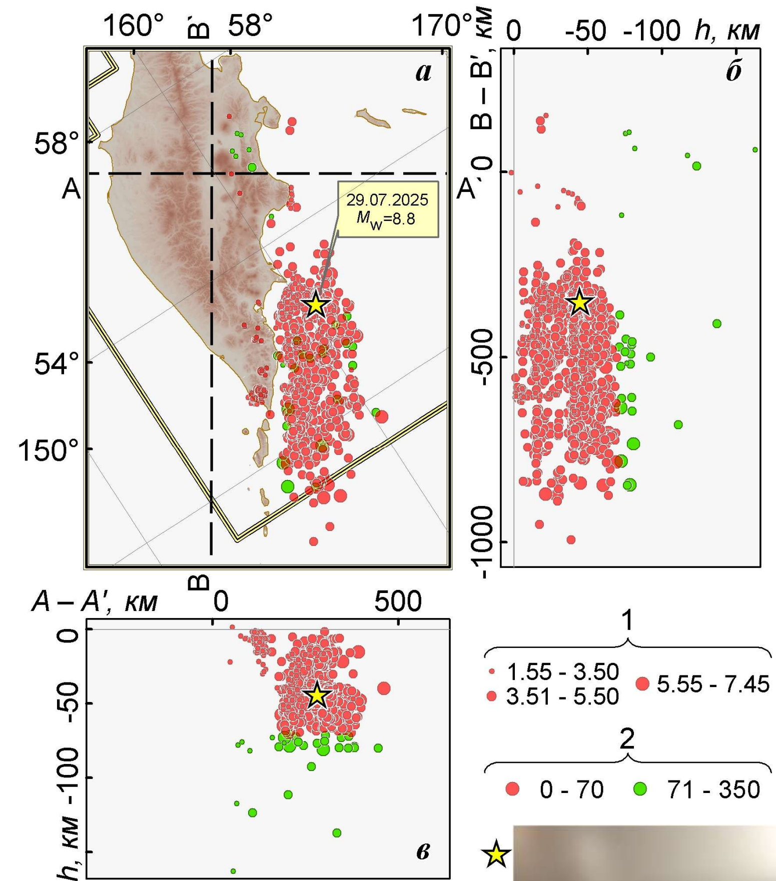


Aftershock Process and Operational Earthquake Processing

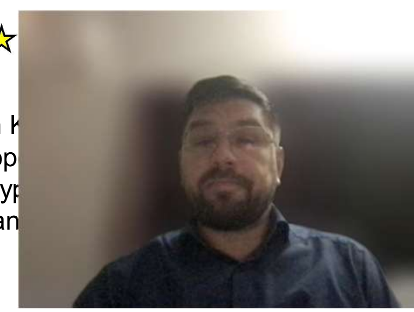
Prompt and timely earthquake processing provides essential data for monitoring the seismic situation and generating expert assessments.

An exceptionally powerful aftershock sequence is ongoing. Since July 29, more than 20000 aftershocks have been detected. Parameters have been determined for about 4000 of these events.

According to the Kamchatka Branch of the Russian Expert Council (KB RES), the probability of a strong aftershock with a magnitude of up to Mw 7.5 persists. Such an event could cause ground shaking in Petropavlovsk-Kamchatsky with an intensity of up to VI (MSK-17).



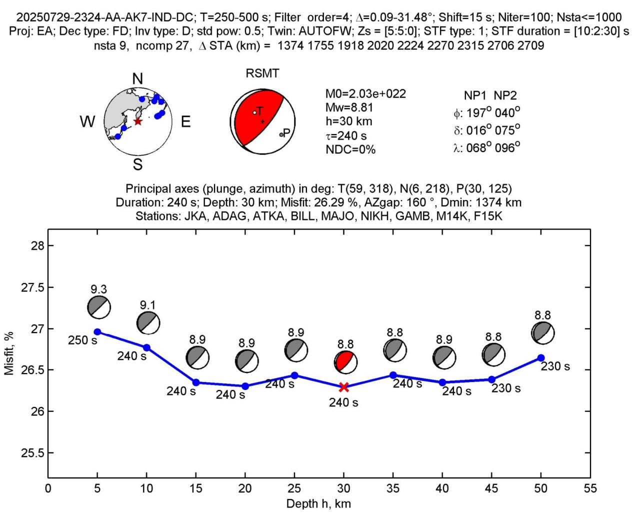
Aftershock Process and Seismicity in K
1 - Earthquake hypocenters (size prop
Hypocenter depths; 3 - Main shock hyp
zone boundary of the Kamchatka Bran
profiles



