14 - 17 March 2017
DAVOS
SCHATZALP
2nd Induced Seismicity Workshop

Discriminating Features of Induced Seismicity in Application to Sakhalin Offshore Hydrocarbon Fields.

Sergey Turuntaev, Alexey Konovalov, Elena Slinkova, Andrey Stepnov, Anna Gubanova

Istitute of Geosphere Dynamics, Russian academy of Sciences

Institute of Marine Geophysics and Geology, Russian academy of Sciences

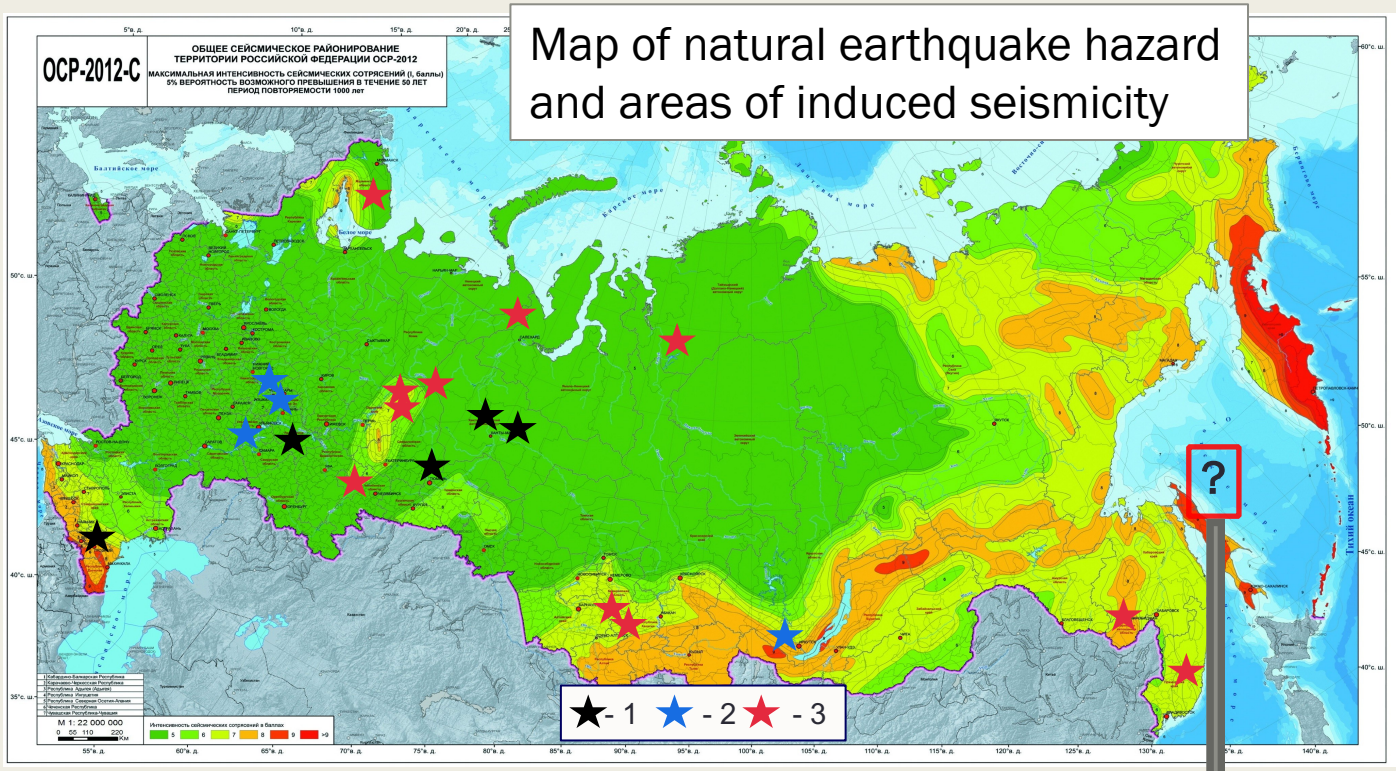
Moscow Institute of Physics & Technology

Outline

- Introduction & aims
- Data characterization
- Used principles of discrimination between natural and induced seismicities
- Results
- Discussion & Conclusions

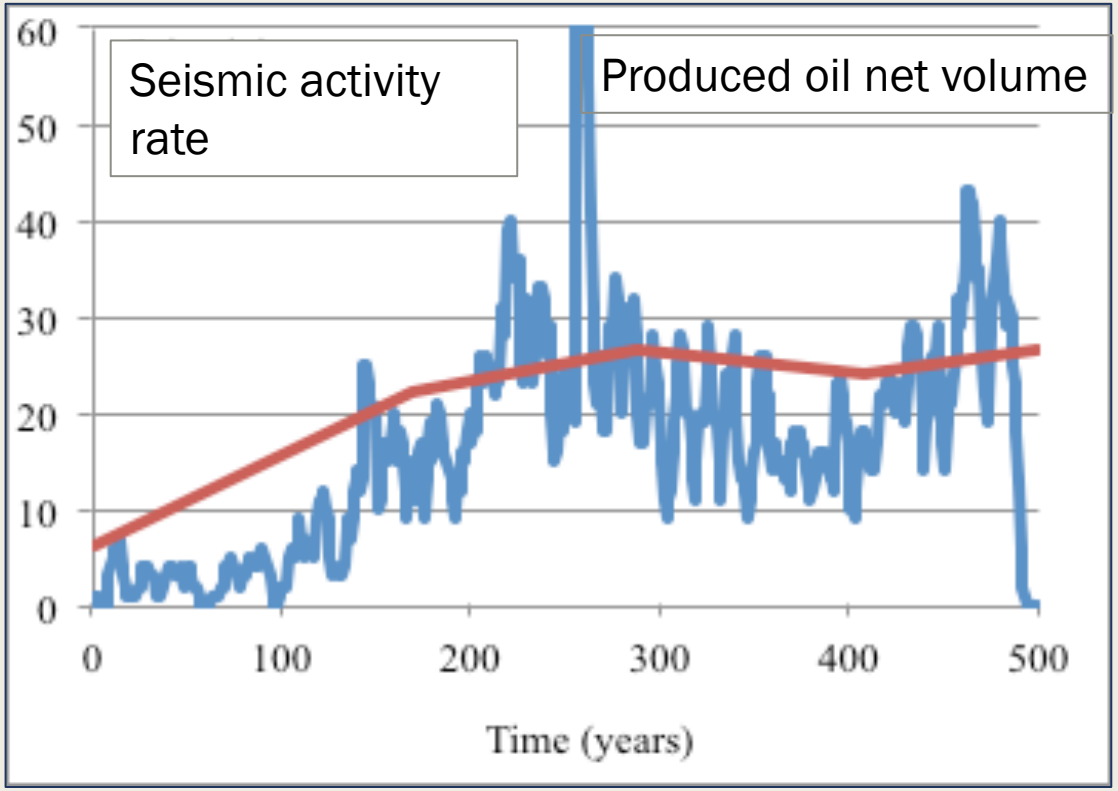
Sakhalin Island is located in the region of high seismic activity.

