НАПРЯЖЕНИЯ В ЗЕМНОЙ КОРЕ ВОСТОЧНОЙ АРКТИКИ ПО НОВЫМ ДАННЫМ О МЕХАНИЗМАХ ОЧАГОВ ЗЕМЛЕТРЯСЕНИЙ

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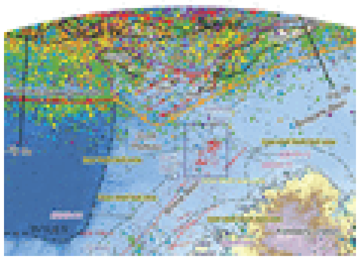

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Key Points:

- Representative data set of earthquake source parameters (1990–2021) are compiled for East Arctic, crustal stresses are calculated from it
- The results obtained indicate that the spreading axis of the Gakkel Ridge does not continue to the Laptev Sea shelf
- The Eurasian-North American plate boundary crosses the eastern Laptev Sea and is likely to pass to the Chersky Range through the Yana Bay

Crustal Stresses in the East Arctic Region From New Data on Earthquake Focal Mechanisms

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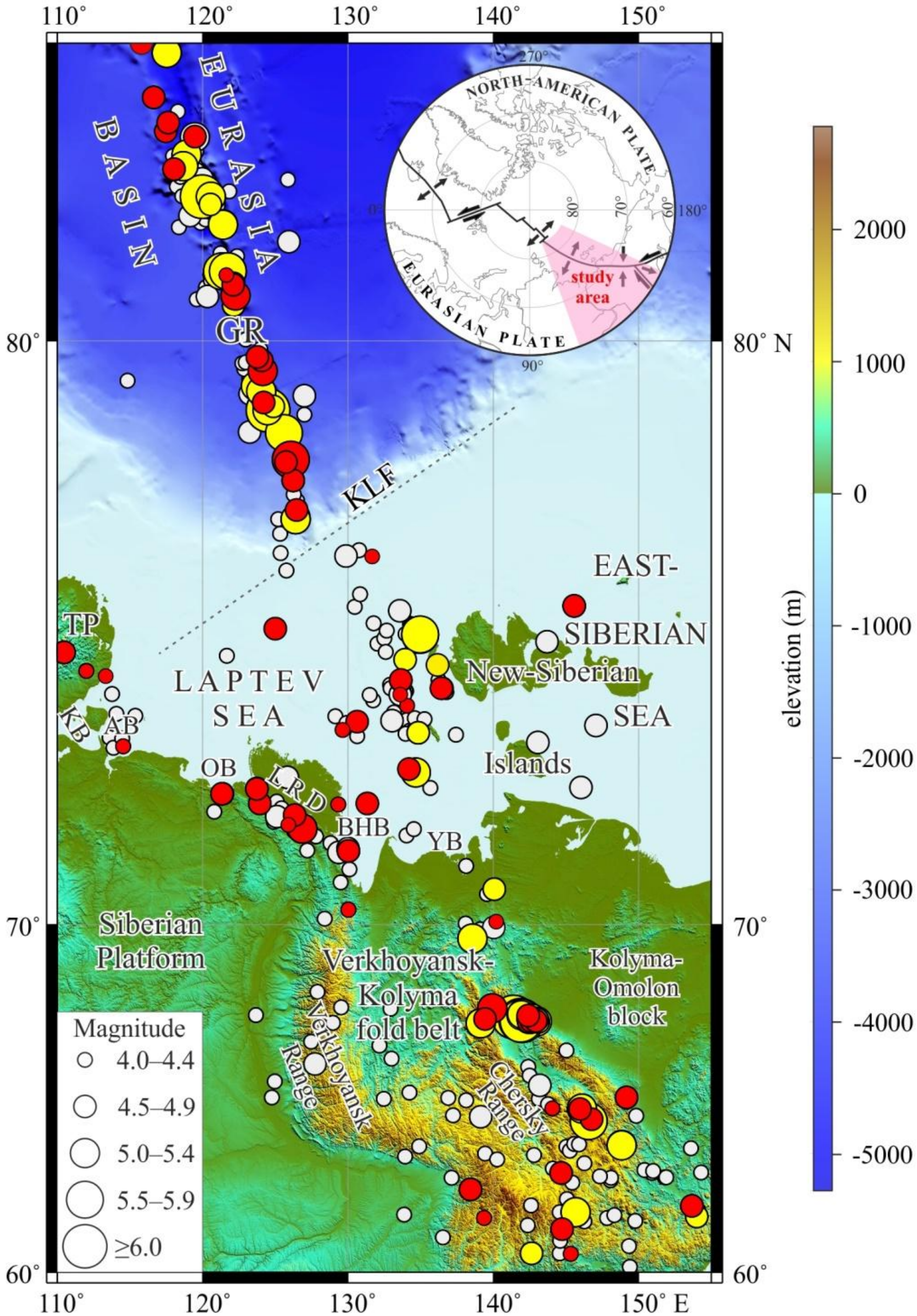
Abstract East Arctic is a key region for understanding the current geodynamic pattern and lithospheric evolution of the whole Arctic. To close an evident gap in regional seismic data, we calculate source parameters for 103 earthquakes ($M_w \geq 4.2$, 1990–2021) and compile a representative uniform data set including source depths, scalar seismic moments, moment magnitudes, and focal mechanisms. On its basis, crustal stresses are estimated within four blocks with the homogeneous stress field. Extension dominates along the Gakkel Ridge and over most of the Laptev Sea shelf. On the continent and east and west of the shelf, it is replaced by compression. The obtained results indicate that the spreading axis of the Gakkel Ridge does not continue to the Laptev Sea shelf and evidence for the Eurasian–North American plate boundary crosses the eastern Laptev Sea shelf and is likely to pass to the Chersky Range through the Yana Bay.



Source parameters are calculated from surface wave amplitude spectra for the first time for 81 seismic events with Mw ≥ 4.2 (1990–2021). We aslo use the data for 22 earthquakes (Mw ≥ 4.2, 1990–2015) considered in our previos studies with the same method (Imaeva et al., 2017a, 2021; Seredkina & Kozmin, 2017; Seredkina & Melnikova, 2018). Crustal stresses within four blocks with the homogeneous stress field are estimated. Possible geodynamic insights of the results (both stress tensors and individual focal mechanisms) are discussed

Fig. 1. Seismicity of the East Arctic region in 1990–2021 (M ≥ 4.0). Earthquake epicenters are plotted according to the ISC catalog. Red and yellow circles are earthquakes (Mw), considered only in this study, and also published in the GCMT catalog, respectively. For all the other earthquakes, magnitudes (mb) are presented according to the ISC catalog.

