# SPATIOTEMPORAL DISTRIBUTION OF SEISMIC EVENTS IN THE PACIFIC REGION AND SOUTH AMERICA

***Elena Sasorova[1], Boris Levin[2]***

**1. Shirshov Institute of Oceanology of Russian Academy of Sciences, Moscow, Russia**
**2. Institute of Marine Geology and Geophysics, Far East Branch of Russian Academy of Sciences, Yuzhno-Sakhalinsk, Russia.**
sasorova_lena@mail.ru

## Abstract

The objectives of this piece of work are to search out a statistically valid regularity of earthquake (EQ) distribution over depth and over latitudinal belts for different magnitude ranges (MRs) and to analyze the temporal distribution of EQs in South America. The worldwide catalog ISC [ICS] from 1966 with Mb>=4.0 was used. The entire set of events under analysis was divided into several MRs. The Pacific and South America were divided into several latitudinal intervals (belts). The latitude distribution of the EQ number and energy released by EQs was studied for all magnitude ranges. The number of events in each latitudinal interval was normalized twice and relative seismic event numbers generated by unit of length of plate boundary were obtained. The comparative analysis of these distributions was carried out, showing that the maximum of seismic activity in the South Pacific is situated in latitude intervals 34º-30º S and 26º-22º S. The comparative analysis was conducted for EQ latitudinal distribution and latitude-depth distributions of EQ sources. The analysis of EQ energy distributions over depth and latitudinal belts shows that the full interval of depth in each latitudinal belt is divided into three parts (clusters) with close-cut separation boundaries. The temporal EQ distributions in South America were later analyzed. Frequency spectra were calculated separately for events belonging to every depth cluster. The typical periods of EQ occurrence for different MRs and for events with different depth levels were extracted.

## Resumen

Los objetivos de este trabajo son buscar una regularidad de la distribución de terremotos en profundidad y en latitud para diferentes rangos de magnitud (MR) válida estadísticamente y analizar la distribución temporal de los terremotos en Sudamérica. Para ello se utilizó el catálogo mundial del ISC desde 1966 para Mb>=4.0.El conjunto total de eventos analizados fue dividido en varios MR. El Pacífico y Sudamérica fueron divididos en varios intervalos latitudinales (cinturones). Se analizó la distribución en latitud del número de terremotos y la energía liberada por estos en todo el rango de magnitudes. El número de eventos en cada intervalo latitudinal fue normalizado dos veces y obtuvimos un número relativo de eventos por unidad de longitud de borde de placa. Se realizó un análisis comparativo de estas distribuciones, donde se muestra que el máximo de la actividad sísmica en el Sur del Pacífico está situado en el intervalo de latitudes 34º-30º S y 26º-22º S. El análisis comparativo fue realizado para las distribuciones latitudinales de terremotos y para las distribuciones en latitud-profundidad de las fuentes sísmicas. El análisis de la distribución de energía en profundidad y en cinturones latitudinales muestra que el intervalo completo de profundidades para cada cinturón latitudinal está dividido en tres partes (clusters) con límites de separación cerca del borde. Luego se analizó la distribución temporal de los terremotos en Sudamérica. El espectro de frecuencias fue calculado separadamente para eventos provenientes de cada

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grupo por profundidad. Finalmente, se calcularon los períodos típicos de ocurrencia de terremotos para diferentes MR y para eventos con diferentes profundidades.

## Introduction

In the last few years, there has been growing interest in problems related to searching global spatiotemporal regularities in the distribution of seismic events on Earth. Irregularity in the latitudinal distribution of EQs (LDE) was noted by Mogi [1985]. Quantitative estimates of the LDE of the planet based on electronic catalogs were obtained in Sun, 1992 and Levin y Chirkov, 2001. It was shown that the planet's seismic activity has a clearly expressed irregularity (significantly increasing in the region of 40°–50° N and 10°–20° S with a stable local minimum near the equator, almost absent at the poles and polar caps of the Earth). The study of spatial EQ distributions over latitude may give us an opportunity to estimate the influence of external and internal factors on the lithosphere of our planet. Such attempt on a theoretical level was made in Levin y Pavlov, 2001 and 2003.