That causes a concern on the possibility to trigger catastrophic earthquake in this region by hydrocarbon field developments.



- The concern is backed by probably triggering nature of the catastrophic Neftegorsk earthquake (M_w=7.2) in 1995. The town was completely destroyed, more than 2000 people died

- The oil recovery started in Northen Sakhalin in 1929, gas production began in 1941.
- Almost 6 mln barrels of oil were recovered in 1947, then the oil production declined a bit.
- In 50th the secondary recovery methods allowed to increase the oil production, which reached more that 14 million barrels in the middle of 1960th.
- Later it was found that near 2/3 of oil and gas deposits are located offshore. The first offshore oil was got in 1977. Now, North Sakhalin offshore is the richest oil and gas region in Russian Far East



Seismicity and oil production

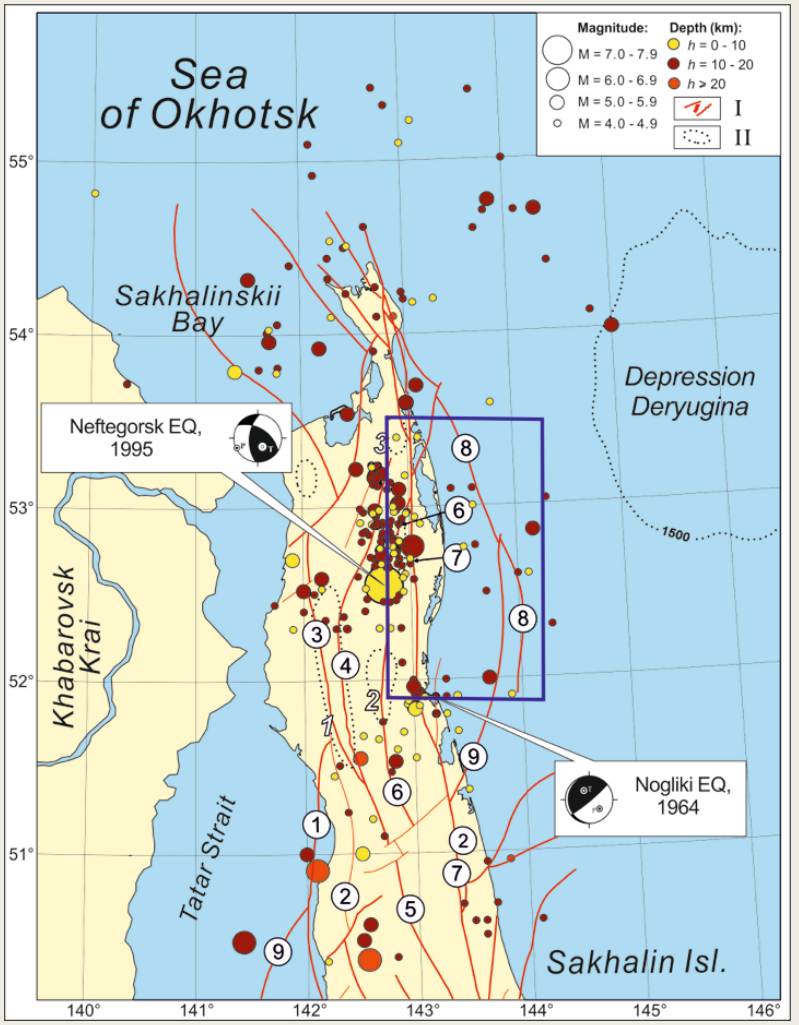
Variation of the seismic activity rate in Sakhalin between 1950 and 1990 (blue line) and produced oil net volume (red line). All values are in arbitrary units.

Research aim

- To compare statistical parameters of the seismic activity in the area of offshore hydrocarbon fields with the statistical parameters of natural seismicity registered previously.
- To find out if there are any signs of offshore hydrocarbon filed development influences on the local seismicity