1. Introduction

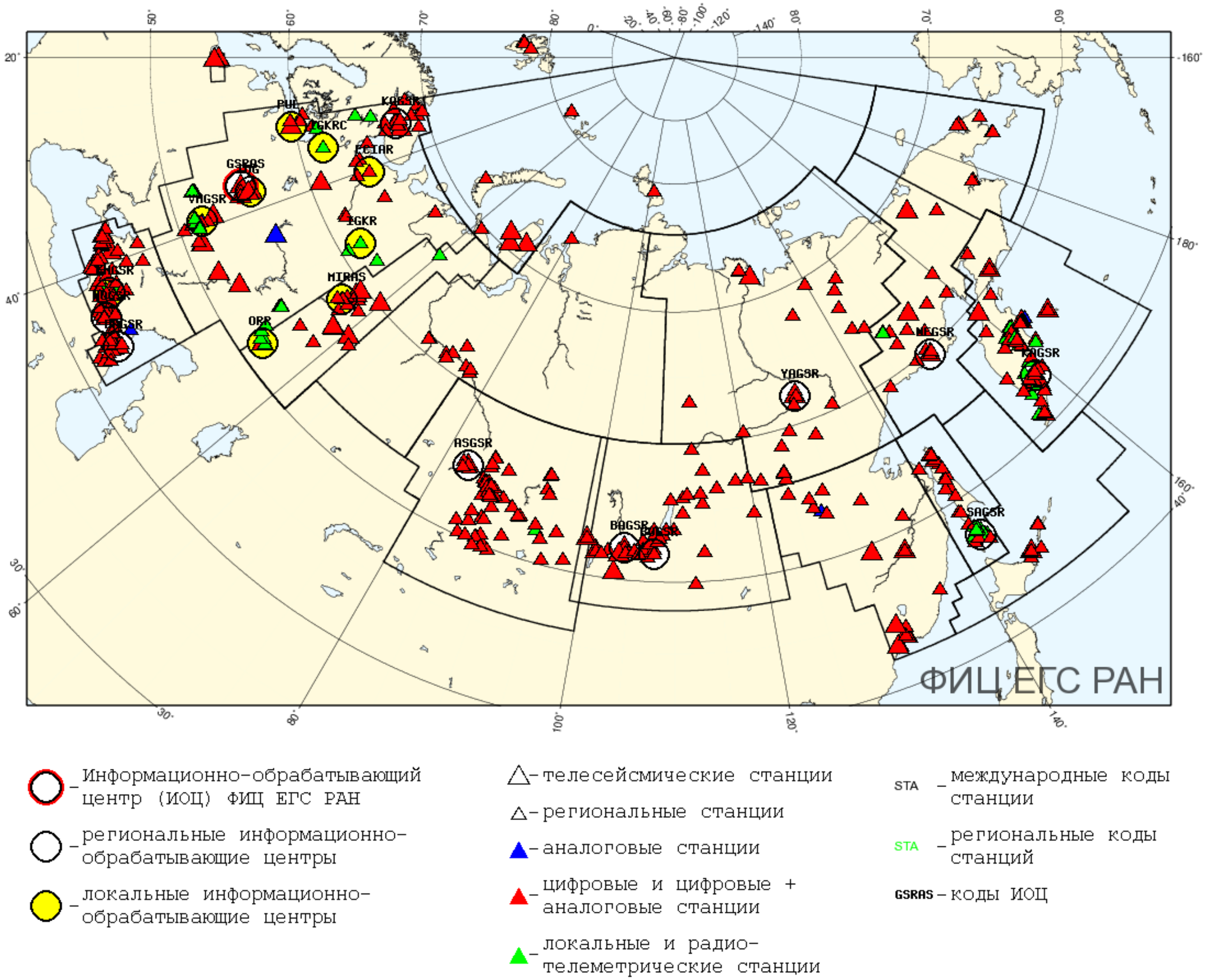


Fig. 2. Seismic stations in Russia according to GS RAS.

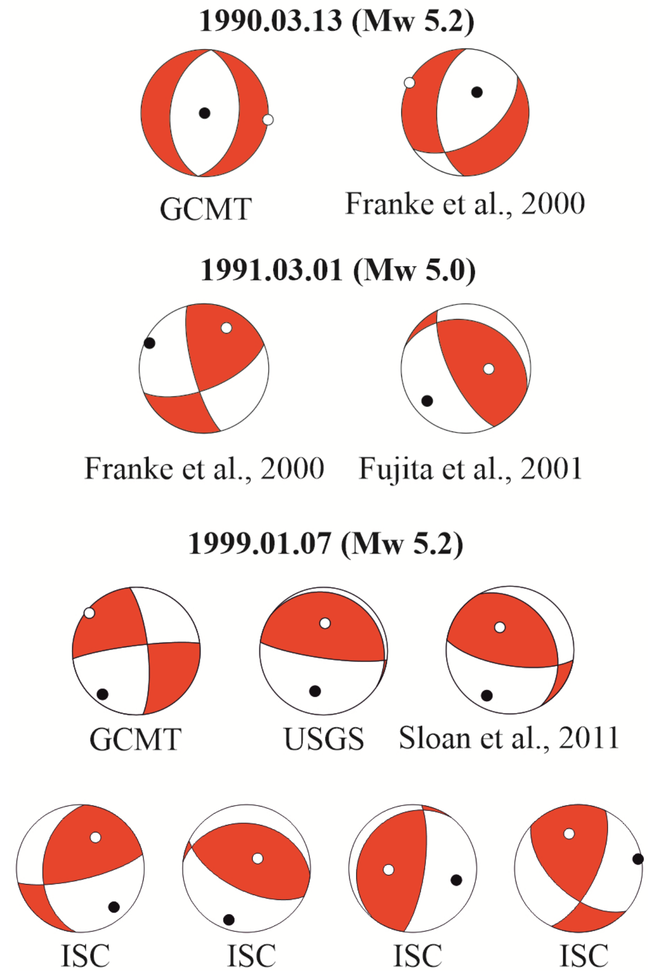


Fig. 3. Some examples of ambiguous focal mechanism solutions.

