Orientation of links connecting pairs of neighbour epicentres on Kamchatka is non-random, and varies in space and time

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Abstract

Large fraction of background seismicity looks random-like. We try to find some system in its apparent chaos. With this goal in view, we study "neighbours", i.e. events that are close in space-time, and we study the statistics of directions for links connecting pairs of formally defined neighbours in the regional Kamchatka earthquake catalogue. The effects of two interfering factors: space-time clustering, and time-independent directivity features, are suppressed. Epicentres were selected from three circles of 150-km radius for five 10-yr periods, and 15 rose diagrams of link directions, each based on 60-500 links, were formed. They show clear and significant deviations from purely random (isotropic) directivity. For rose diagrams within the Kurile-Kamchatka arc, the strongest petal is enigmatic: it is directed along the maximum compression (P) axis, and across the strike of the arc. Each of the petals is thought to reflects a direction of a family of subparallel (en-echelon) faults that accompany the main subduction mega-thrust. Rose diagrams show clear variation in time.

Keywords: seismicity, **epicenter, neighbor,** space-time, direction, lineament, rose diagram, temporal variations, migration

Introduction.

Small earthquakes, often treated as “background seismicity”, are not distributed in space-time in a random manner. They show space-time clustering in the form of aftershock sequences or swarms. Such phenomena can be viewed at as increase of probability of short interevent distances and times as compared to the reference “pure random” or Poisson case. Such a tendency can be seen in statistics of *distances* between epicentres. In the present work however we study the statistics of *directions* for vectors connecting pairs of epicenters of small earthquakes. Components of such pairs will be called "neighbours", and the mentioned vectors will be called “link vectors” or links. Study of statistics of links may help to find new properties of statistical structure of observed epicentres fields (“clouds”); to establish interactions between earthquake sources of small earthquakes, to reveal geometrical properties of the pattern of active faults of low rank. We will show that directions of links are non-isotropic, and show non-uniform, often peaked, distribution, visually represented as clear petals on rose diagrams of link directions. Earlier study along similar lines has been carried out by Lukk (1978) and Lukk and Turchaninov (1998). Instead of pairs, they analysed approximately straight-line chains of five to seven members, and obtained quite impressive and apparently convincing results; they however did not verify their conclusions by formal statistical checks.

2. Data and their processing. Checking significance of violation of directional isotropy.

Pairs of neighbours are extracted from the catalogue of small (M_L=3.5-5) shallow earthquakes of the Kamchatka subduction zone. To define neighbours, bounds are set on distance (10-60 km) and relative delay (0.5 day) between members of a pair. Before pair extraction, the work catalogue was decimated to reduce space-time event density within dense clusters. The thinning procedure throws out from the catalogue the weakest events among those which have fallen into “congested” bins of the 3D (X×Y×T) histogram. Bins with the number of events K_{ijk} in excess of K_0 are considered as «congested». See Fig.2 for illustration. With the catalogue of pairs at hand, we constructed distributions of azimuths of links (rose diagrams).

In Fig 3 one can see example histograms and corresponding rose diagrams for two 10-year periods (see Table 1 for definitions and labels of the periods); processing was done using two variants of maximum delay: 0.5 and 5 days. Angles (modified azimuths, ν,) in all histograms and rose-diagrams are counted off from the direction with azimuth of 37° that represents the strike of the island arc. Before constructing rose diagrams, the modified azimuths were reduced to the [0° 180°] range by subtracting 180° when needed. One can see that with the stricter limit of 0.5 days, histograms and rose diagrams show more expressed deviations from the uniform (isotropic) distribution of angles. For both variants of the maximum delay, the along-arc oriented pairs jut out (at ν about 0° and 180°). At the less strict limit of 5 days, this orientation becomes dominating. Although this tendency formally means a break of isotropy, it is not of any interest because it results from the fact that a large fraction of epicentres occupy a relatively narrow strip, well seen on Fig. 1. Therefore the observed 0°-180° preferred direction has no connection to epicentre distribution within narrow space-time neighbourhoods that we intend to analyse.

To suppress contribution of this interfering direction, a special normalization of angle histograms was performed. We additionally calculated similar histograms for larger delays, 100 to 150 days, marked T, and considered them as representing pure effect of geometry of epicentre field These were used for normalisation, performed in the following way. Values of initial or raw (R) histograms are divided (point by point) by corresponding values of T-histograms. In this way normalised (N) histograms are obtained, considered as most representative of preferred directions of neighbour pairs.

To make the results more convincing, we performed statistical testing of the hypothesis «N-histogram differs from a constant»; actually, the equivalent hypothesis «the R-histogram differs from the T-histogram» was tested. The Pearson’s χ^2 criterion was used. The significance value, Q, is indicated on plots, in most cases it is below 0.1 %. Such is the methodological basis of the study; then the analysis of data was performed.