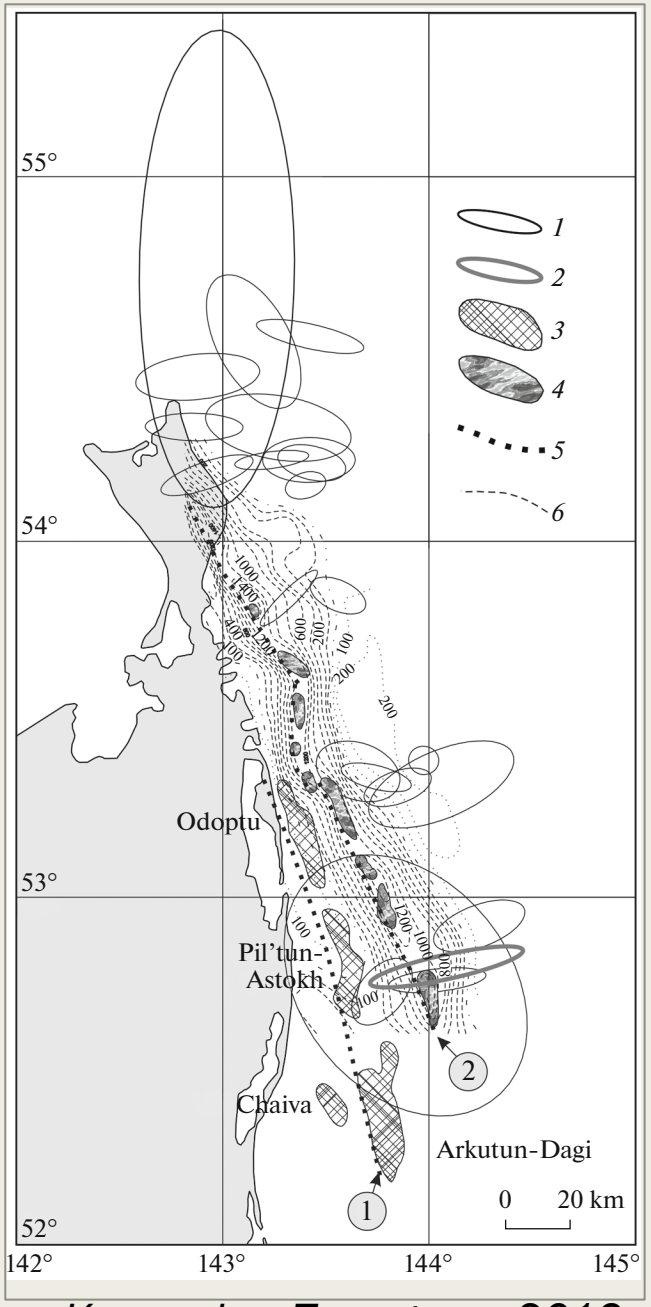
Data characterization: spatial distribution of the natural earthquakes

- The earthquakes are shallow.
- The areas of high seismicity are located in the vicinity of the largest sub-meridional faults as clusters or “spots” in the western, eastern offshore and central zones of Northern Sakhalin.
- All earthquakes with M≥5 occurred within these zones: in 1932 and 1953 Okhinskoye with M=5.5 and M=5.2, in 1963 Pomorskoye with M=5.0, in 1964 Noglikskoye with M=5.8.



Data characterization: seismic network

- In 2006 in addition to existing regional seismic network, 6 seismic stations were installed along the Eastern coast of the Northern Sakhalin.
- The main aim of the seismic network installation was to detect any possible changes in the controlled area natural seismic activity, which could be caused by the field developments.
- More than 2200 seismic events have been localized for the period 2006-2014. The magnitude of completeness of the catalogue is close to 1.5.



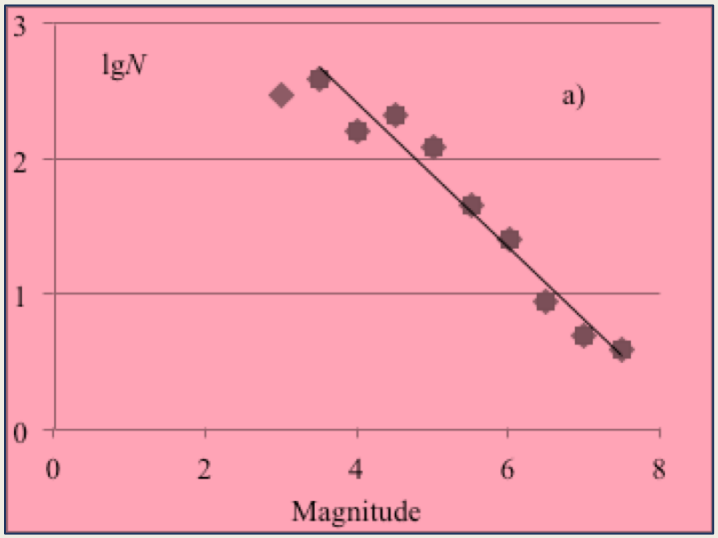
Zabolotin, Loskutov, Konovalov, Turuntaev, 2016.

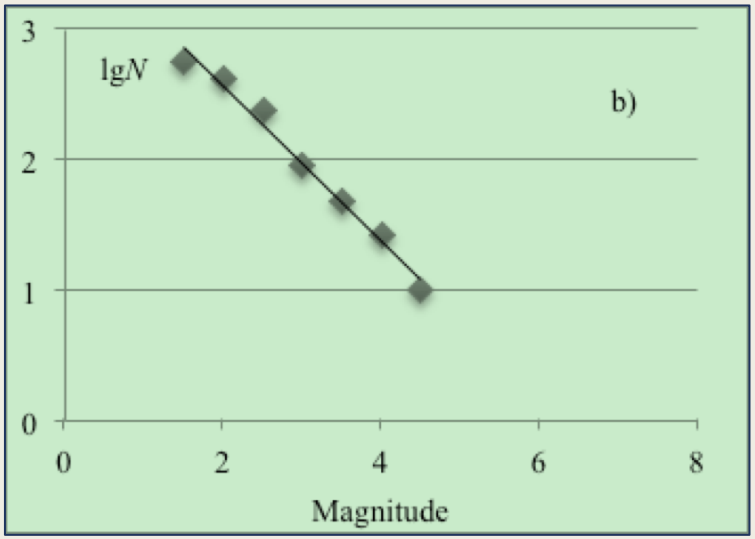
Considered Discriminating Indicators:

- b-value of magnitude-frequency relationship (the value is higher in case of induced seismicity than in case of natural earthquakes);
- distribution of the time intervals between successive seismic events (Weibull distribution, in case of the induced seismicity the Weibull distribution shape factor is less than 1);
- migration of the earthquake hypocenters to/from hydrocarbon field boundaries;
- diminishing of the correlation dimension of the seismic activity variations;
- correlation between seismic activity variation and variations of man action characteristics (injection pressure, injection and/or production volumes