2. Tectonic settings

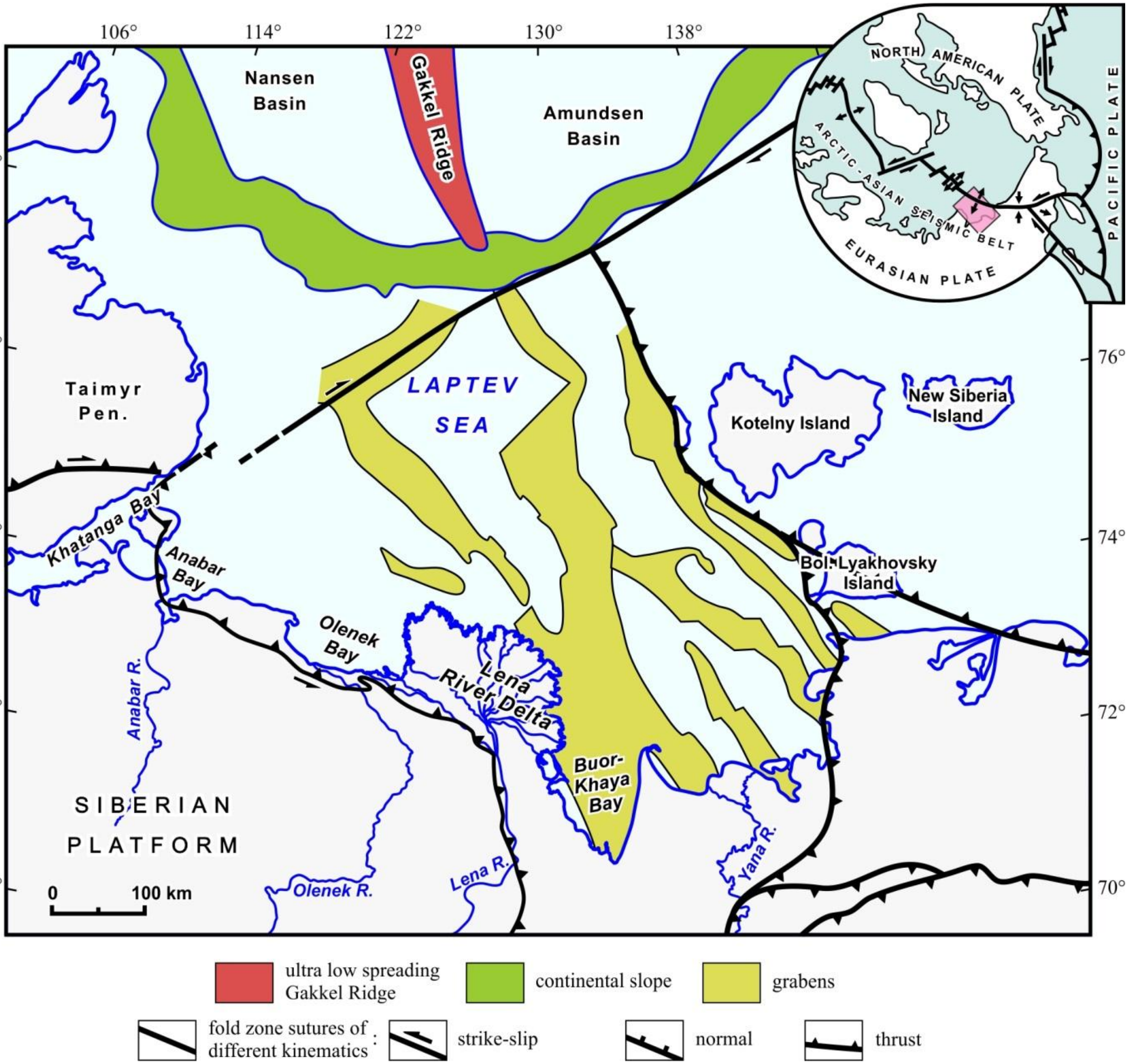
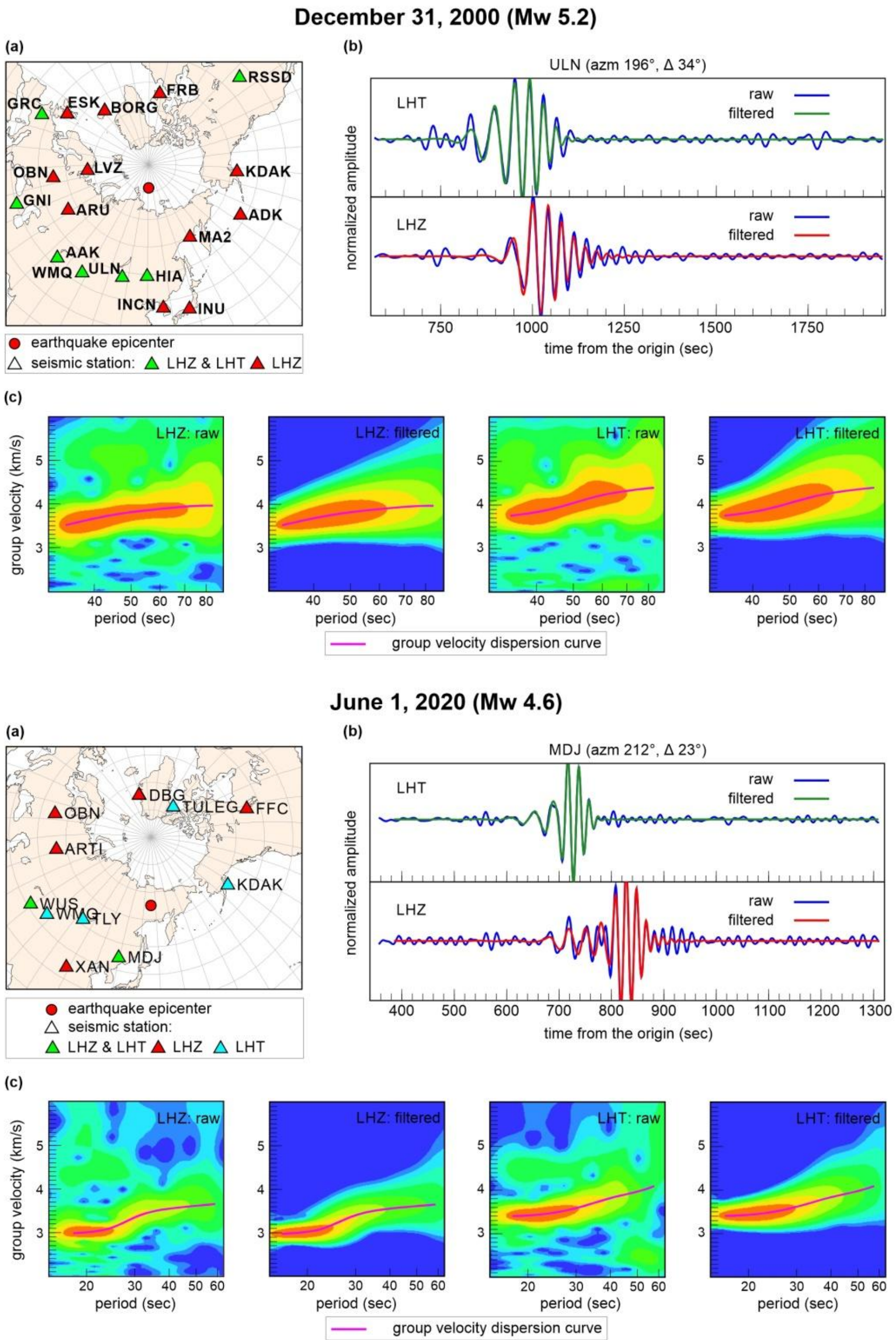


Fig. 4. Tectonic scheme of the study area after (Imaeva et al., 2017).

The Eurasian–North American plate boundary passes along the Gakkel Ridge, the eastern Laptev Sea, and the Chersky Range (Drachev & Shkarubo, 2017; Parfenov & Kuz'min, 2001). To the south of the Gakkel Ridge, the boundary becomes diffuse (Gaina et al., 2002). In the southern part of the shelf, it is determined in the Buor-Khaya (Gaina et al., 2014) or Yana Bays (Bird, 2003; Imaeva et al., 2017).



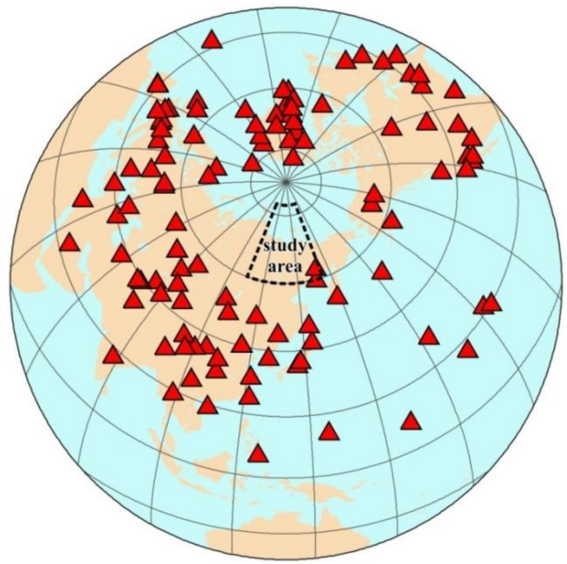


Fig. 5. Seismic stations used in surface wave analysis.