Assessment of Focal Mechanisms for the Mainshock and Strongest Aftershocks

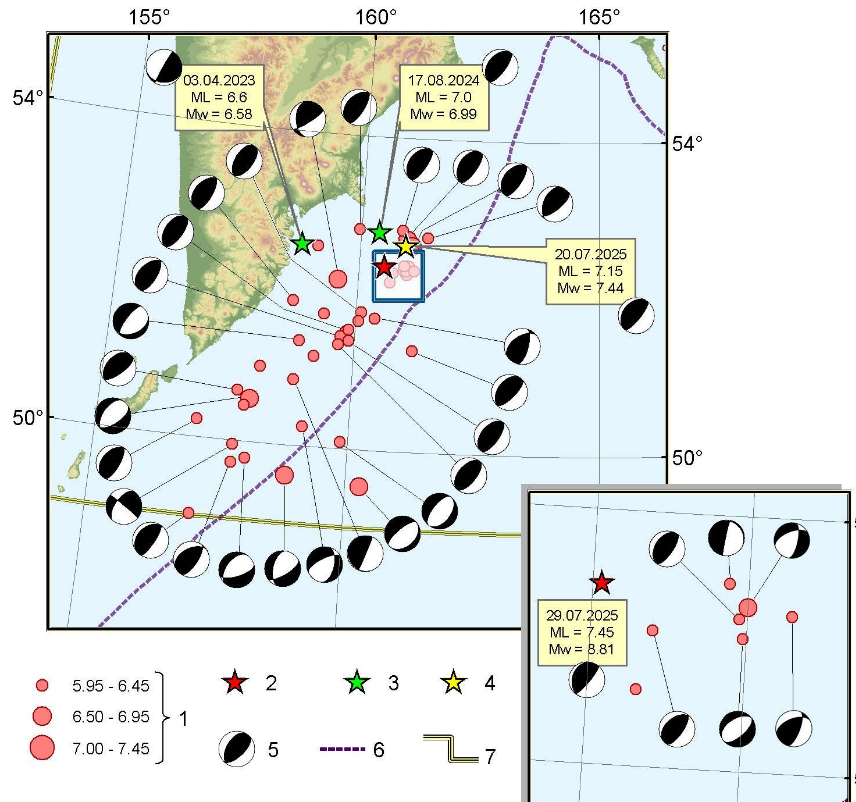
The Kamchatka Branch of the GS RAS has developed and implemented a method for determining seismic moment tensors based on recordings from regional stations (RSMT). The method is designed for the rapid assessment of focal mechanisms.

Focal mechanisms have been determined for the mainshock and approximately 35 of the strongest aftershocks. The majority of events exhibit a "standard" mechanism characteristic of subduction zone earthquakes.

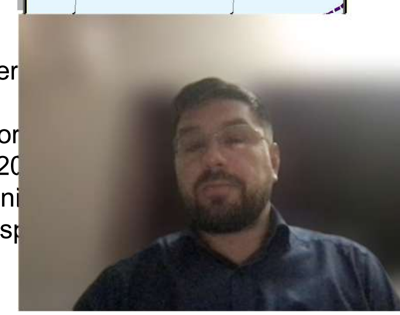


Calculating the Mainshock's Focal Mechanism

Determining the focal mechanism required a significant amount of time, as it was necessary to select undistorted recordings from stations at regional distances (epicentral distance Δ < 20 degrees).