The analysis of the LDE in the Pacific region was made in Levin y Sasorova, 2009. Taking into account the fact that earthquakes generally occur along lithospheric plate boundaries, the number of events in each latitudinal zone is normalized using the total length of the plate boundary in a given zone. Thus, the seismic event number by unit of length of plate boundary was obtained. Previous attempts to normalize the number of events in the Pacific by the square of the latitudinal zone were ineffective and physically wrong due to a serious irregularity in the distribution of earthquakes within the latitudinal zones. Normalized latitudinal distributions of the EQ number have clearly expressed bimodal character with two peaks located in the Northern Hemisphere (40°–50° N) and in the Southern Hemisphere (20°–40° S), local minimum near the equator (10°–20° N), and almost zero values in the polar cap regions.

In order to analyze spatiotemporal EQ distributions and especially to prepare the lists of events to be analyzed in the Pacific and South America, the worldwide catalogs ISC (from 1966) and NEIC (from 1973) were used. All EQs with Mb>=4.0 were extracted. The preliminary standardization of magnitudes (to Mb value) was fulfilled for all events. Aftershocks were removed from the list of events (using the program by V.B. Smirnov, Moscow State University). After pre-processing, the total amount of events from 1966 was more than 200,000 in the Pacific and more than 20,000 in South America.

The entire set of events was divided into several magnitude ranges (MR): 4.0<=Mb<4.5; 4.5<=Mb<5.0; 5.0<=Mb<5.5; 5.5<=Mb<6.0; 6.0<=Mb<6.5; and 6.5<=Mb. Earthquake subsets of each studied segment were thus compiled with respect to six MRs. Further analysis was performed separately for each MR. The separation of each event set into several subsets with different magnitude ranges allowed us to analyze the peculiarity of the seismic process for various energy levels. The region under study was divided into several latitudinal intervals (the size of each interval was 10º, 5º, and sometimes 2º).

## An analysis of the spatial distribution of earthquakes over latitudinal belts

The distributions of the EQ number over latitudinal belts for the Pacific are shown in Fig. 1a (18 latitudinal belts with scale interval $10^{o}$).