115 IRIS, GEOFON, and GEOSCOPE seismic stations;

epicentral distances 2000–7700 km.

4–22 stations in the case of an individual earthquake

Frequency time analysis (FTAN) (Levshin et al., 1989) is implemented for periods 25–120 s.

Fig. 6. Examples of data processing: (a) seismic stations and earthquake epicenters; (b) and (c) examples of the frequency-time analysis procedure: raw and filtered velocity waveforms (b) and frequency-time analysis diagrams for raw and filtered signals (c).

Determined parameters (seismic moment tensor in a double-couple approximation):

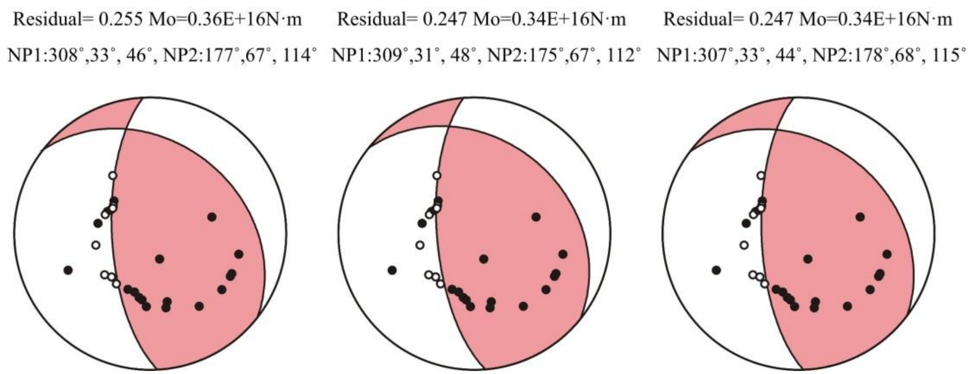
1. Scalar seismic moment (M_0, N m);
2. Moment magnitude (Mw);
3. Source depth;
4. Focal mechanism.

•Inversion of surface wave amplitude spectra [Bukchin, 1990]

•Joint inversion of surface wave amplitude spectra and P-wave first-motion polarities [Lasserre et al., 2001]

Crustal and mantle models:

1. Crust under seismic stations – 3SMAC [Nataf, Rucard, 1996]
2. Crust in a source area – 3SMAC or CRUST 2.0 [Bassin et al., 2000]
3. Mantle – PREM [Dziewonski, Anderson, 1981]



3SMAC

CRUST 2.0

DSS Tengis Lake – Norilsk city – Laptev Sea profile [Belousov et al., 1991]

Fig. 7. FM solutions obtained with different crustal model for the 6 June, 1990 Taimyr earthquake Mw 4.3 (Seredkina and Kozmin, 2017)

4. Inversion procedure: Stress tensor

To calculate the stress regimes of the crust the **Win-Tensor** program (improved version 5.8.6 of 23/11/2016) (Delvaux and Sperner 2003) was used.

The best-fit stress model is defined by the 4 parameters: the stress axes **σ1**, **σ 2**, **σ 3** and stress ratio **R** (0-1). The horizontal stress components are expressed by 2 parameters: the horizontal stress axes (**SHmax/Shmin** – maximum/minimum principal compressional stress) and the stress regime index **R'**.

To estimate the quality of the obtained results, the stress tensors were assigned a quality rank varying from **A** (highest) to **E** (lowest) according to the World Stress Map (Heidbach et al. 2010).

Initial data:

103 focal mechanism solutions considered in this study (1990-2021)

+

13 Global CMT solutions (1977-1989)

Quality classification

SH orientation

A ±15°

B ±20°

C ±25°

D ±40°

E insufficient or widely scattered

Stress regime classification

Stress Regime	R'	Color code
Normal	0 0,5 1	
Strike-slip	1,5 2	
Thrust	2,5 3	

Table S1 (part)

Source parameters for 103 East Arctic earthquakes (Mw 4.2–6.7) occurred in 1990–2021.

Date dd.mm.yyyy	Time hh:mm:ss	Lattitude, deg	Longitude, deg	N	Δmin, deg	Δmax, deg	Period range, s	Crustal model	ε	Mw	M_0, N m	h, km	Nodal plane 1			Nodal plane 2			T axis		P axis		B axis		Focal mechanism	Reference
													azm, deg	dp, deg	slip,deg	azm, deg	dp, deg	slip, deg	azm, deg	pl, deg	azm, deg	pl, deg	azm, deg	pl, deg		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*21*	*23*	*24*	*25*	*26*	*27*
13.03.1990	00:33:01.01	73.29	134.67	8	24.09	64.05	30-60	CRUST2.0	0.291	5.2	$0.67*10^{17}$	11-12	190	70	-60	311	36	-144	258	19	138	55	359	28		SM
09.06.1990	18:24:32.20	75.09	113.34	4	34.39	45.57	25-55	DSS	0.247	4.3	$0.34*10^{16}$	15	307	33	44	178	68	115	124	59	250	20	348	23		SK
02.11.1990	21:54:04.22	64.87	146.75	7	23.04	49.77	30-60	3SMAC	0.330	4.6	$0.97*10^{16}$	19	190	65	-55	311	42	-141	255	13	146	55	353	32		TS
01.03.1991	01:57:05.98	72.14	126.87	7	23.19	47.11	30-60	3SMAC	0.263	5.0	$0.35*10^{17}$	21	2	23	106	165	68	83	63	66	260	23	167	6		SM
22.03.1991	17:02:22.21	79.81	123.76	8	18.82	50.27	30-60	3SMAC	0.235	4.9	$0.25*10^{17}$	2-3	276	26	-135	144	72	-71	219	25	80	59	318	18		TS
29.03.1991	11:34:24.60	79.64	124.12	10	18.72	45.62	30-60	3SMAC	0.254	5.0	$0.41*10^{17}$	6	155	75	-100	9	18	-57	253	29	51	59	158	10		TS
04.04.1991	12:09:52.84	82.53	116.62	7	26.89	50.03	30-65	CRUST2.0	0.272	4.8	$0.21*10^{17}$	7	137	61	-110	354	35	-58	242	14	7	67	147	18		TS
18.06.1991	23:01:38.70,	82.17	119.46	17	26.80	60.94	40-75	CRUST2.0	0.315	4.9	$0.22*10^{17}$	6	181	37	-57	322	60	-112	68	12	188	67	334	19		TS