Focal Mechanisms of the Strongest After
Earthquake
1 – Earthquake hypocenters (size propor
Mainshock; 3 – Strong earthquakes of 20
of July 20; 5 – Earthquake focal mechani
6 – Axis of the deep-sea trench; 7 – Resp
the Kamchatka Branch



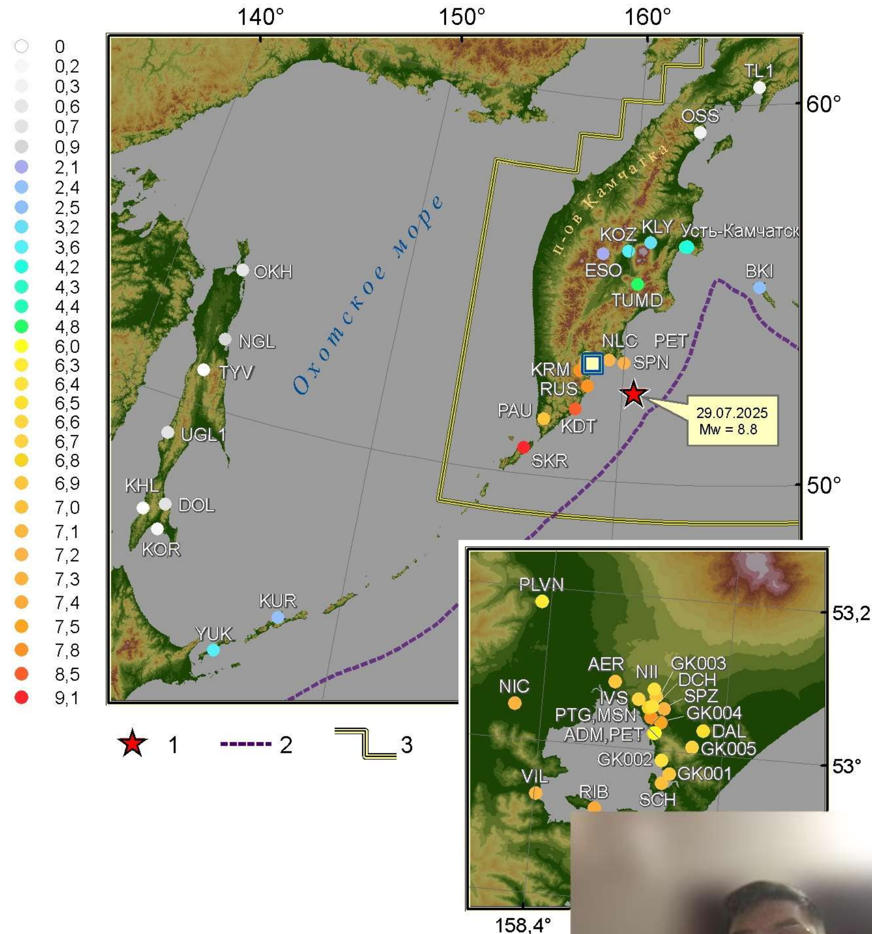
Macroseismic Data: Instrumental

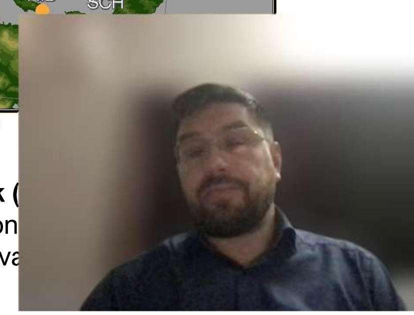
Macroseismic survey of the 2025 Kamchatka earthquake still in progress.

The hidden nature of building damage prevented the prompt determination of shaking intensity in Petropavlovsk-Kamchatsky and the immediate vicinity. For this reason, the assessment long remained phrased as "greater than VI points." Collaboration has now been established with the Ministry of Construction of Kamchatka, and data on the nature of the damage has begun to reach KB GS RAS experts.

The current distribution of instrumental intensity and macroseismic survey data indicates weaker shaking in Petropavlovsk-Kamchatsky, while Severo-Kurilsk was subjected to the maximum possible impacts.

Macroseismic effects were observed throughout the Kamchatka Peninsula south of the settlement of Klyuchi.





Instrumental intensity map for the mainshock (
1 – Mainshock; ; 2 – deep-sea trench; 3 – Respon
Kamchatka Branch. **Legend:** Shaking intensity (va

Macroseismic Data: Expert

Macroseismic survey of the 2025 Kamchatka earthquake still in progress.

