Jet streams anomalies as possible short-term precursors of earthquakes with *M*>6.0

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Abstract

Satellite data of thermal images revealed the existence of thermal fields, connected with big linear structures and systems of crust faults. The measuring height of outgoing longwave radiation is located to the range of jet stream. This work describes a possible link between strong earthquakes and jet streams in two regions. The front or tail ends of jet groups maintain their position for 6 or more hours in the vicinity of epicenters of strong (*M*>6.0) earthquakes in 2006-2010. The probability of observing a stationary jet stream behavior is estimated in 93.6% of the cases on one six-hour map and in 26.7% of cases - on two adjacent maps. The median of distribution of distances between epicenters and the relevant positions of jet stream corresponds to 36.5 km. Estimates of cumulative probability of realization of prediction were 24.2% for 10 days, 48.4% for 20 days, 66.1% for 30 days, 87.1% for 40 days, 93.5% for 50 days and 100% during 70 days. The observed precursory effects are of considerable interest for possible use for real short-term prediction of earthquakes.

Introduction

In recent years considerable amount of research concentrated on identification of coupling between processes in the lithosphere, atmosphere and ionosphere during the periods of preparation of strong earthquakes. Analysis of various local anomalies (electrotelluric field, underground gases, thermal flux, electromagnetic radiation in various bands of frequencies, cloudy structures, concentration of electrons in ionosphere, etc.) generally focused on search of earthquakes precursors. A number of perspective directions of research was outlined. Let us provide some examples. The work by Ondoh[1] describes the sharp increase in concentration of radon in underground waters which arises, at least, before strong earthquakes.

Satellite data of thermal images revealed the existence of thermal fields, connected with big linear structures and systems of crust faults.[2] Anomalous variations of latent heat flow were observed for the 2003 *M* 7.6 Colima (Mexico) earthquake.[3] The atmospheric effects of ionization are observed at the altitudes of top of the atmosphere (10-12 km). Anomalous changes in outgoing longwave radiation were recorded at the height of 300 GPa before the 26 December 2004 M_w 9.0 Indonesia earthquake.[4] These anomalous thermal events occurred 4-20 days prior the earthquakes.[5-8]

Local anomalous changes in the ionosphere over epicenters can precede earthquakes.[9-11] Statistical analysis showed that these changes occurred about 1-5 days before seismic events.[12] To connect the listed above abnormal phenomena to preparation of earthquakes, some authors made an attempt to develop a model of lithospheric-atmospheric-ionospheric links.[13,14] These models study a set of possible short-term earthquakes' precursors which were observed in the lithosphere, atmosphere, atmospheric electricity, ionosphere and magnetosphere. Jet streams can be one of such possible precursors.

A jet stream is a rapidly flowing narrow air stream with almost horizontal axis in upper troposphere or low stratosphere, characterized by high vertical and horizontal gradients of wind speed and one or more maxima of speed.[15,16] Wind speed is maximal on a jet axis. Linear sizes of a certain jet stream (length, width, depth) are determined according to wind speed contour (isotach) of 108 km/h (30 m/s). As usual, a jet stream's length is several thousand kilometers, its width could be hundreds of kilometers and thickness could be 4-5 km. There are several types of jet flows: arctic (to the north of 65° N), polar, subtropical, equatorial etc. The polar jet stream is located in the mid-latitudes zone (approximately between 30° N and 60° N), the subtropical - in both two hemispheres in the range of latitudes approximately between 23.5° and 33.0°.[17] The jet stream flowing over Western Africa is an example of equatorial jet stream. In summer it is located between 10° N and 20° N.

Each of these atmospheric phenomena corresponds to a specific range of altitudes. A polar stream, which we described in this work, flows at a height of 9-12 km over sea level. Another, a weaker subtropical jet stream is located at a height of 11-16 km over sea level. Central part of a jet stream (core), where wind speed is maximal, has the following size in its cross-section: 50-100 km horizontally and 1-2 km vertically. Wind speed at the jet stream axis is usually 150-200 km/h (45-55 m/s), and the maximal measured wind speed was 700 km/h (200 m/s).[16]

Jet streams are very important for meteorology and aviation. Meteorologists use location of jet streams for weather forecasting. Fronts of jet streams can cause formation of meteorological fronts and storms. The main commercial use of jet streams at air transport: time and fuel is saved when planes go in the direction of jet streams.