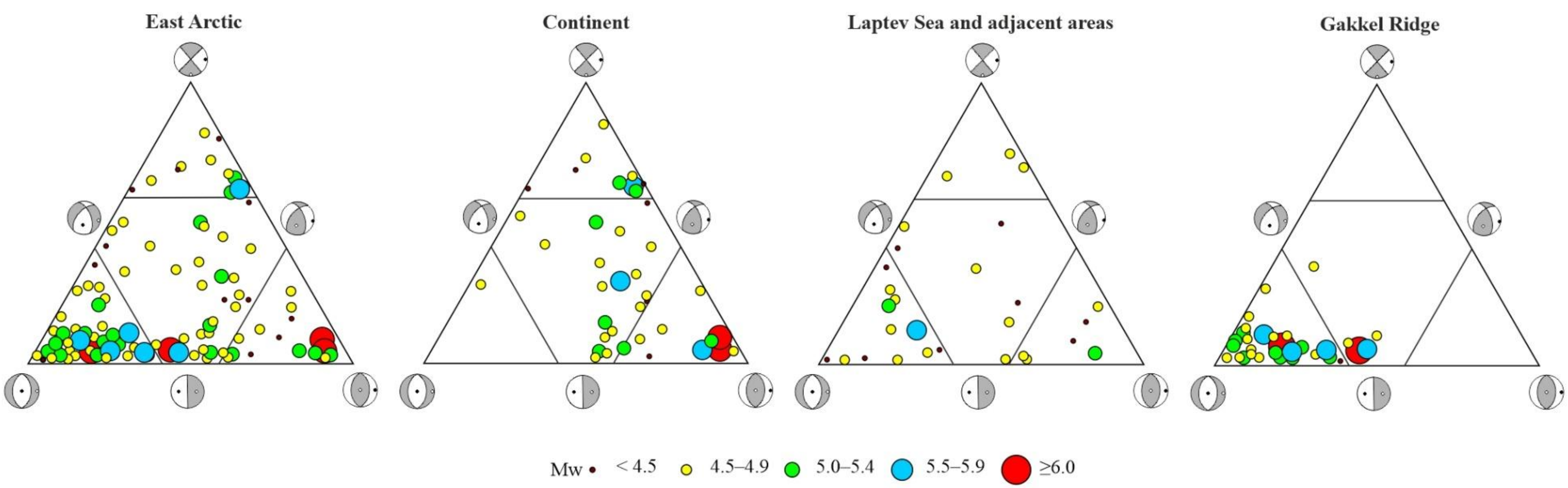


Fig. 8. Earthquake focal mechanisms plotted on the Frohlich (1992) triangle diagrams for East Arctic, its continental part, the Laptev Sea and adjacent areas, and the Gakkel Ridge.

5. Results: Earthquake source depths

- The northward shallowing of earthquake sources along the Gakkel Ridge;
- The earthquakes in the east of the Laptev Sea are slightly shallower than under the rest of the shelf.
- Earthquakes, occurred in the uppermost mantle, are detected in the Buor-Khaya Bay and Lena River delta, assuming the Moho depth to be 30 km (Avetisov, Guseva, 1991).

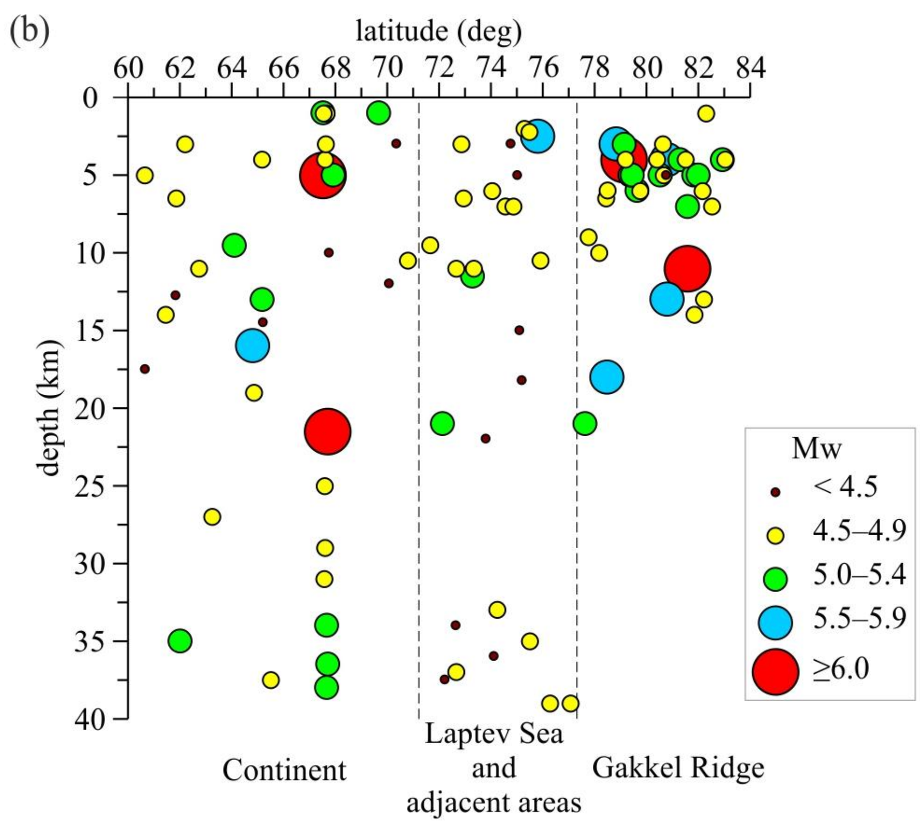


Fig. 9. Latitudinal variations of earthquake source depths for 103 earthquakes in 1990–2021.

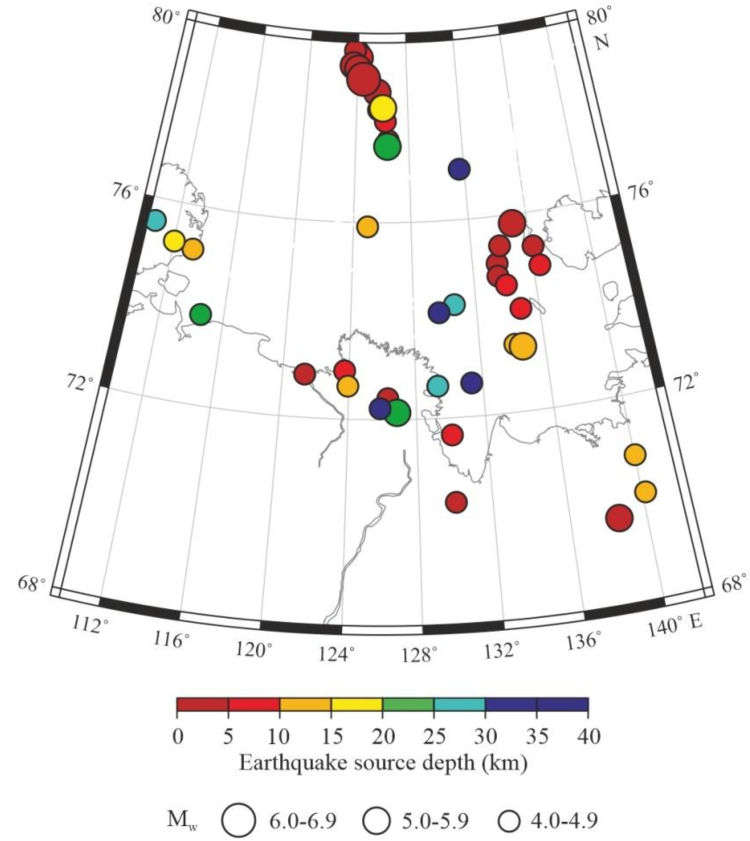


Fig. 10. Earthquake source depths for a part of the study area.