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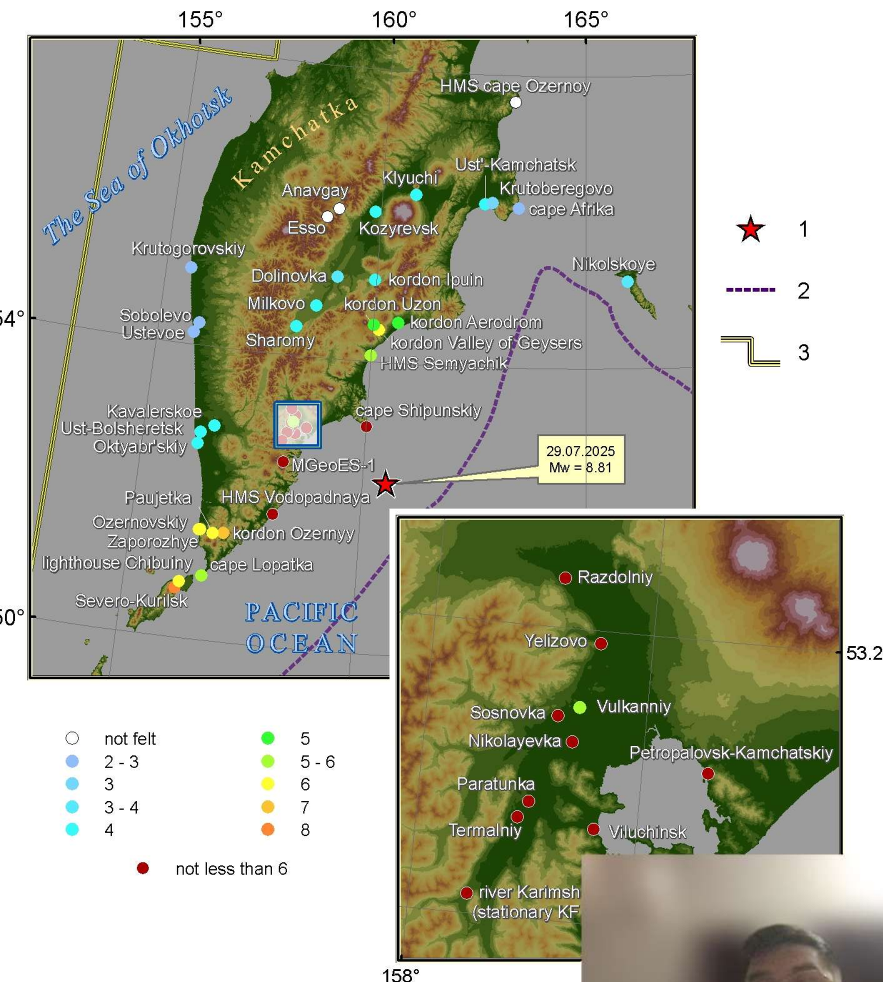
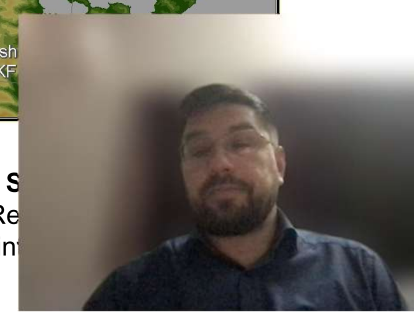


Shaking Intensity Based on Macroseismic S
: 1 – Mainshock; ; 2 – deep-sea trench; 3 – Re
of the Kamchatka Branch. **Legend:** Shaking in



Tsunami Impact

The earthquake generated a significant tsunami, which was recorded along the entire coast from the Shipunsky Peninsula to the Northern Kuril Islands. Thanks to the timely issuance of a warning signal, casualties were avoided.

The most intense impact occurred on the uninhabited coast of Eastern Kamchatka. After such events, it is necessary to conduct coastal surveys and measure run-up heights as quickly as possible. With the onset of the winter season, traces of the tsunami will be irrevocably lost.

With the support of the Government of Kamchatka and the EMERCOM an aerial survey along the route Petropavlovsk-Kamchatsky – Severo-Kurilsk was organized, and aerial photography of the coast was carried out by specialists from the Institute of Volcanology and Seismology (IVS) of the Far Eastern Branch of the Russian Academy of Sciences (FEB RAS). Fieldwork and data processing in Kamchatka are led by **Tatiana Pinegina** (IVS FEB RAS).