3. Data analysis and its results.

N-histograms have been determined for three circles of the 150-km radius shown on Fig. 1, and for five approximately ten-year periods from 1962 to 2010, coded by centre year as “65”, “75”, “85”, “95”, and “05”. For corresponding R-, T- and N-histograms and rose diagrams see Fig. 5, 4 and 6. One can see clear and mostly significant deviation from isotropy; instead, narrow petals are seen in many cases. To discern in the original map view the links that are aggregated into some narrow petals see examples on Figs 7 and 8.

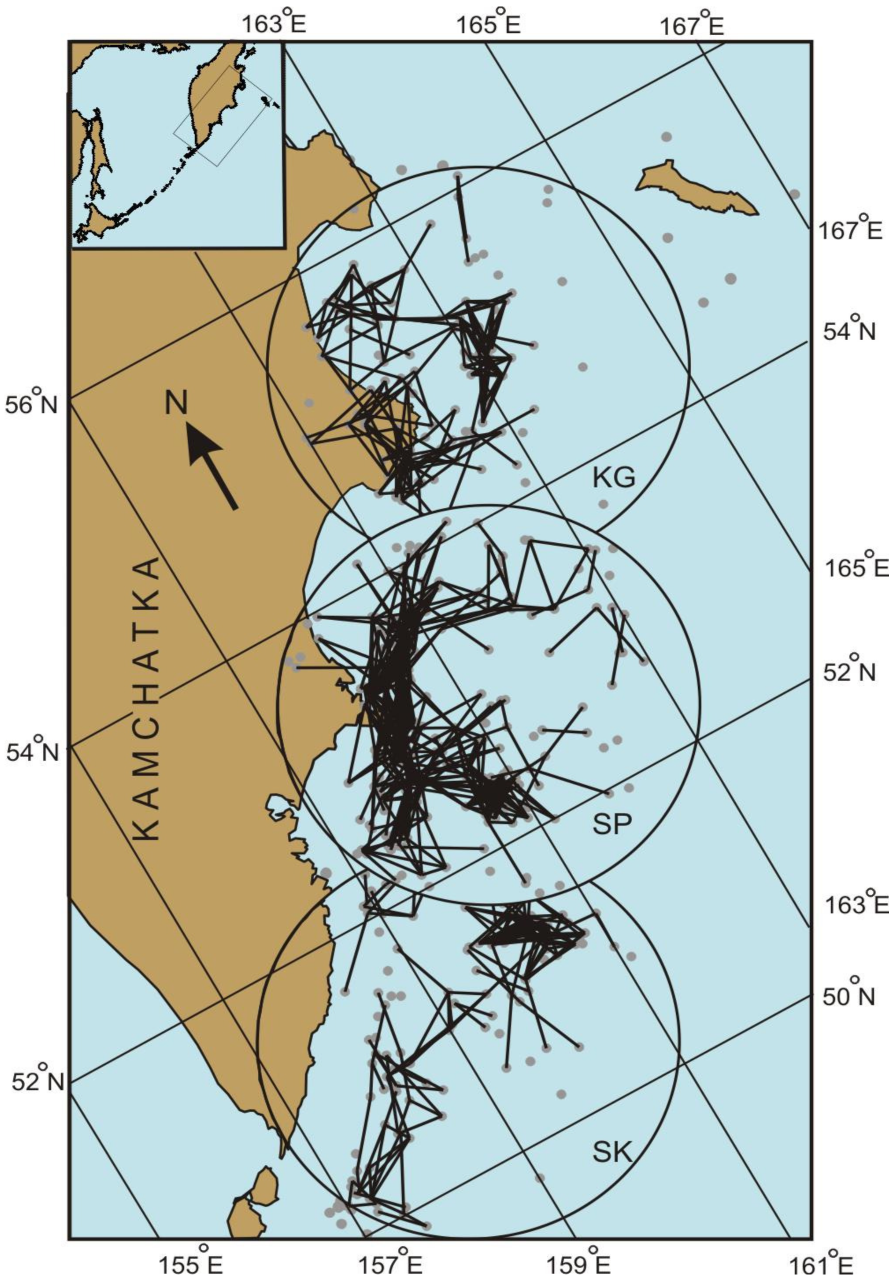

Fig. 1. Examples of distribution of pairs of epicentres for three studied circles SP, SK and KG, for 1962. Parameters of selection of pairs are the following: [Δt_1 Δt_2] =0-15 days, [D_1 D_2] =15-60 km, M_L=3.5 - 5. See the location of the study area within NW Pacific on the insert.