5. Results: Comparison with Global CMT

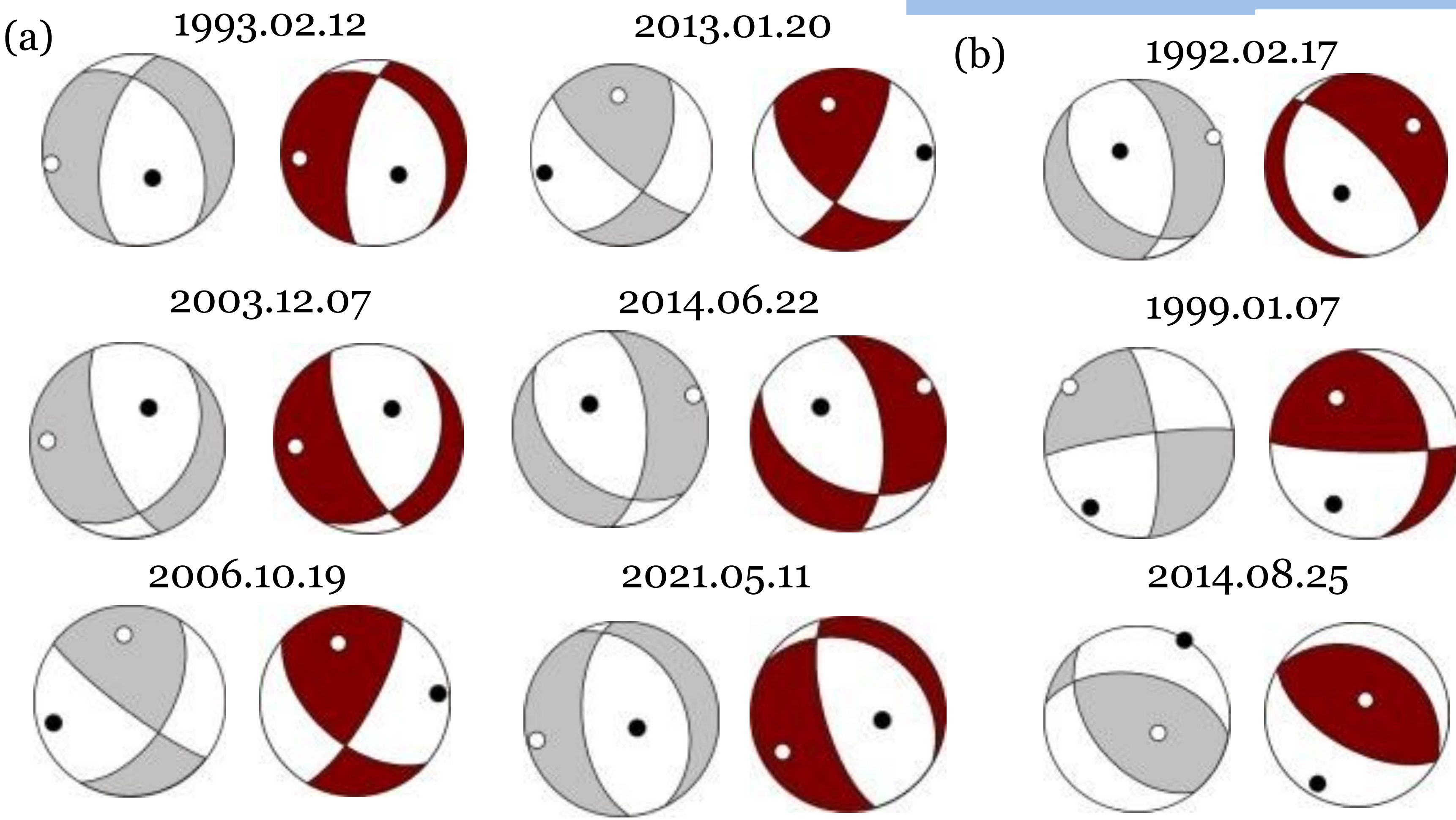


Fig. 11. Examples of comparison of our results with data from the GCMT catalog. In total, 45 earthquakes are considered. Different focal mechanisms are found to be almost identical and close to each other for about 87% of the analyzed earthquakes (a), for other 13% the differences are significant, but the types of motions are the same for different solutions (b).