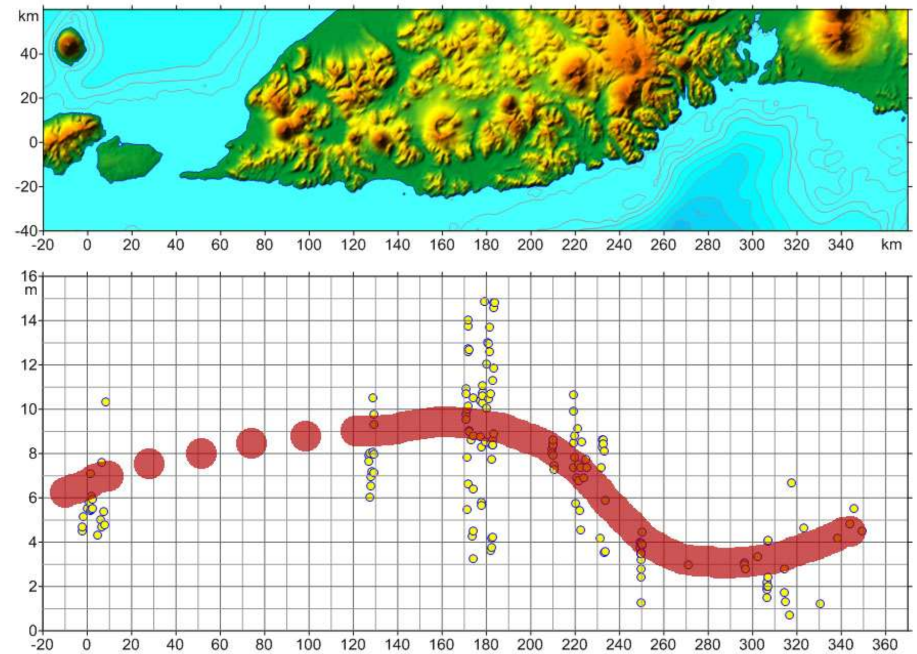
According to consolidated data (see figure), it is evident that the minimal tsunami impact occurred in the central part of Avacha Bay (the sector of Avacha Bay and Khalaktyrsky Beach). This fact helped avoid casualties, as a significant number of tourists are always present on the coast in this area.

Working Group for Surveying the Impacts of the July 29, 2025 Tsunami and Modeling Run-Up Heights:

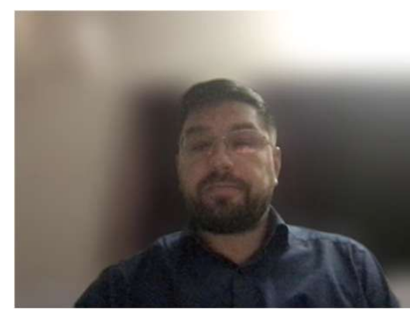
Tatiana Pinegina (IVS FEB RAS) – Fieldwork, data interpretation

Vyacheslav Gusiakov (ICM&MG SB RAS), Leonid Chubarov, Oleg Gusev, Sofya Beizel (ICT SB RAS), Alexander Lander (IEPT RAS) – Data interpretation, source model development, tsunami wave modeling