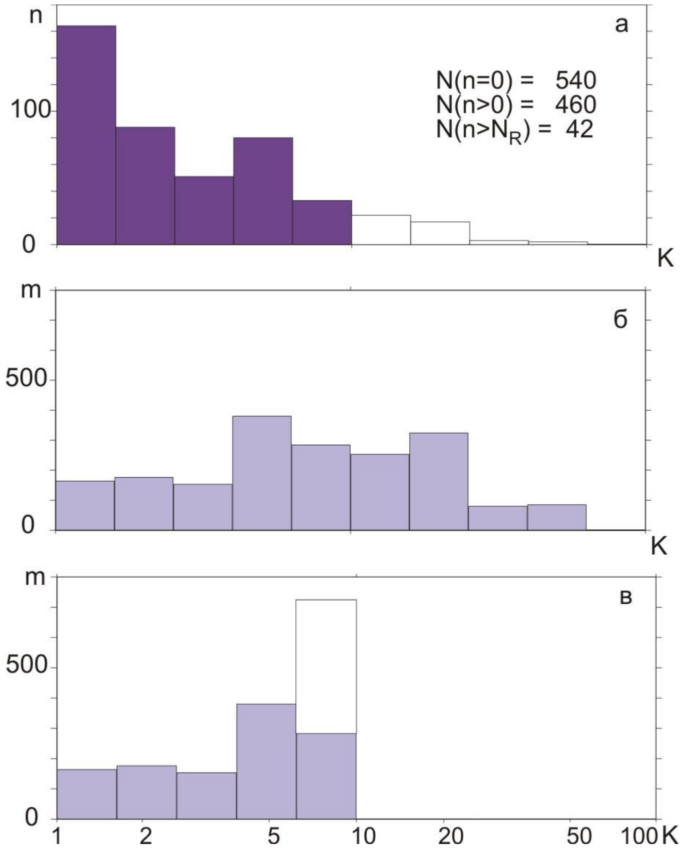

Fig. 2. An illustration of swarm thinning. a – This histogram shows the distribution of bins of the 3D histogram over the number *K* of events in a 3D bin, for data of area KG during 1981-1990. Columns (*n* values) are obtained by summation of number of bins with different *K* over the preset ranges of *K* with bounds that form a geometrical progression. Light-grey columns represent congested 3D bins ($K \geq 11$), to be thinned out. b - Total numbers of *events*, *m*, summed over all 3D bins that belong to a particular column of the histogram "a"; the initial state, before thinning. c - Analogue of the plot "b" after thinning. The number of events within 3D bins with $K = 10$ is now artificially increased (light grey).

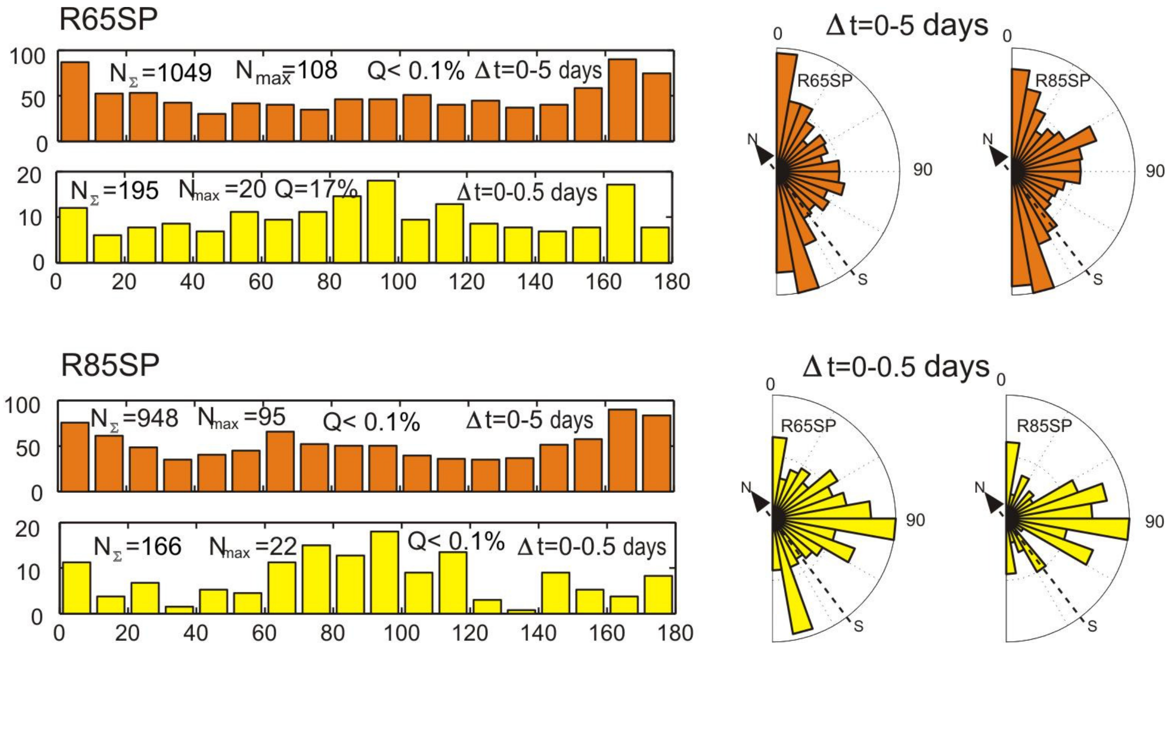

Fig. 3. Examples of histograms of directions of link vectors, defined through the parameter ν (at the left) and corresponding rose diagrams (on the right), for Circle SP, for two periods «65» and «85», and for two variants of parameter Δt_2 - 5 and 0.5 days