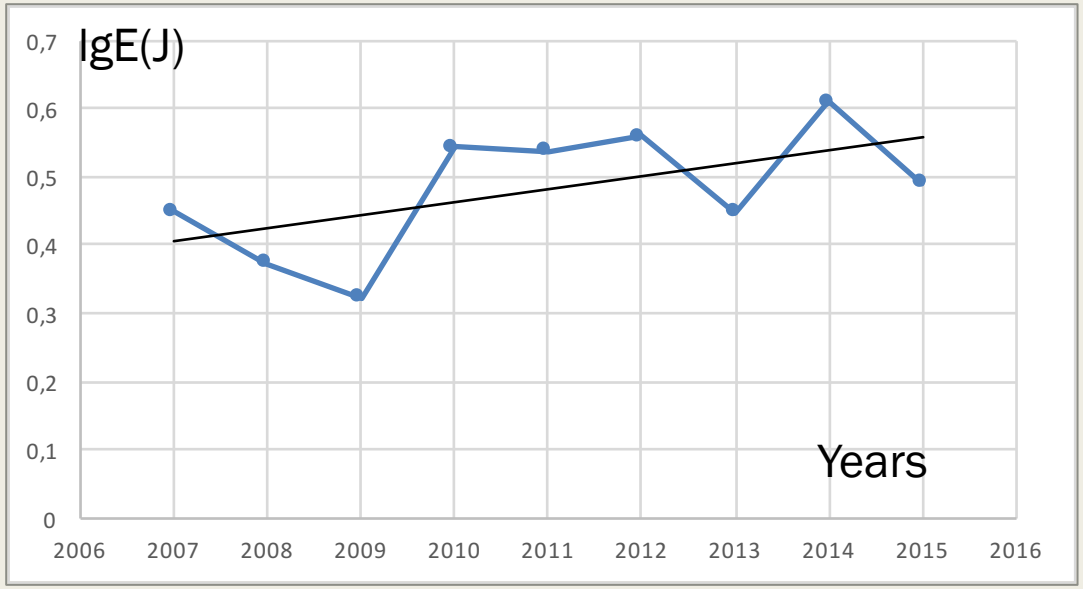
(McClure, 2012; Turuntaev & Razumnaya, 2002; Lasocki, 1992; Turuntaev et al., 2012)

Results: b-value

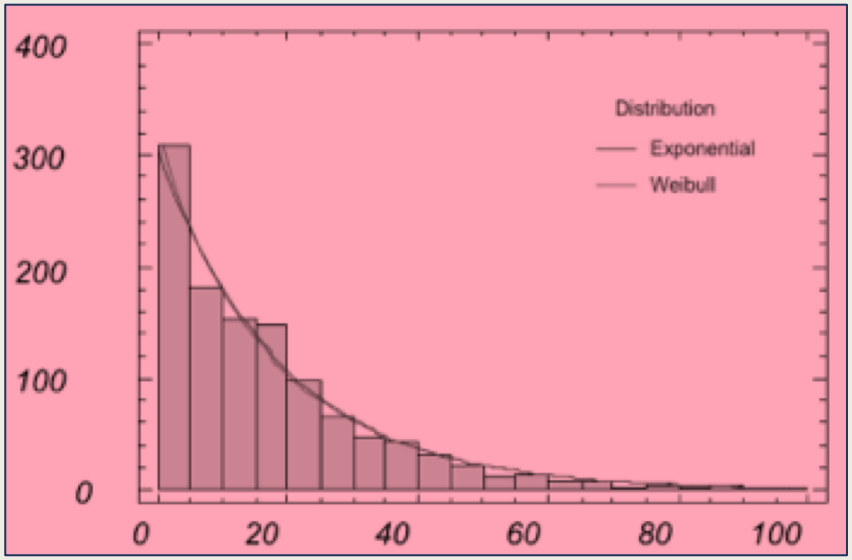


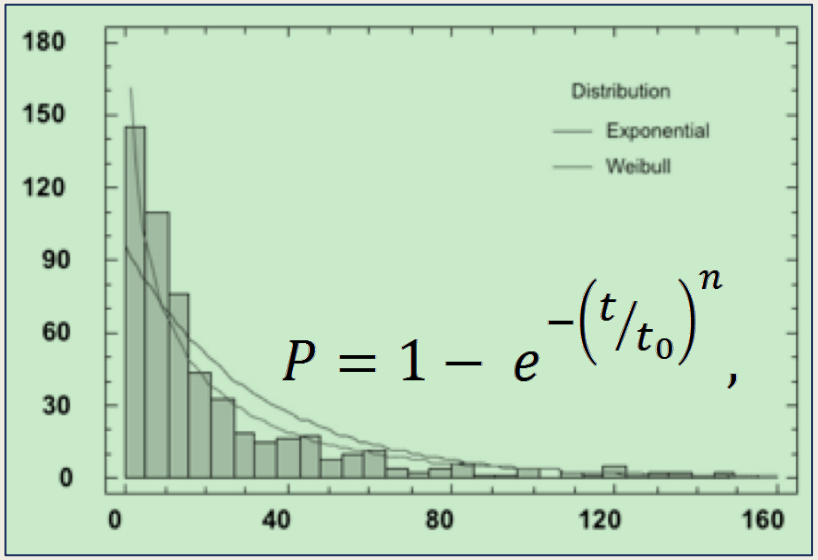


- Magnitude-frequency relationships for Sakhalin regional seismicity in 1950-1990 (a) and for Northern Sakhalin local seismicity in 2006-2014 (b). In the first case the seismic catalog completeness can be estimated as 3.5, for local seismic catalog its completeness is 1.5.
- b-value for natural seismicity is 0.95, b-value for the second catalog is 1.06 and it has some tendency to increase with time.