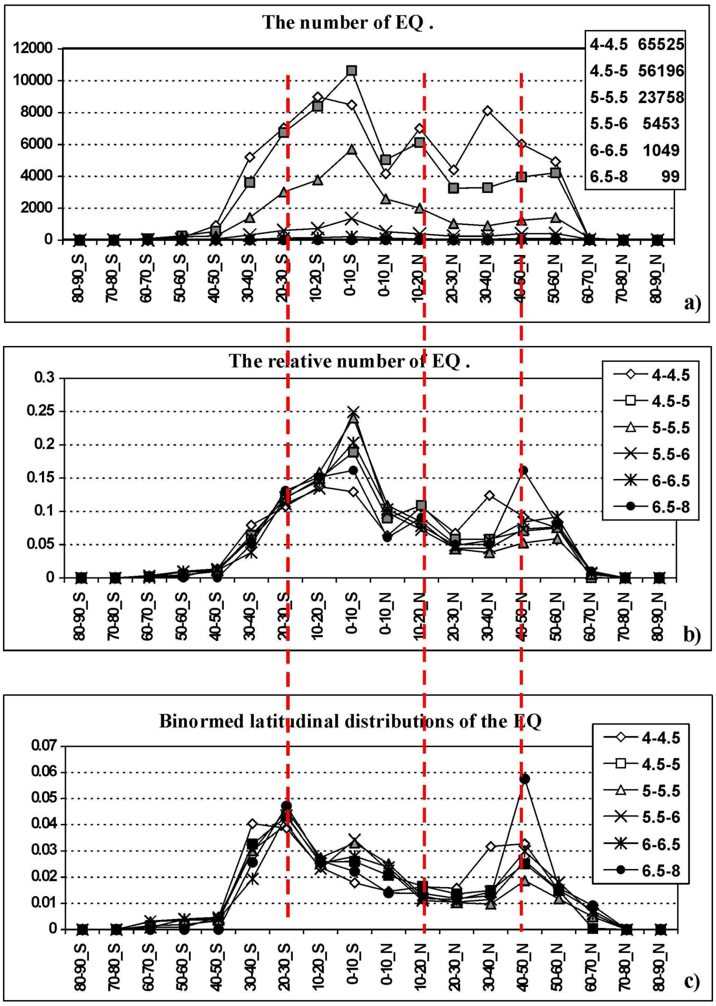


Figure 1: The latitudinal distributions of EQs for six magnitude ranges. Plot a): Number of EQs. Plot b): Relative number of EQs. Plot c): Binormed latitudinal distributions of EQs. The horizontal axes in all plots are the latitudinal belts. The total number of events in each MR is situated in the upper right-hand corner of plot a). Captions for MR are situated in the upper right-hand corner of plots b) and c).

It is impossible to compare the distribution character of the EQ number for different MRs (for example 4.0<=Mb<4.5 and 6.0<=Mb<6.5, because the EQ number for these two MRs differs in an order of 80 times). The distributions of the relative number of EQs are presented in Fig. 1b (after the first normalization by total EQ number in each MR). In this case the distributions for all MRs can be compared, being practically similar. The binormed EQ distributions in latitude for six MRs are illustrated in Fig. 1c (two step-by-step normalization: by total number of EQ in a given MR and with respect to the length of lithosphere plate boundary in a given latitudinal belt). Double normalized latitudinal distributions of the EQ have clearly expressed bimodal character

The binormed EQ distributions in latitude in South America are shown in the Fig. 2 (32 latitudinal belts with a belt size equal to $2^o$). This distribution was much more detailed. Here the peak of seismic activity located in 30°–40° S of the Pacific disintegrates in two peaks: 34º-30ºS and 26º-22ºS, and one clearly expressed local minimum into 30º-26ºS. The binormed values of the EQ number in all the other latitudinal belts are less than the average value of all studied latitudinal belts. These calculations were repeated for 13 latitudinal belts with a belt size equal to $5^o$ (in South America) and similar results were obtained: two clearly expressed peaks in two latitudinal belts ($30^o$-$35^o$S and $20^o$-$25^o$S) and local minimum in belt $25^o$-$30^o$S.

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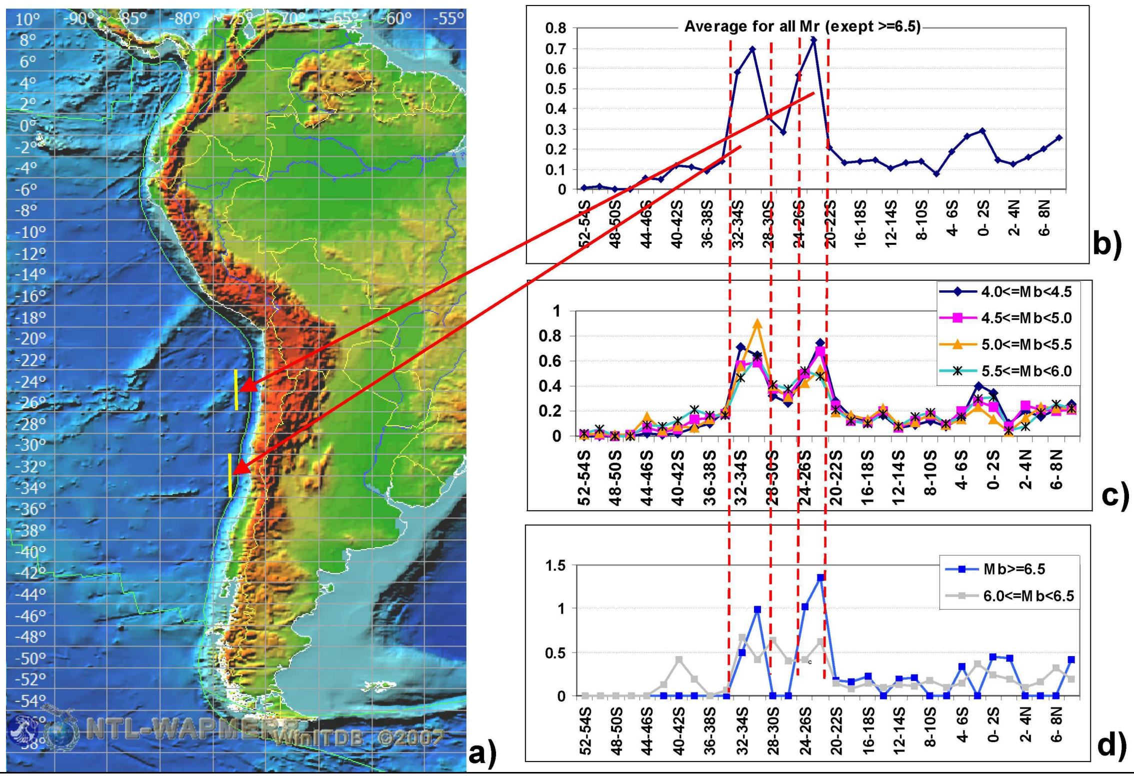