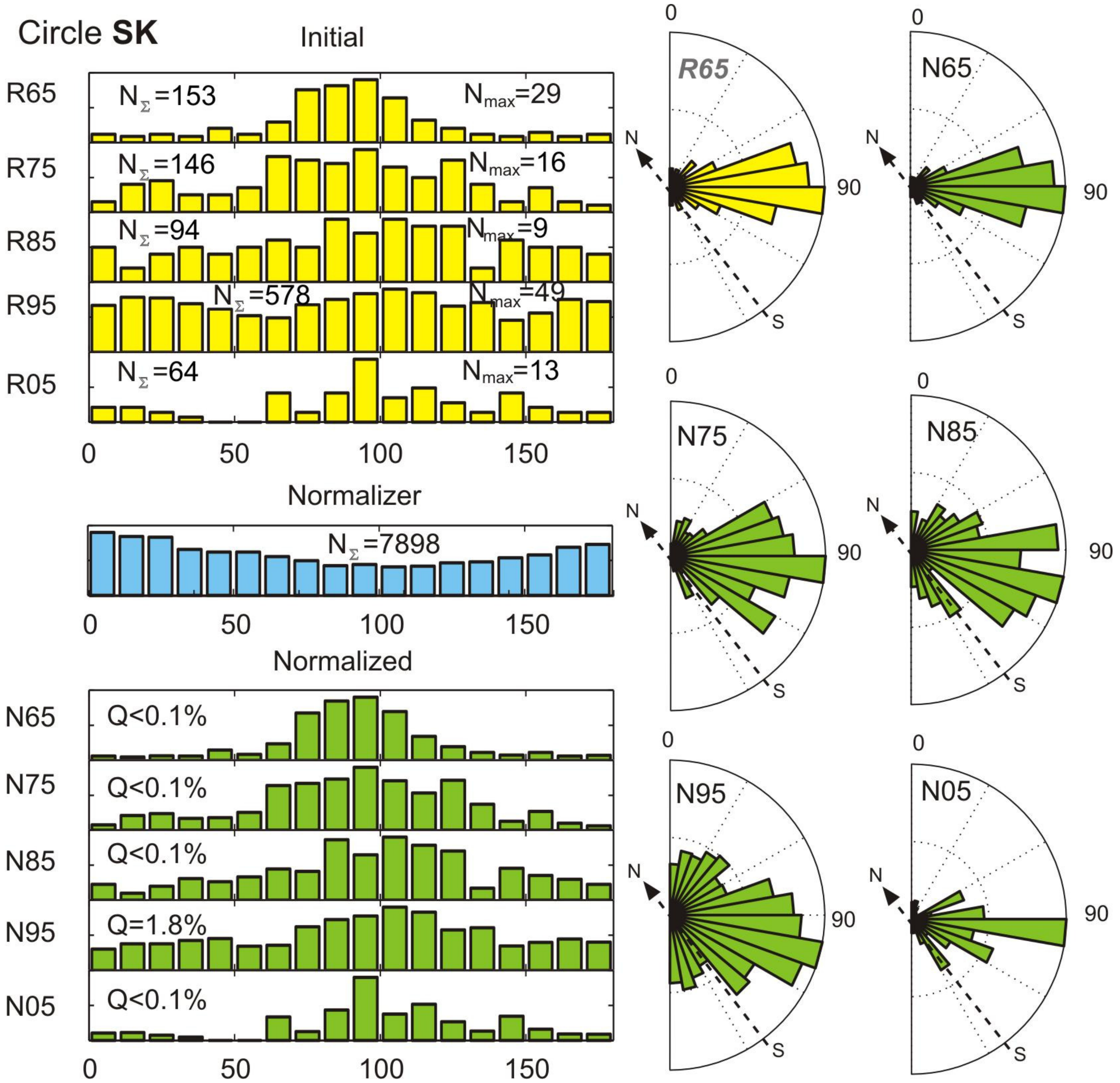

Fig. 4. Histograms of directions (at the left) and corresponding rose diagrams (on the right) for Circle SK, for five periods. Each histogram and rose diagram is scaled to its own maximum. Histograms, from top to bottom, represent: (1) the group of five initial (R) histograms (codes R65, R75 etc.), each for a particular 10-yr period; (2) a single T-histogram used for normalization; and finally (3) the group of five normalised (N) histograms (codes N65, N75 etc.). Rose diagrams correspond: the top left histogram to R65, the others - to histograms N65-N05. The direction of the geographical north is shown by a dashed arrow.