Danila Chebrov (KB GS RAS) – Discussion of results



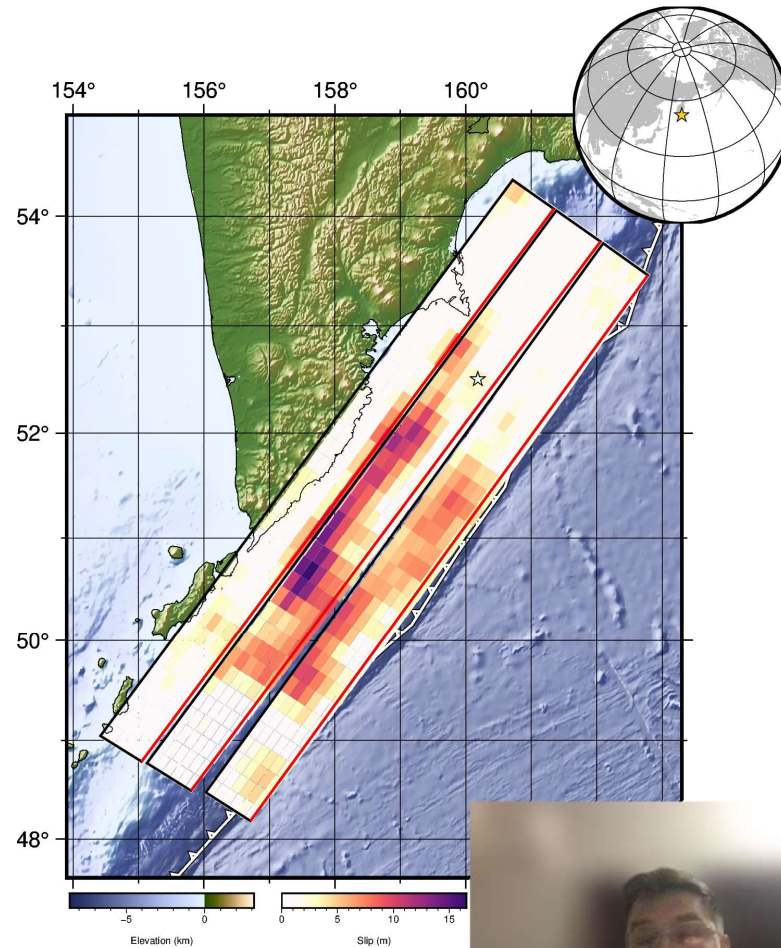
Preliminary Results of Tsunami Wave Impact Assessment on the Kamchatka Coast
Yellow circles: Measurement results.
Red line: Smoothed data.
Dashed line: Data gap area.



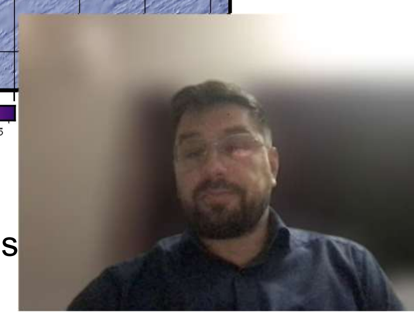
Earthquake Source Modeling

The first rapid inversion was performed by colleagues from the USGS (USA) using teleseismic data. It was subsequently refined using satellite radar interferometry (InSAR) and further complexified by incorporating three fault planes with varying dip angles.

https://earthquake.usgs.gov/earthquakes/eventpage/us6000qw60/finite-fault



Source model of
Teleseismic stations



Earthquake Source Modeling

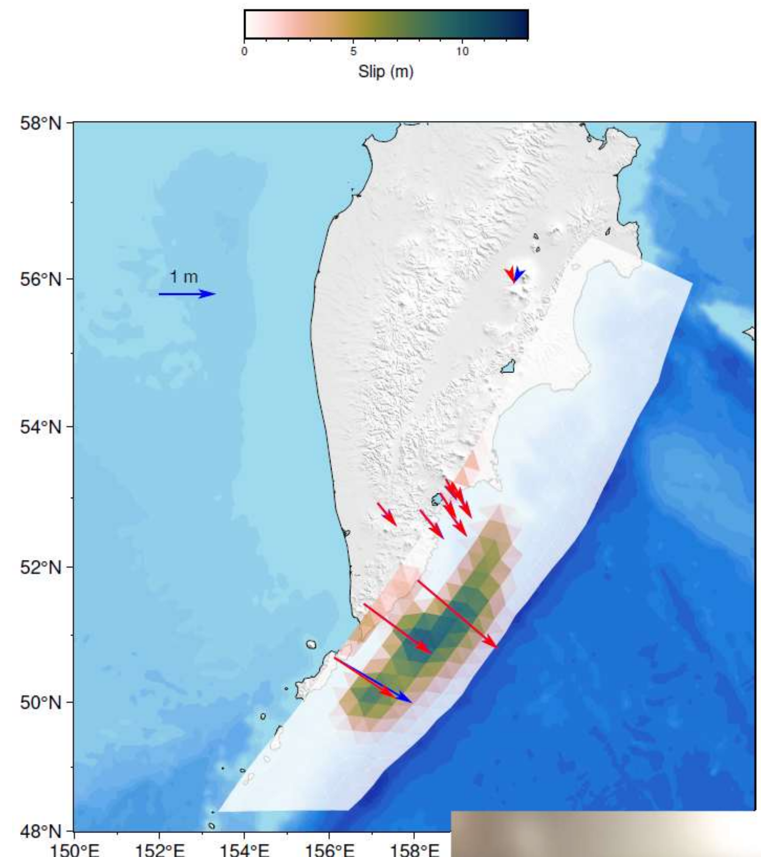
An international team (KB GS RAS; ITES, Strasbourg; ISTerre, Grenoble; FEFU; IAM FEB RAS) is currently developing a source model using data from GNSS stations and strong-motion accelerometers.