Results: the time interval distributions



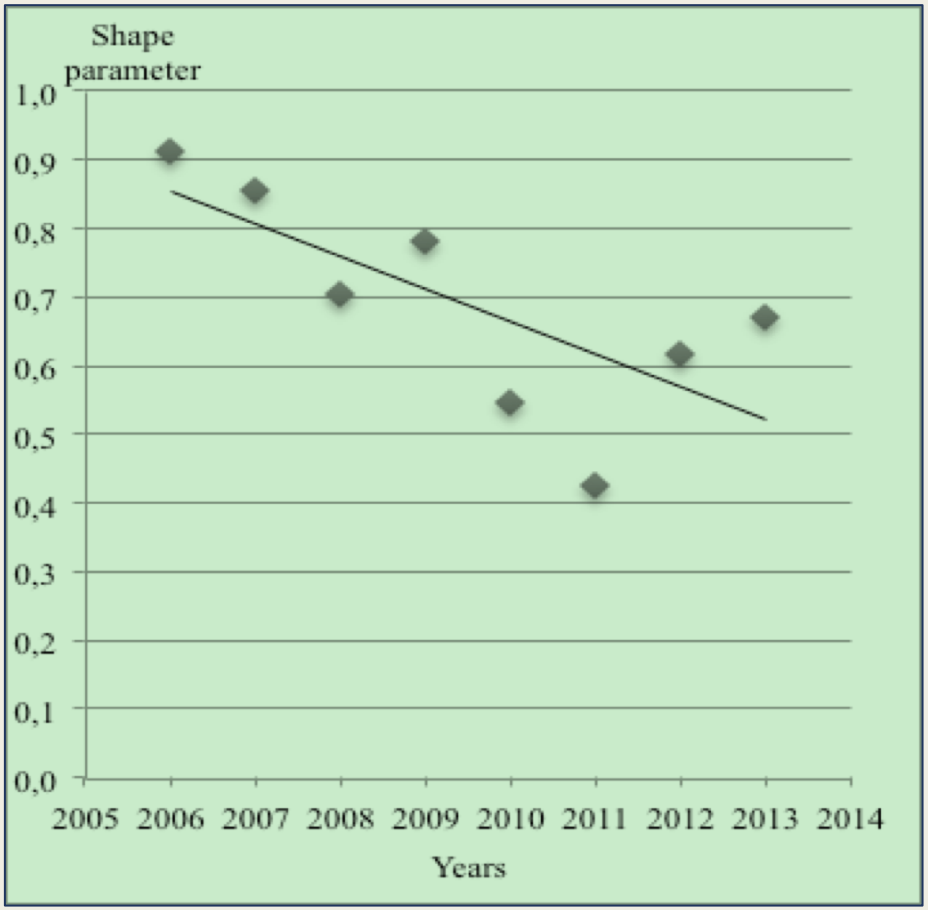


- Distributions of the time intervals between successive seismic events: (a) for natural seismicity between 1950 and 1990; (b) for local seismicity in the region of the Sakhalin offshore oil & gas fields. Exponential and Weibull distributions are shown by blue and red lines.

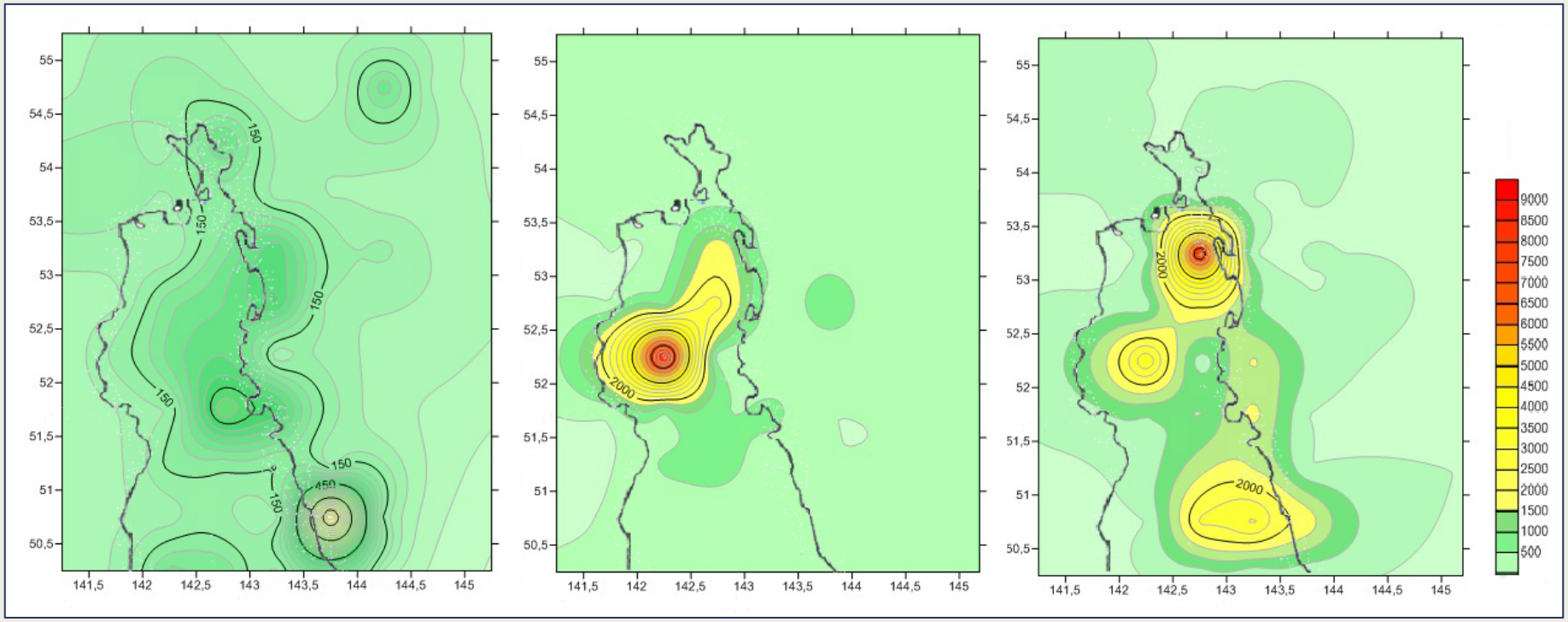
	Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2016
P-value	Exponentia	0,217	0,572	0,033	0,11	0	0	0	0	0	0	0
	Weibull	0,657	0,319	0,9	0,818	0,015	0	0,216	0,944	0,199	0,403	0,302

Results: the time interval distributions

- Variation of the Weibull distribution shape parameter with time for seismicity in the region of offshore fields. It can be seen that values of the shape parameter became smaller with time and stabilized at value near 0.64.