Figure 2: a) Map of South America with lithosphere plate boundaries (green line). Latitudinal belts are the horizontal axes and the binormed number of EQs are the vertical axes in plots b), c) and d). Plot b) presents binormed distribution for an average value over six magnitude ranges. Plot c) shows binormed distribution for four magnitude ranges, plot d) shows the same distributions for large EQs. Captions of plots c) and d) are located in the upper right-hand corner. Two bold red arrows label the latitudinal belts with the peaks of seismic activity.

The problem of time stability of these distributions is one of the debatable problems in research works on global seismicity. Therefore, we specially analyzed latitudinal distributions over four 10-year time intervals. It was observed that latitudinal distributions in different ten-year periods slightly vary for all MRs. Thus, the character of distributions is generally preserved in all the analyzed intervals.

The latitudinal distribution of EQ energy release and the EQ energy normalized by the length of lithosphere plate boundaries in South America were calculated. It should be highlighted that the distribution of the binormed EQ number for MR 6.5<=Mb (Fig. 2d) is quite similar to that of the EQ energy normalized by the length of lithosphere plate boundaries.

In addition, 3D distributions of the EQ relative number were taken into consideration: in latitude, depth, and MR. Depth distributions for events in each latitudinal belt in South America were later analyzed. It was detected that up to 90% of the EQ sources in high latitudes are located at depth 20<=H<=60 km. The essential part of the EQ sources in latitudinal belts near the equator (30$^{o}$ S - 0$^{o}$) are located at depths 100<H<=240 km (intermediate EQ) and H>=500 km (deep EQ). Shallow EQs (H<=80 km) increased up to 90% in latitudes from the equator to 10$^{o}$N.

The distribution analysis of EQ energy release in depth and in latitude shows (Fig.3)

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that the full interval of depth in each latitudinal belt disintegrates into several isolated parts (clusters) with close-cut separation boundaries (K1 – with 0<H<=80 km, K2 - with 120<H<=240 km and K3 - with H>=500 km).