Earlier[18-20] it was noticed that before an earthquake during a certain period of time almost stationary contour lines of wind speed appeared at the end of the front or tail of groups of jet streams over a seismically active

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Dedications: the authors dedicate this work to the memory of Miss Cai Bi-Yu, who died in Taiwan during the 1999 earthquake with magnitude *M*=7.3.

Contributions: Mr. Wu is the first researcher who discovered the existence of the short-term precursors of strong earthquakes, which described in the article. The idea of systematic processing and comparing two types of data (jet streams and strong earthquakes) for the two territories (China region and the north-western part of the Pacific seismic belt) was proposed by Dr. Tikhonov. In preparing this article, the authors responsibilities were divided as follows: the first author processed data of jet streams on weather maps, and the second author, as a seismologist, was responsible for the seismological part. Mr. Wu done a search and identification of precursor effect on weather maps. He also calculated the coordinates of the anomaly of the jet streams. Dr. Tikhonov prepared two samples of large earthquakes from the USGS/NEIC PDE catalog, carried out calculations of the R and T parameters, which described in the article. The introduction is written by Mr. Wu and the rest of the article was prepared jointly by the two authors.

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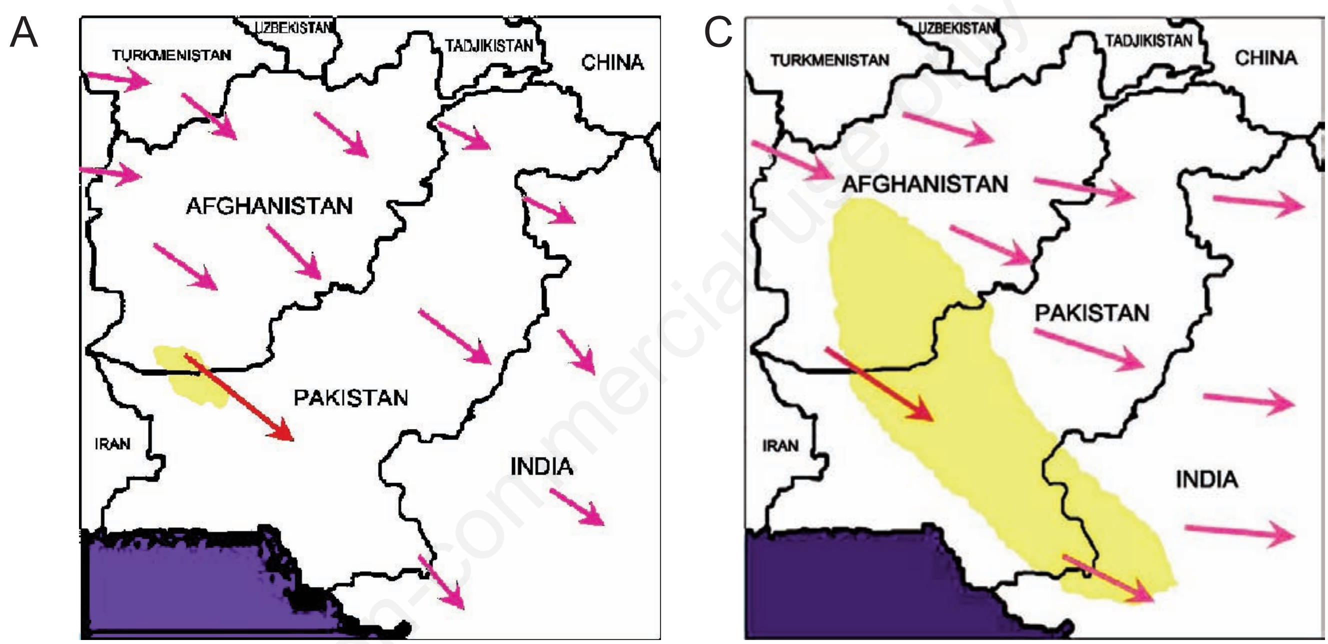
region. The purpose of this study is to establish the location and time of appearance of anomalous jet streams and to compare these parameters with the data of epicenters and time of occurrence of strong earthquakes.