The following conclusions can be derived from this material.
(1) The observed distribution of link azimuths deviates significantly from the uniform law; in many cases, this deviation manifests itself as narrow petals. In deriving this conclusion, the effects of non-uniformity of link directions produced by spatial non-uniformity of epicentre field were suppressed (through formation of a rose diagram of the N kind).
(2) In a rose diagram of the N kind, an expressed petal is systematically seen oriented mainly across the island arc. The along-arc direction is, generally, weakly expressed.
(3) Two rose diagrams for the two southern circles SK and SP, located in the main part of the island arc, are more or less alike. There is evident difference between these two, and one for the circle KG located near to the junction of Kurile-Kamchatka and Aleutian arc.
(4) Comparing rose diagrams of successive 10-year periods, clear temporal variations of rose diagrams can be observed.

4. Possible interpretation. Conclusion.

We believe that the observed picture can be explained on the basis of the notion of propagation of pulses of aseismic slip along secondary faults. Such pulses are accompanied by small earthquakes; in this way, a pattern of oriented epicentre pairs arises, akin to the notion of migration of epicentres. In such a way, links are formed. The location of links seem to be defined by several systems of subparallel (en-echelon) faults; each such system is manifested as an individual petal of a rose diagram. This interpretation is illustrated by Figs 7 and 8 where one can see in map view how a separate petal of a rose diagram is related to a set of subparallel epicentres pairs that formed it. Systems of subparallel faults are quite common feature of fault grids of the Earth (and some celestial bodies), and its manifestation in statistics of link directions could be expected. As for temporal variations of rose diagrams, these can reflect short-term evolution of parameters of seismotectonic deformation (of “seismic flow of rock masses” in terms of Kostrov).

An enigmatic across-arc petal is oriented along the maximum compression (P) axis (close to the plate convergence orientation), and across the strike of the arc. Its formation is difficult to explain from the geomechanical viewpoint. A possible, though exotic, explanation is to relate this direction to tension failures related to fluid overpressure.

The main result of the study is the design and testing of a new technique of investigation of hidden anisotropy of the field of epicentres; establishing the existence of such anisotropy, and detection of time variations of the revealed features. The technique has a potential for monitoring the stress regimen of the lithosphere.