Working Group:

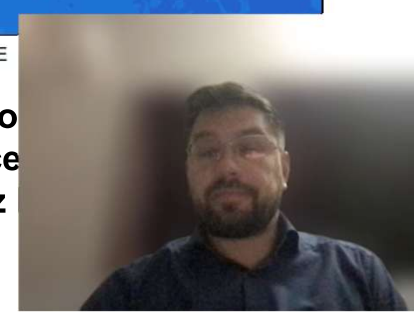
Baptist Rousset (ITES, Strasbourg), Nikolai Shapiro, Michel Campillo, Andrea Walpersdorf (ISTerre, Grenoble) – Source modeling

Nikolai Shestakov, Grigory Nechaev (FEFU, IAM FEB RAS), Nikolai Titkov (KB GS RAS) – GNSS data processing

Nikolai Titkov, Danila Chebrov (KB GS RAS) – Observation coordination and data collection

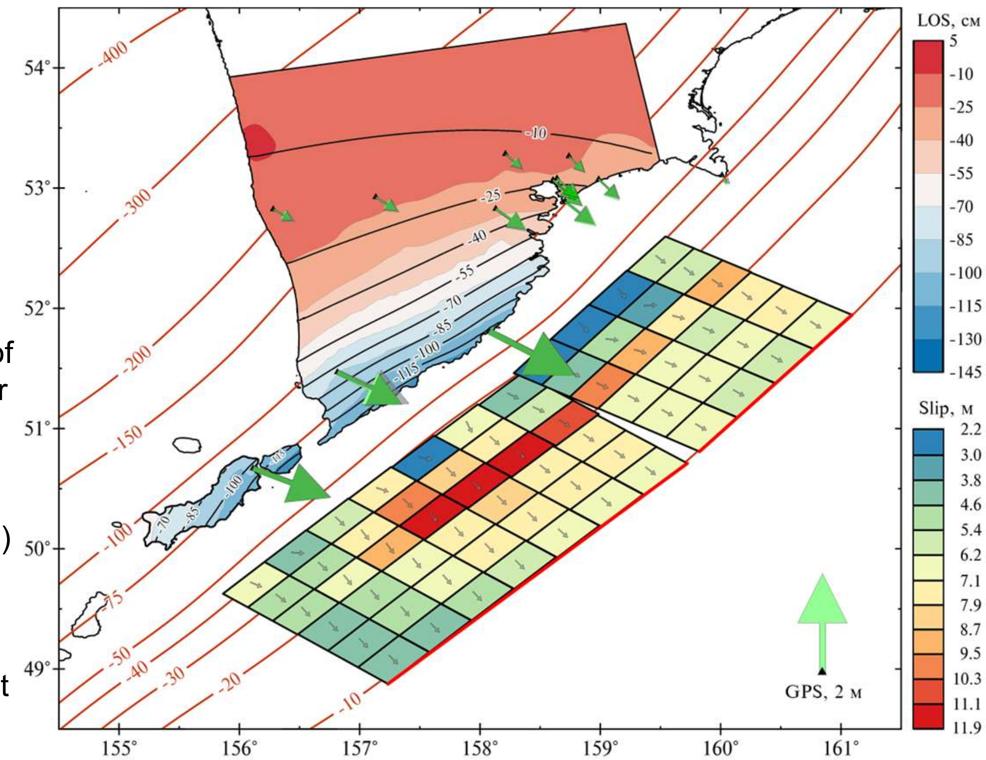


Preliminary Results: So
on Co-seismic Displace
Stations (1 Hz



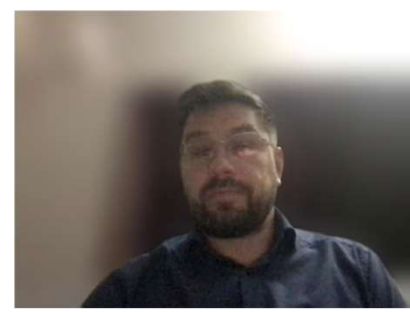
Earthquake Source Modeling

Under the leadership of RAS Academician V.O. Mikhailov, a model has been developed that incorporates local data from the Kamchatka Branch (KB GS RAS) and satellite radar interferometry (InSAR) data