5. Results: Stress tensor

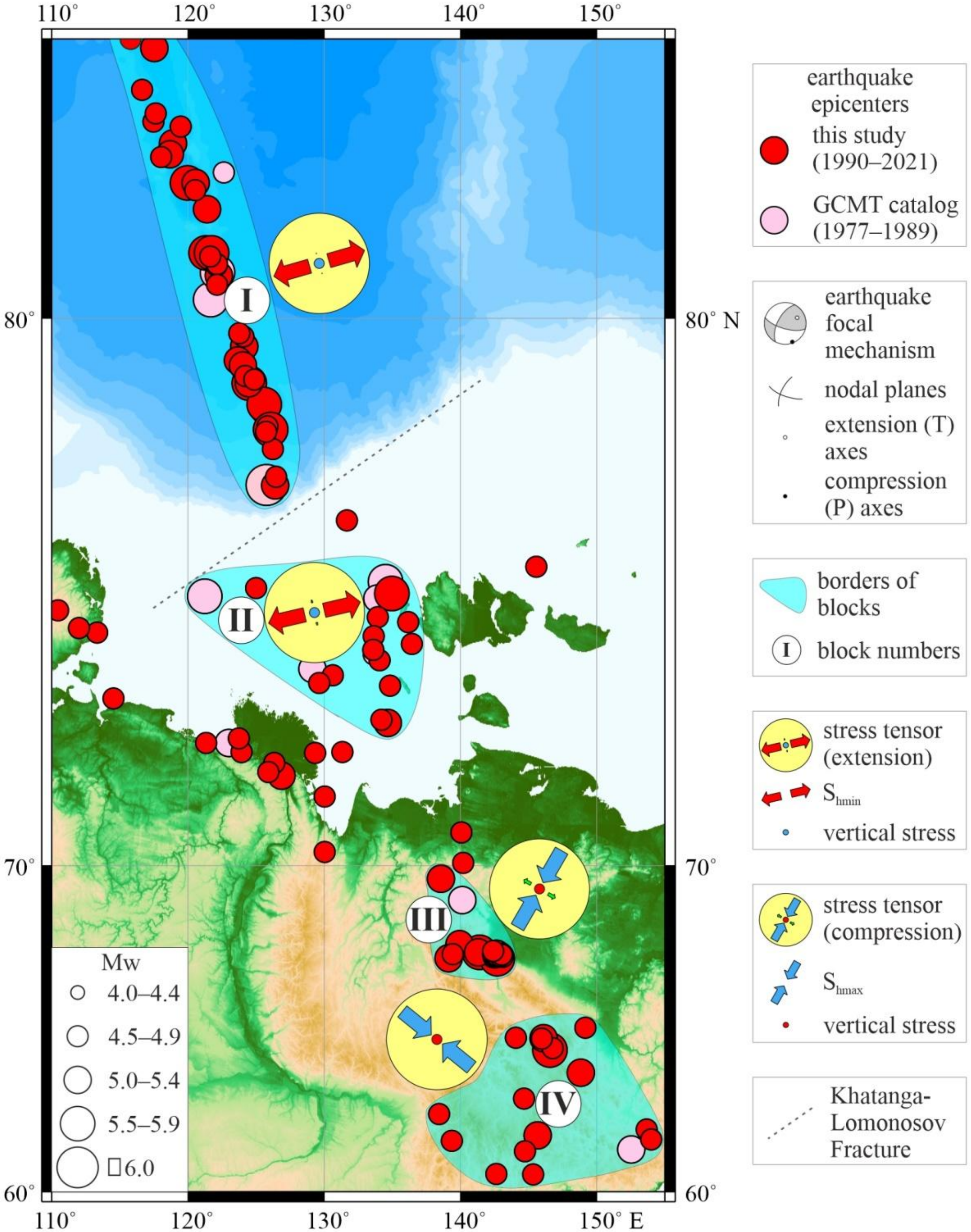
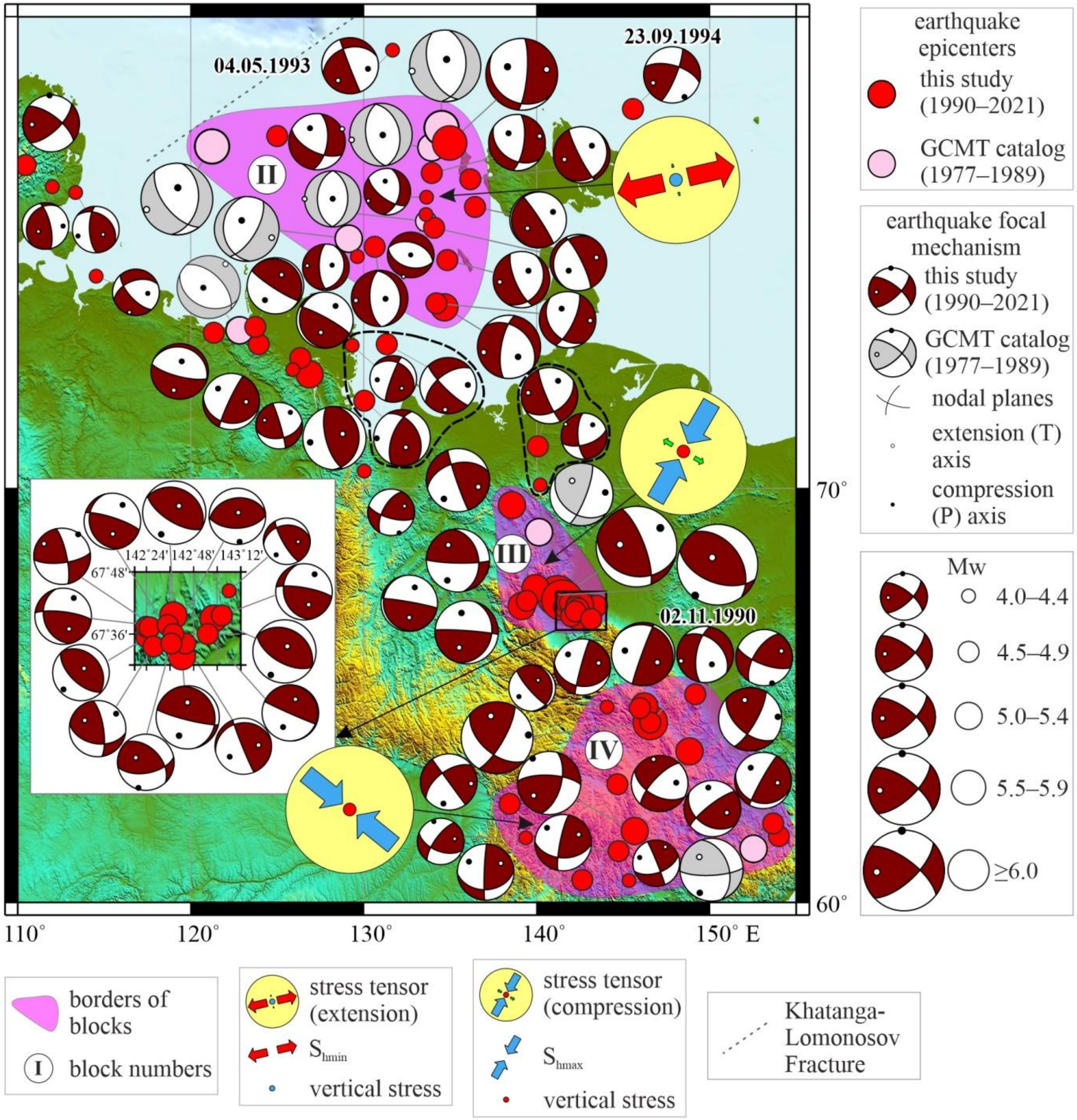


Table 1. Stress tensor inversion results

Block	Nt	S_{Hmax}	Stress regime	QR
I. Gakkel Ridge	82	163	extension	B
II. Laptev Sea	36	167	extension	B
III. Northern Chersky Range	44	30	compression	C
IV. Central Chersky Range	24	129	compression	B

Nt is a total number of nodal planes; S_{Hmax} is maximum horizontal principal compression; QR is a tensor quality rank.

Fig. 12. Stress tensors. Blocks: I – Gakkel Ridge, II – Laptev Sea, III – Northern Chersky Range, IV – Central Chersky Range.



Earthquake focal mechanisms:

- The Buor-Khaya Bay and Lena River delta are characterized by complex and inhomogeneous stress field.
- The Taimyr Peninsula and New Siberian Islands are influenced by compression.
- Extension dominates between the Yana Bay and Chersky Range.

Fig. 13. Stress tensors and individual focal mechanisms for 103 earthquakes in 1990–2021 (Table S1) and 13 earthquakes in 1977–1989 (Table S3).-Epicenters and focal mechanisms of the earthquakes, occurred in the Buor-Khaya Bay and between the Yana Bay and the Chersky Range, are contoured by thick dashed lines.

Crustal thinning confirms rifting processes in the Yana-Indigirka lowland (between the Yana Bay and Chersky Range) (Mackey et al., 1998; Laske et al., 2013) (Fig. 14).