Materials and Methods

To achieve the mentioned above aim we used the maps of jet streams were used, presented at the California regional weather server,[17] and the data of the U.S. Geological Survey/National Earthquake Information Center (USGS/NEIC) preliminary determination of epicenters catalog[21] within two regions:

Table 1. Strong earthquakes of M>6.0 from the National Earthquake Information Center preliminary determination of epicenters catalog which occurred in the studied region of China in the period from May 22, 2006 to December 23, 2010.

No.	Origin time (UTC)	Latitude (degree)	Longitude (degree)	Depth (km)	Magnitude
1	2007/05/05 08:51:39	34.25 N	81.97 E	9	6.1
2	2008/01/09 08:26:45	32.29 N	85.17 E	10	6.4
3	2008/03/20 22:32:58	35.49 N	81.47 E	10	7.2
4	2008/05/12 06:28:02	31.00 N	103.32 E	19	7.9
5	2008/05/12 11:11:02	31.21 N	103.62 E	10	6.1
6	2008/08/25 13:21:59	30.90 N	83.52 E	12	6.7
7	2008/11/10 01:22:03	37.56 N	95.83 E	19	6.3
8	2009/08/28 01:52:07	37.70 N	95.72 E	13	6.3
9	2010/04/13 23:49:38	33.17 N	96.55 E	17	6.9
10	2010/04/14 01:25:16	33.19 N	96.45 E	7	6.1



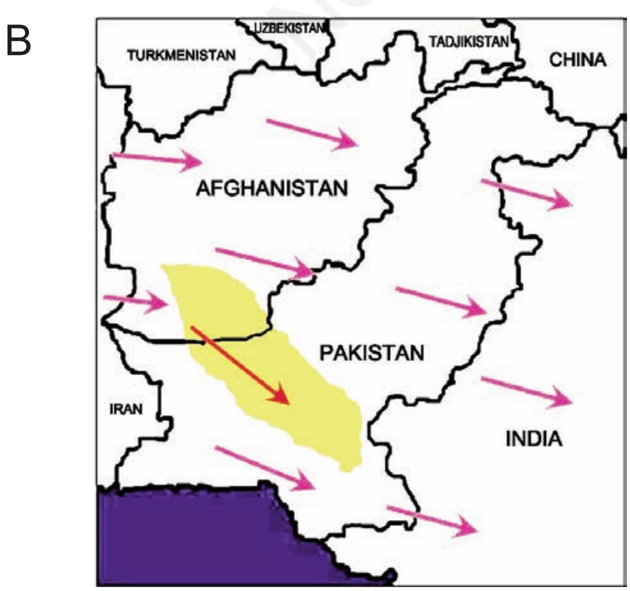


Figure 1. Example of dynamics of change of a jet stream (yellow spot), moving at a speed of 108 km/h, according to the data of three meteorological maps at the surface pressure of 300 GPa. A) Map, corresponding to the moment of time of 12 h 00 min on 20 October, 2006; B) The same map at 18 h 00 min on 20 October, 2006; C) The same map at 00 h 00 min on 21 October, 2006.

China and the Northwestern part of the Pacific seismic belt. The first sampling of earthquakes of M>6.0 was done within the limits of the following latitude and longitude coordinates: 30° N - 40° N; 80° E - 105° E (Table 1). The second sampling was done for the Kurile Islands, Kamchatka and the Aleutian Islands (Table 2). Thus the character of jet streams was studied over the continental and oceanic seismically active regions with different types of events (inter and intra-plate), located to the north of 30° N latitude. Comparison of two types of seismic data with jet stream maps was made for the period from 22 May, 2006 to 23 December, 2010.