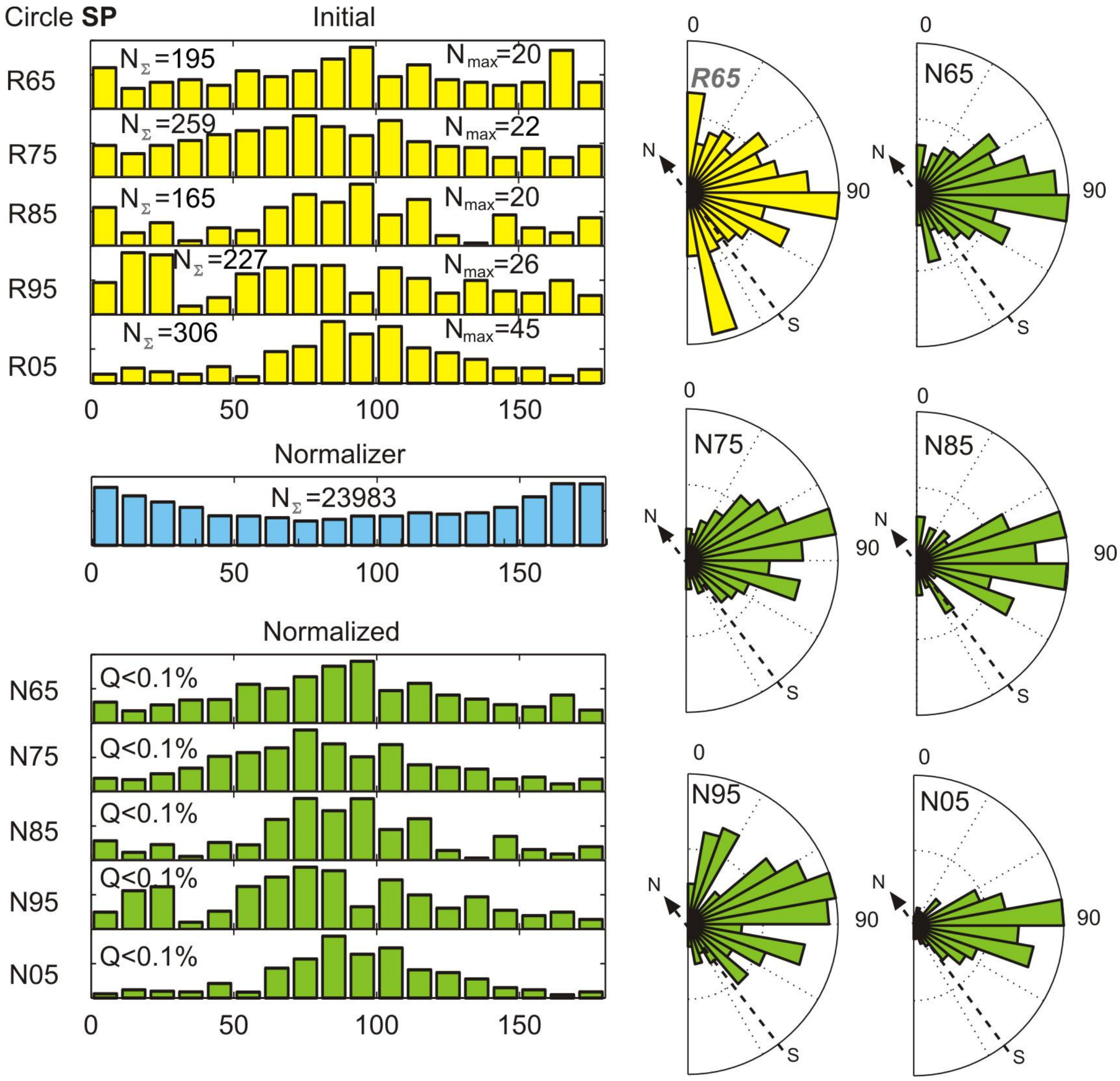

Fig. 5. Similar to Fig. 4 for Circle SP.