Fault Model of the Kamchatka Earthquake of July 29, 2025, consisting of four planes, each discretized into smaller subfaults (black rectangles). Color represents slip displacement on the fault surface, and arrows indicate the direction of slip. The upper edge of the fault is marked by a red line.

The color map shows line-of-sight (LOS) displacement fields on land (in cm) derived from Sentinel-1A (orbit 111) and Sentinel-1C (orbit 9) satellite data. Contours represent modeled displacements calculated from the source model. Gray and green arrows indicate observed and modeled horizontal displacements at Kamchatka GNSS stations, respectively. Black triangles at the base of arrows mark the planimetric positions of GPS stations. In many cases, the arrows overlap completely. The scale for the arrows is shown in the lower right corner. Red contours depict the depth to the top of the subducting slab.



MODEL OF THE RUPTURE SURFACE OF THE KAMCHATKA EARTHQUAKE OF 29.07.2025 M 8.8 BASED ON SATELLITE GEODESY AND INTERFEROMETRY DATA

© 2025 **academician of the RAS V. O. Mikhailov[1], A. M. Konvisar[1,2], V. B. Smirnov[1,2], E. P. Timoshkina[1], N. N. Titkov[3], S. A. Khairetdinov[1], D. V. Chebrov[3]**

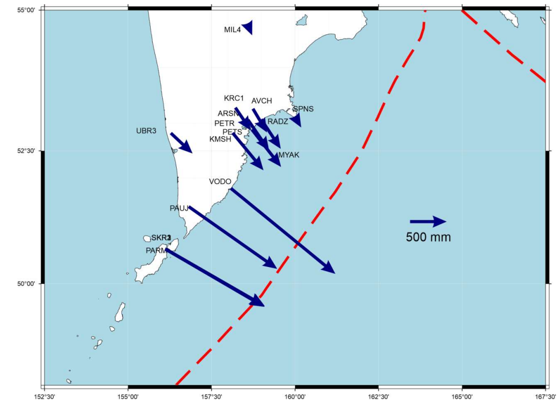
Conclusion

Kamchatka has survived one of the strongest earthquakes of the instrumental era without a single human casualty. It should be noted that, in addition to reasonably well-constructed buildings, this was made possible by a number of favorable factors. Below are some of them:

- **Location of the hypocenter in Avacha Gulf**, opposite the most developed segment of the Far East monitoring network, which ensured the fastest possible response time.
- **Low shaking intensity in Petropavlovsk-Kamchatsky**, explained by uneven slip distribution in the source and the Doppler effect.
- **All buildings in Petropavlovsk-Kamchatsky were prepared for such shaking (~VII intensity)**, which prevented collapses and associated casualties.
- **High professionalism of the operators of the Seismic Subsystem of the Tsunami Warning System.**
- **The event occurred during daytime working hours**, which reduced the response time of KB GS RAS staff from scientific and analytical departments and ensured direct expert support for decision-making within the Emergency Control System.
- **All other components of the Emergency Control System operated with maximum clarity.**
- **Anomalously low tsunami height in the Khalaktyrsky Beach area (Avacha Bay, in close proximity to the city)**. This is an extended, uninhabited coastline without a warning system, yet constantly frequented by tourists.

Negative factors that, fortunately, did not lead to fatal consequences include:

- **Imperfections in the monitoring system**: A lack of strong-motion recording stations could have led to an inadequate assessment of the earthquake's parameters or a delayed response from the Warning System.
- **Shortcomings in the public warning system were revealed**: In the event of a stronger earthquake, significant casualties could have occurred.
- **The powerful flow of fake news increased panic among the local population.** This could have hindered rescue operations had there been significant destruction



Thank you for attention!

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