Results: spatial variation of the seismic activity

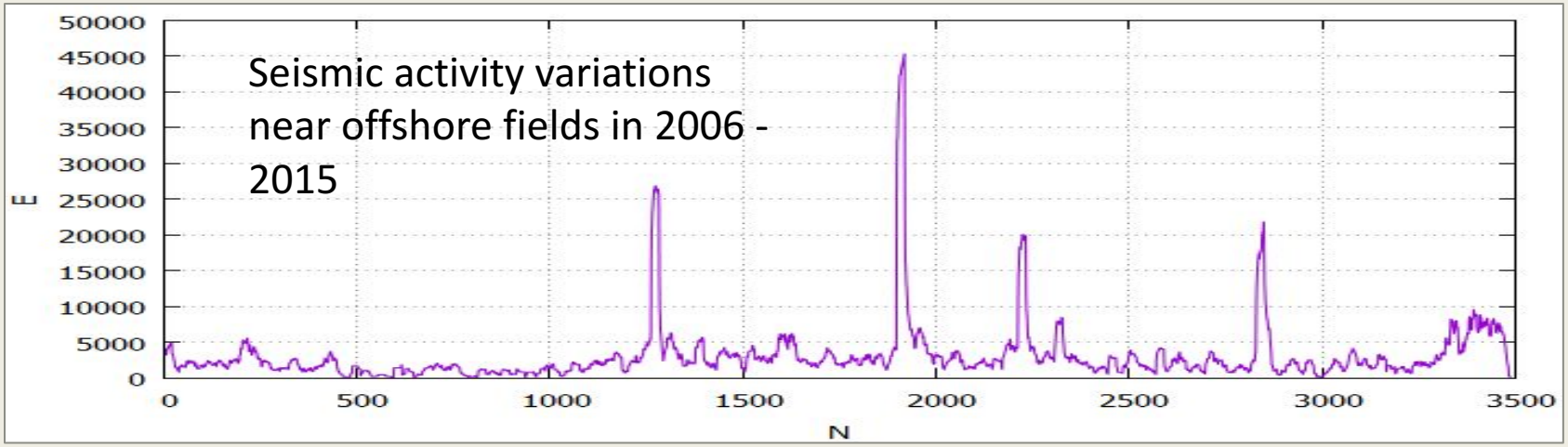


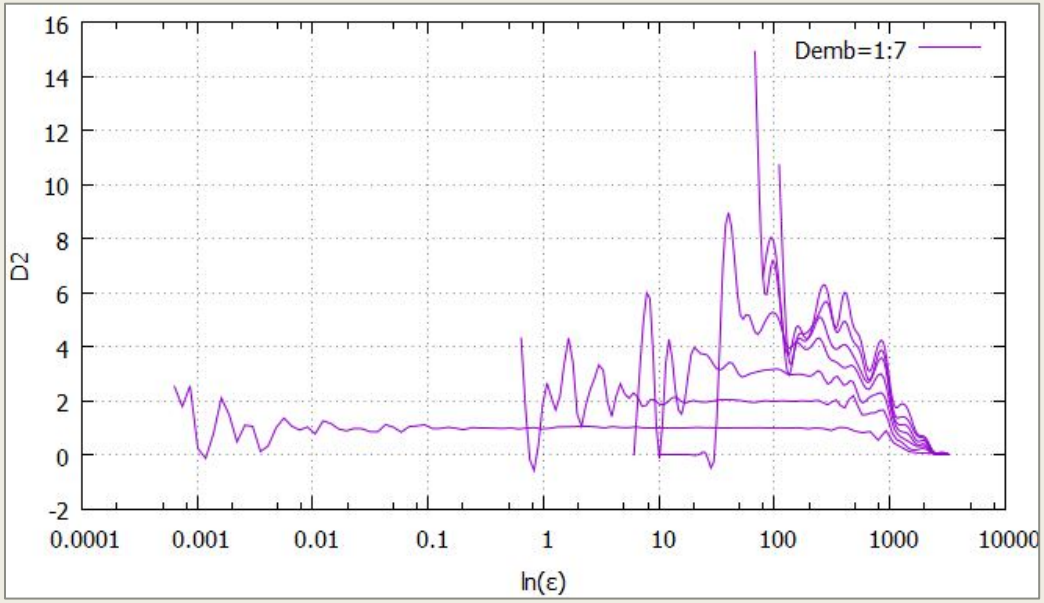
1970 - 1991

2006 - 2010

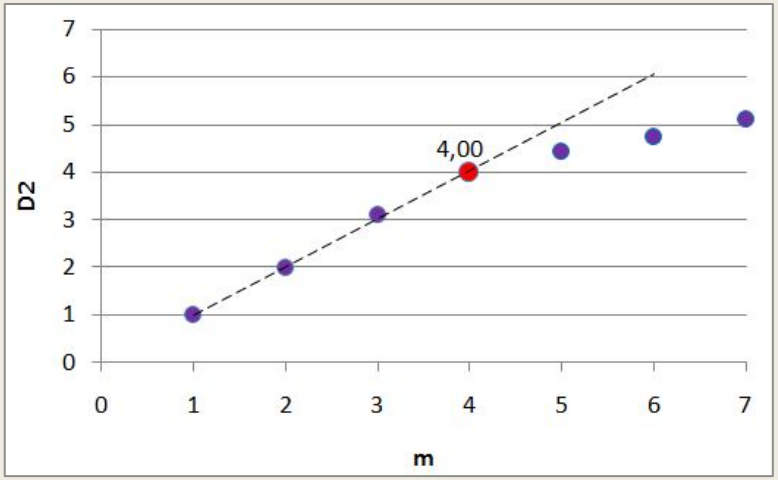
2011 - 2014

Results: correlation dimensionality





Correlation dimension vs. parameter of closeness