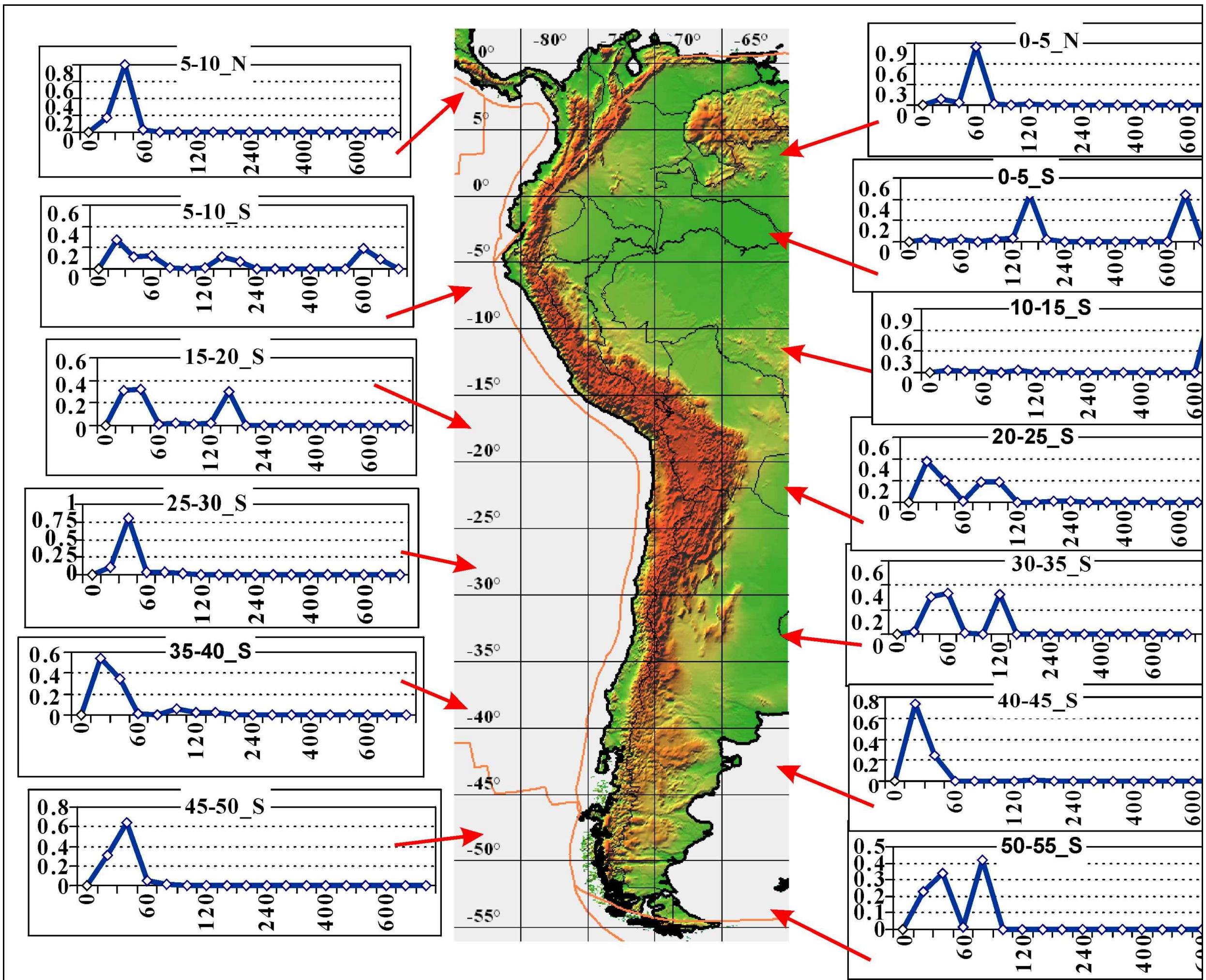


Figure 3. Distributions of EQ energy release over depth in each latitudinal belt (size 5°) are shown in 13 plots. The horizontal axes represent depth in km; the vertical axes represent the relative value of released energy (normalization by total value of energy released in a given latitudinal belt). The red arrows indicate the relevant latitudinal belt.

We can see that more than 90% of the energy in latitudinal belts from 55°-50°S to 40°-35°S is released by EQs whose sources are located at depth H<=80 km (cluster K1). The energy released by EQs from clusters K2 and K3 is negligible for these latitudes. However, the energy released by EQs in middle latitudinal belts (35°-15°S) partitions between clusters K1 and K2. A noticeable part of the energy released by EQs with depth H>=500km (cluster K3) appears in latitudes located near the equator (15° - 0°S). Practically all the energy in the northern latitudes (0°-10°N) is released by shallow EQs (cluster K1).