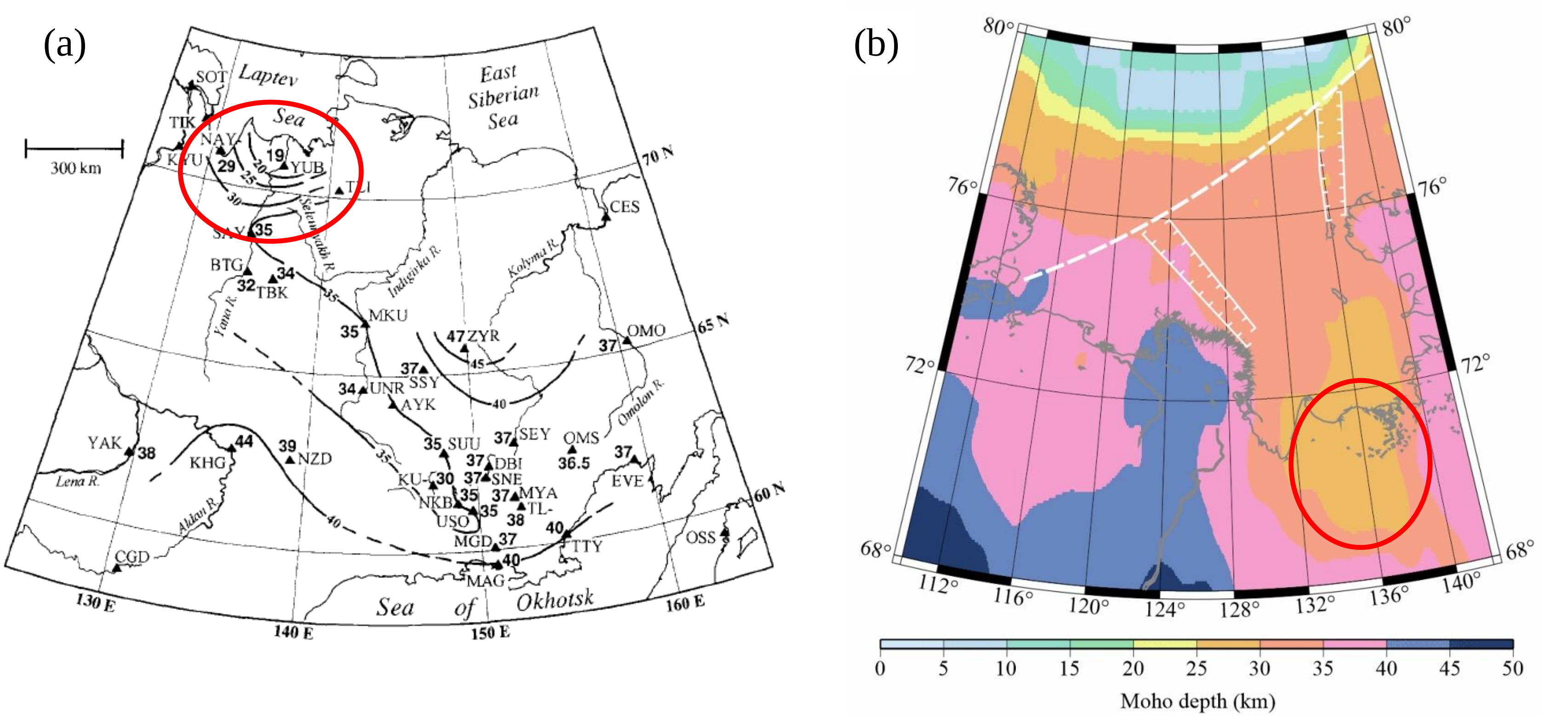
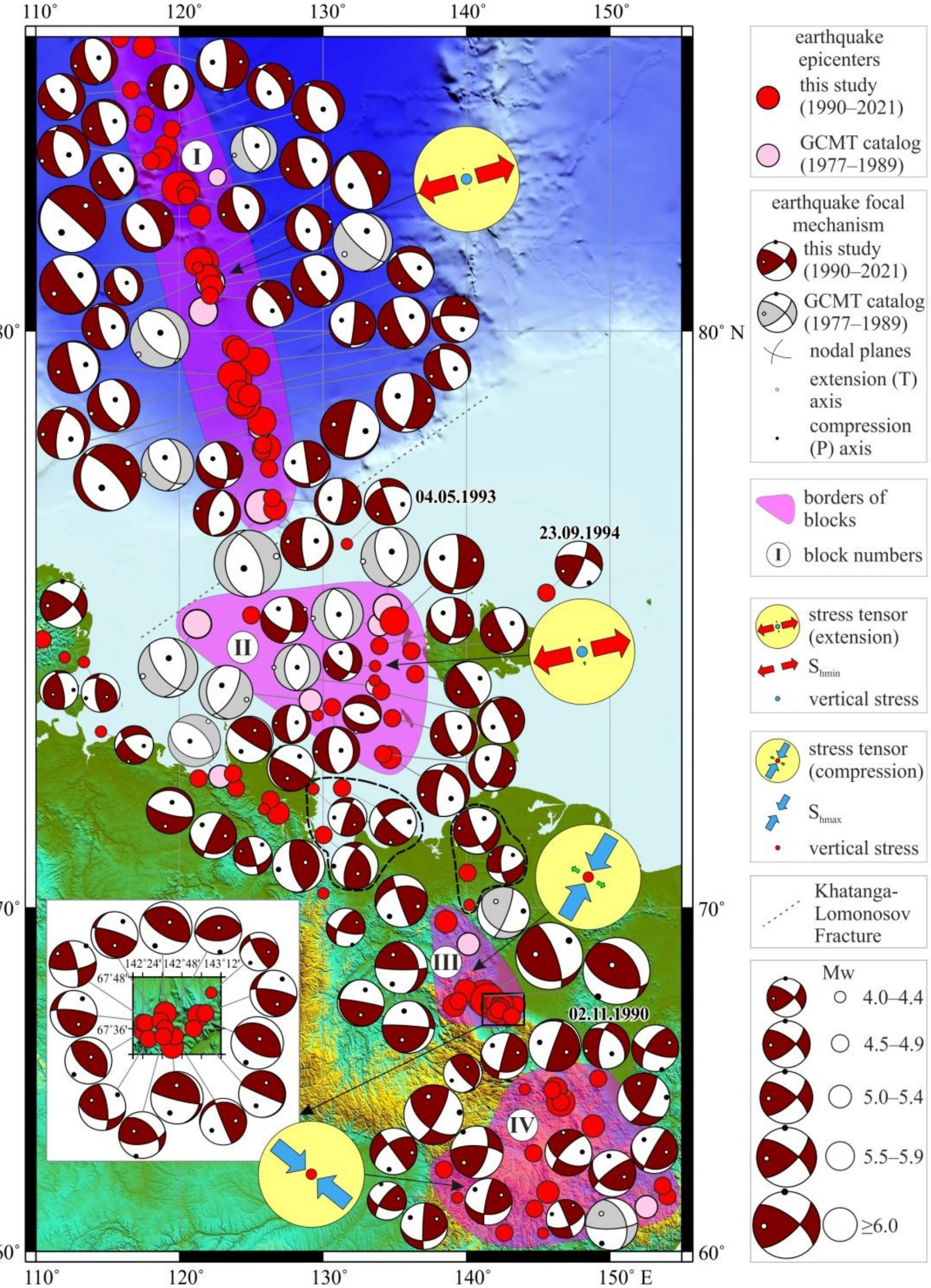


Fig. 14. Crustal thickness according to (Mackey et al., 1998) (a) and to the CRUST 1.0 model (Laske et al., 2013) (b). Red ellipses schematically mark the discussed area in the Yana-Indigirka lowland.

7. Результат



По результатам расчетов очаговых параметров 103 землетрясений восточной Арктики с Mw>4.1 (1990–2021 гг.) показано, что вдоль хребта Гаккеля и на шельфе моря Лаптевых преобладает растяжение близкой ориентации, которое на континенте (хребет Черского), а также в восточном и западном обрамлении шельфа (Таймыр и Новосибирские острова) сменяется сжатием. Также наши результаты позволяют предположить, что растяжение на шельфе моря Лаптевых не связано с продолжением под него хребта Гаккеля, а само растяжение продолжается на континент в области Яно-Индигирской низменности (между Янской губой и хребтом Черского). Актуальность исследования обусловлена недостатком данных об очаговых параметрах землетрясений региона. Полученные результаты востребованы для задач по оценке сейсмической опасности региона.