Correlation dimension vs. embedding space dimension

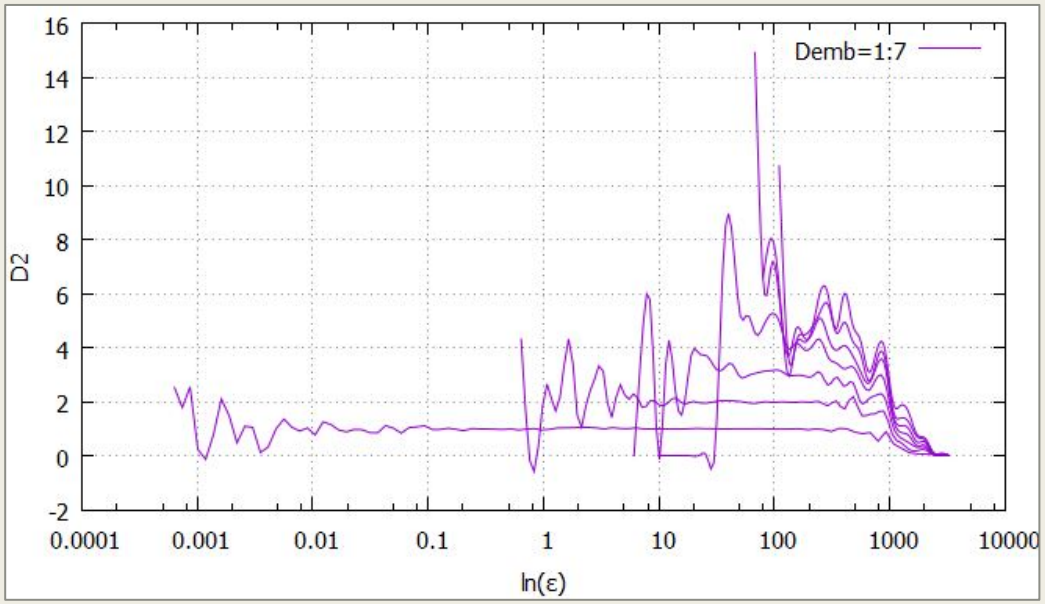
$m = 4$

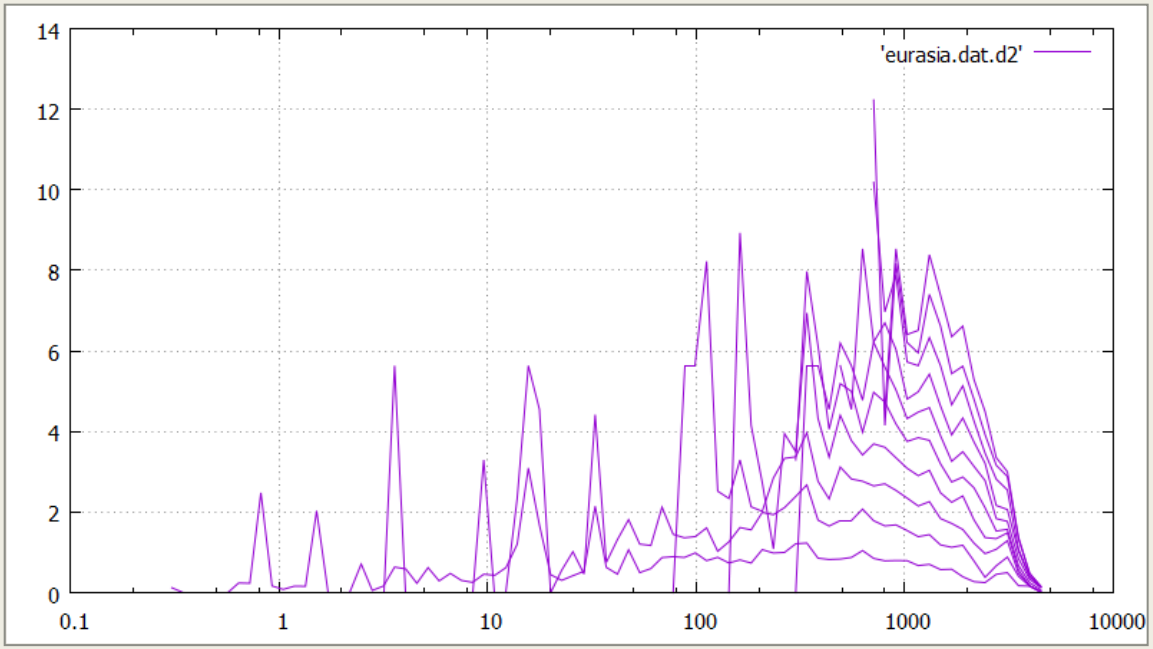
$D_2 \approx 4$

Grassberger P., Procaccia I., 1983.

Results: correlation dimensionality

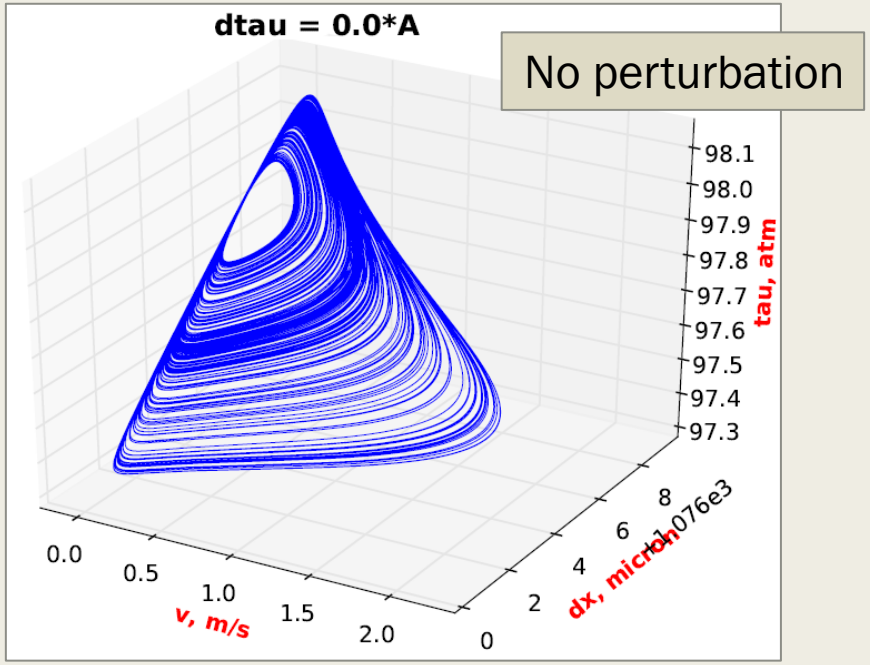
Seismicity near offshore fields in 2006 - 2015