A general trend for both EQ number distributions in depth and latitude and EQ energy distributions in depth and latitude can be observed. Hence, if we study the spatiotemporal peculiarities of EQ distributions, three EQ subsets should be considered separately: shallow events, intermediate EQs and deep EQs.

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## Temporal EQ distributions in South America

Firstly, the entire set of events was partitioned into three subsets in compliance with the EQ source depth: shallow EQs, intermediate EQs and deep EQs. Secondly, each depth subset was divided once more into six subsets according to magnitude range. The full observation period lasted from 1966 to 2004. Every year was divided into 26 intervals (14 days). The total number of time intervals in this period of observation equalled 995. The EQ number in every time interval was calculated for each depth cluster and each MR. These values formed time series (TS). The total number of TS under analysis was eighteen.

At first we tried to verify hypotheses about correlation between TS belonging to the same depth interval but to different MRs. Three correlation matrixes for shallow, intermediate and deep events were calculated, for six MRs each. It was shown that reliable time correlation between events from different magnitude ranges does not exist. The average values of the correlation coefficient are equal: for shallow events 0.2 (maximal value - 0.46); for intermediate events 0.05 (maximal value - 0.10); for deep events 0.10 (maximal value - 0.26).

Afterwards, the spectrum analysis for eighteen TS was carried out. Power spectrum density (PSD) and 95% confidence interval for every TS was calculated. It should be noted that all TS with M>=6 were poor-filled TS and reasonable spectrum analysis for such TS was impossible. Hence, the representative periods for all well-filled TS were detected. The following periods were revealed for shallow EQs: 10-13, 6.7-5.5, 2-3, 1 and 0.5 years for events with 4<=M<4.5; and 10-13, 6.7, 2-3, 1 and 0.5 years for events with M>=4. Those for intermediate EQs were: 13, 6.7-5.5 and 1 years for events with 4<=M<4.5; and 13, 6.7-5.5, 4.4, 3 and 0.5 years for events with M>=4. We failed to find the characteristic periods for deep event TS. These events are distributed in a random manner.

## Conclusions

There is clear irregularity in the latitudinal distribution of EQs. The most active seismic zone (by relative number of binormed events) according to our analysis is located in the area 20º-24ºS and 30º-34ºS. The most active energy output also occurs in the same latitudinal belts. Very remarkable variations of EQ distribution over depth and distributions of energy over depth also occur in latitudinal belt 20º-35ºS. The maximum difference in the plate traveling velocities in subduction zones in South America (from 5ºN to 45ºS) is not higher than 7.2%. Nevertheless, the EQ number in the same latitudinal belt is 20 to 30 times higher and in energy distribution it is more than 1,000 times higher.

The characteristic periods for time series (TS) of shallow events are 10-13; 6.7-5.6; 1 and 0.5 years. These periods are well-discriminated from the TS spectra of EQs with 4<=M<5. The TS spectra presenting the sum of EQs in all magnitude ranges (4<=M) are practically the same as that of EQs with 4<=M<4.5. The studied period of observation is not long enough to estimate the TS spectra of large EQs (6<=M). We succeeded in discriminating the characteristic TS periods of intermediate EQs only for events with 4<=M<5. We failed to find the characteristic TS periods of deep events. These events are distributed randomly.

It should be noted that the period 6.7 year is close to the periods of the Chandler wobble of the Earth's geographic pole and the period near 13 year is a multiple of 6.7. At the same time, the periods equal to 1 and 0.5 year are typical periods for solar tidal cycles.

The temporal analysis of EQ distribution was conducted in the whole South American region. It would be very reasonable to repeat such analysis separately for some South American subregions. The decomposition into subregions may be fulfilled following the data obtained after analyzing the spatial distributions of seismic events in the first part of this

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research work. It is possible to use already developed software and methodology for future analysis.

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