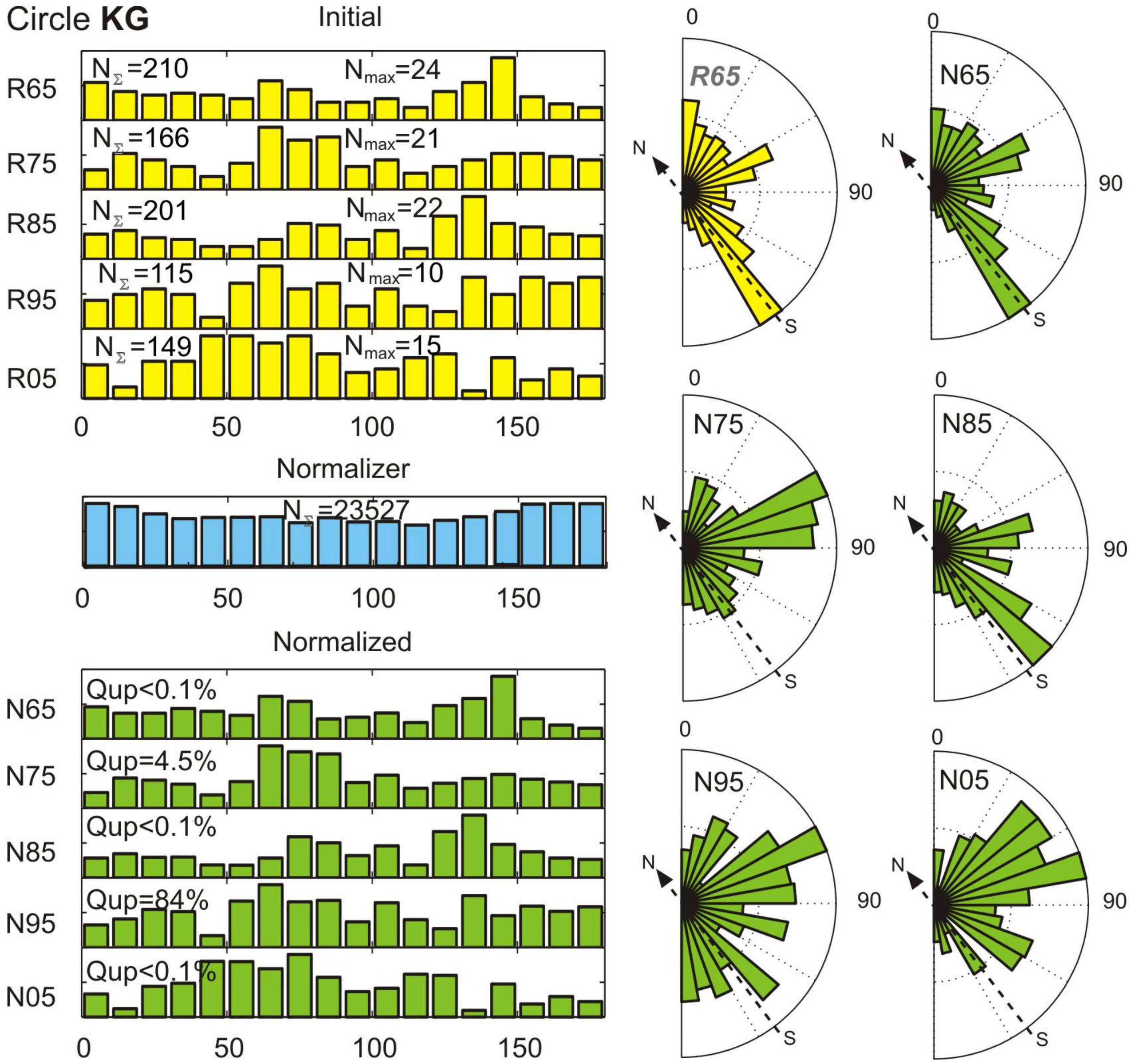

Fig. 6. Similar to Fig. 4 for Circle KG

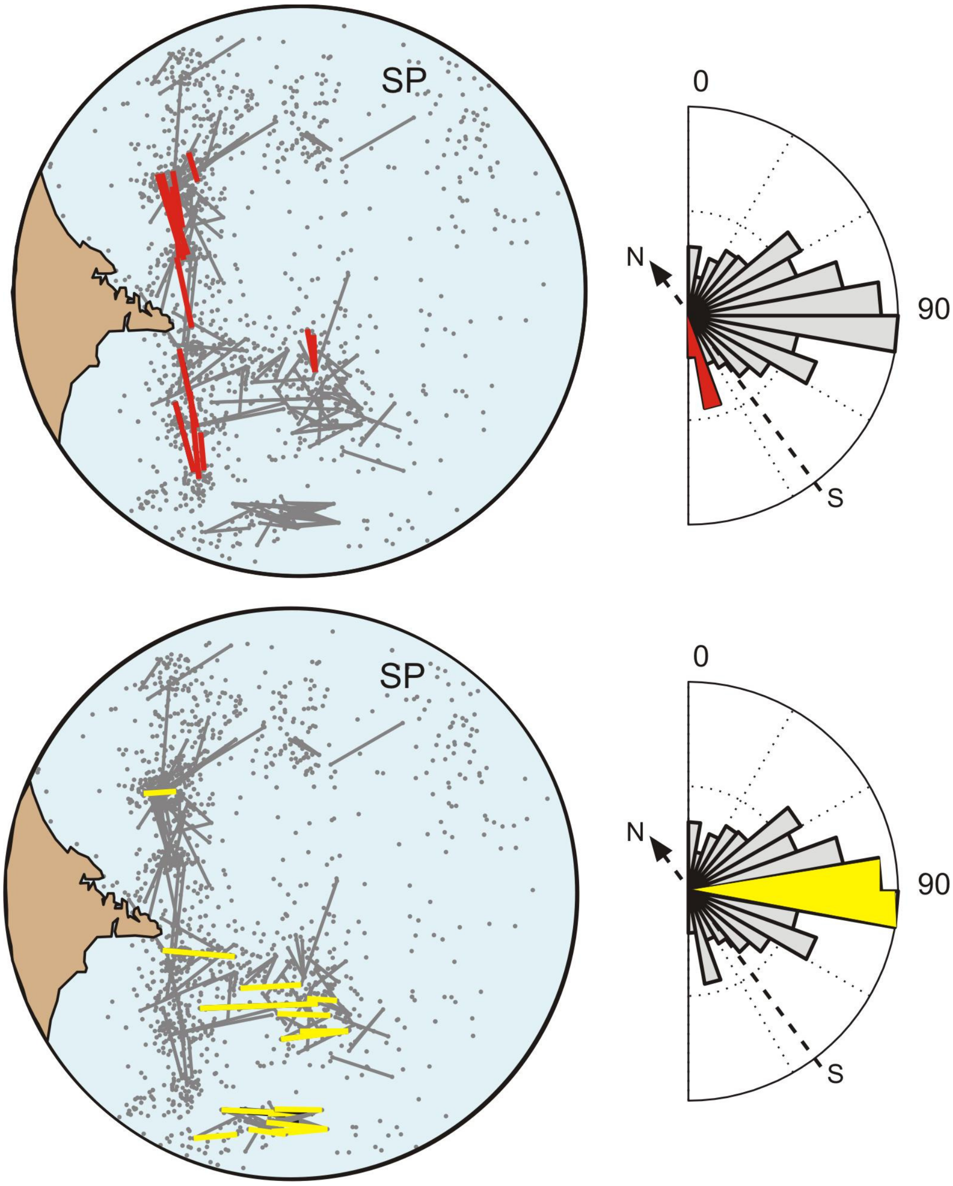

Fig. 7. Two variants of the map of Circle SP (at the left) for the period "85". On each variant the links with a certain direction (ν) range are highlighted as black: for the top circle ν =160°-170°, for the bottom circle ν =80°-100°. Links with other directions, and epicentres, are grey. The highlighted directions are displayed as black sectors on the normalised rose diagram on the right of each map.