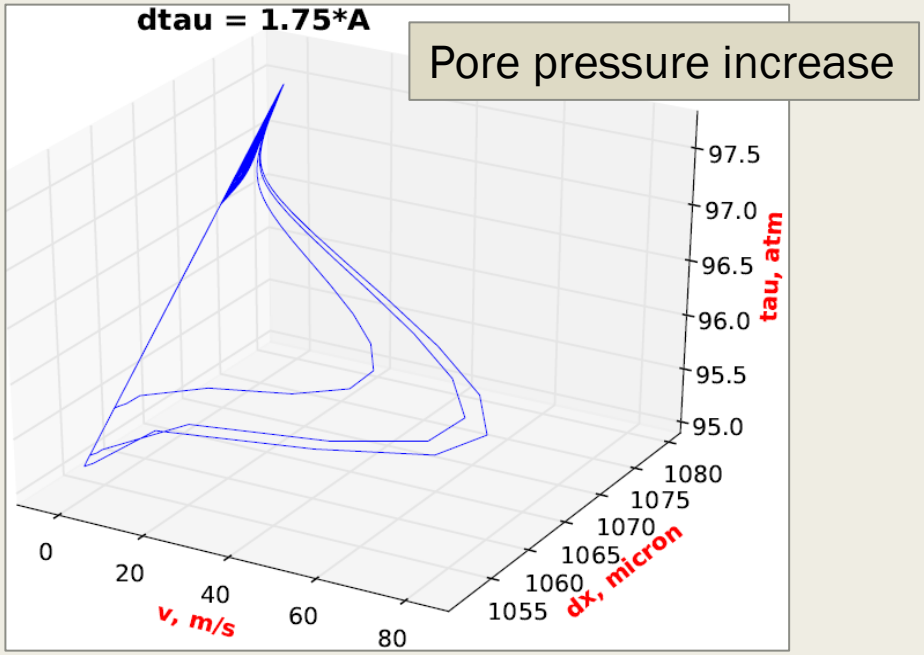


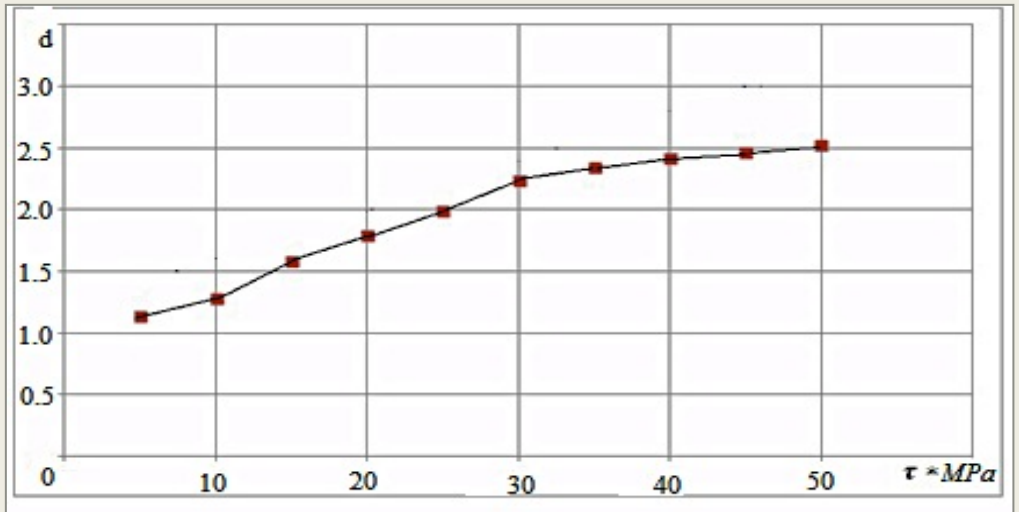


Seismicity in the Northern Sakhalin in 1957 - 1990

Discussion: rate-state two-parameter one-block model, phase portraits







Dependence of correlation dimensionality on critical stresses

Turuntaev, Kamay, 2014. in: Chaotic Modeling and Simulation (CMSIM) 4: 357-367, 2014
Turuntaev S.B., Riga V.Y., 2016

Discussion

- Usually it is difficult to prove triggered type of the particular earthquake, its relation with man activity.
- Mainly the difficulty is related with an absence of preliminary installed seismic network in the region of hydrocarbon fields.
- Installation of the seismic network in the region of Sakhalin offshore hydrocarbon fields in advance allows us to hope that potentially dangerous changes in the seismic activity in that region will be detected in due time.
- The best way to determine if the seismicity is related with hydrocarbon production would be to look for a correlation between seismic activity and injection pressure and/or volumes of produced fluid and injected water.

We plan to study a presence of this correlation in the future.

Conclusions

- *b*-value became a bit higher and the distribution of the time intervals between successive seismic events started to be described by Weibull distribution with the shape factor less than 1, which is usual for induced seismicity, but not for the natural one.
- The correlation dimensionality and embedding space dimensionality became low.

These changes in the seismic activity parameters indicate possible influence of the offshore field developments on the seismic regime.

At present, there are no signs of dangerous increase of the seismic activity in North Sakhalin region due to offshore hydrocarbon field developments.


Thank you
for attention!

Method

Grassberger-Procaccia method includes a construction of so-called *z*-vectors based on experimental measurements of a parameter *x* time variations

$$z_t = \left\{ x_t, x_{t+\tau}, x_{t+2\tau}, \ldots, x_{t+(m-1)\tau} \right\}$$

m is a dimensionality of *z*-vectors, *t* is tim

Correlation integral

$$C(\varepsilon) = \frac{1}{N^2} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} \theta\left(\varepsilon - \left\| z_i - z_j \right\|\right)$$

If there is a constant *D* so that

the constant is called the correlation dimensionality

The correlation dimensionality is calculated for several values of *m*, and the value *m** is to be found for which the correlation dimensionality became independent on *m*. The value *m** is considered as embedded space dimensionality, the corresponding value of correlation dimensionality is taken as fractal dimensionality of the attractor.

$$D \; 8 \lim_{\lozenge \perp 0} \frac{\log C(\lozenge)}{\log \lozenge}$$