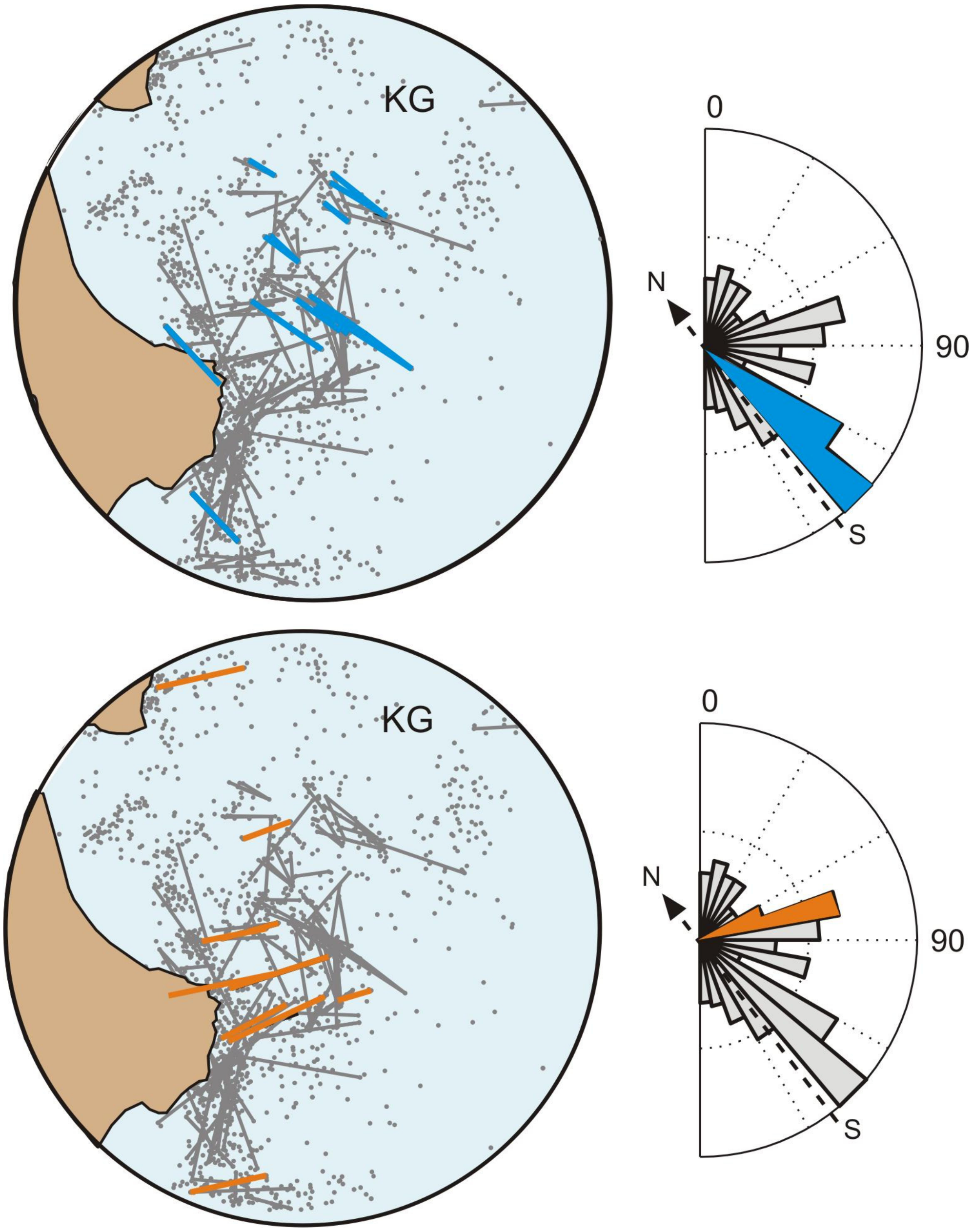

Fig. 8. Similar to Fig. 7 for Circle KG, for the period "85". The highlighted directions: for the bottom circle ν =60°-100°, for the top circle ν=120°-150°.

References

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Table 1.
Time intervals and codes

Time interval	Code	Comment
1962 - 1971.11.24	«65»	two M=7.6+ earthquakes after the end of the interval
1972-1980	«75»	
1981-1990	«85»	
1991-1997.12.05	«95»	M=7.9 earthquake after the end of the interval
1998-2010	«05»	