Let us consider several parameters of the meteorological maps of jet stream analysis, which we have used. They display the data on contours and vectors of wind speed, constructed on the basis of the GFS global prediction model.[17] Such forecast was made four times a day (every 6 h) by the National Center for Environmental Prediction in the framework of the Meteorology Program of the Department of Geosciences of the San Francisco University. These maps show the parameters of jet streams in the upper troposphere at the surface pressure of 300 GPa. Wind speed contour on these maps, as it was mentioned above, start from 108 km/h (30 m/s).

Jet streams are not continuous air streams. A group of jet streams constantly change its shape and a speed of movement of its front or tail end could be reach 100 km/h. For example, in one case (Figure 1) from noon on 20 October, 2006 to midnight on 21 October, 2006 a jet stream changed its shape from small to large. A front end of a group of jet streams passes about 1200 km in 12 h, *i.e.* its speed was about 100 km/h. If a speed of front or tail end of a jet stream is less than 10 km/h, we can consider such movement an anomalous phenomenon.

The previous research[18-20] examined groups of jet streams existing during 70 days prior earthquakes with magnitude >6.0. The procedure of analysis of meteorological maps at a level of 300 GPa consisted of searching the areas (points) where the disturbance of lines with jet stream uniform speed is observed or a front (or tail end) of a jet stream stops during 6 hours and more followed by formation of a sharp angle. Such areas (points), located over zones of tectonic faults, must be studied, because their vertical projections could indicate the location of a preparing strong earthquake.

Figure 2 shows an example of two types of precursors (anomalous behavior of a jet stream). At the first type of anomaly the front end of a jet stream (Figure 2A) remains practically at the same point (Figure 2B) during six hours or more. This point could indicate the epicenter of a future earthquake. The other

Table 2. Strong earthquakes of M>6.0 from the National Earthquake Information Center preliminary determination of epicenters catalog which occurred in the studied region of the Kuril Islands, Kamchatka and the Aleutian Islands in the period from May 22, 2006 to December 23, 2010.

No.	Origin time (UTC)		Latitude (degree)	Longitude (degree)	Depth (km)	Magnitude
1	2006/05/22	11:12:01	60.77 N	165.74 E	19	6.6
2	2006/05/22	13:08:03	54.27 N	158.45 E	197	6.2
3	2006/06/14	04:18:43	51.75 N	177.08 E	14	6.5
4	2006/06/27	02:39:33	52.23 N	176.16 E	17	6.2
5	2006/07/08	20:40:01	51.21 N	179.31 W	22	6.6
6	2006/08/24	21:50:37	51.15 N	157.52 E	43	6.5
7	2006/09/30	17:50:23	46.35 N	153.17 E	11	6.6
8	2006/10/01	09:06:02	46.47 N	153.24 E	19	6.5
9	2006/11/15	11:14:14	46.59 N	153.27 E	10	8.3
10	2006/11/15	11:29:23	46.37 N	154.48 E	10	6.2
11	2006/11/15	11:34:58	46.65 N	155.30 E	10	6.4
12	2006/11/15	11:40:55	46.48 N	154.73 E	10	6.7
13	2006/12/07	19:10:22	46.15 N	154.39 E	16	6.4
14	2007/01/13	04:23:21	46.24 N	154.52 E	10	8.1
15	2007/04/29	12:41:57	52.01 N	179.97 W	117	6.2
16	2007/05/30	20:22:13	52.14 N	157.29 E	116	6.4
17	2007/07/15	13:08:02	52.49 N	168.04 W	15	6.1
18	2007/08/02	02:37:42	47.12 N	141.80 E	5	6.2
19	2007/08/02	03:21:43	51.31 N	179.97 W	21	6.7
20	2007/08/15	20:22:11	50.32 N	177.55 W	9	6.5
21	2007/09/03	16:14:54	45.84 N	150.06 E	94	6.2
22	2007/10/25	13:50:04	46.01 N	154.23 E	20	6.1
23	2007/12/19	09:30:28	51.36 N	179.51 W	34	7.2
24	2007/12/21	07:24:34	51.37 N	178.98 W	25	6.3
25	2007/12/26	22:04:55	52.56 N	168.22 W	25	6.4
26	2008/03/03	09:31:02	46.41 N	153.18 E	10	6.5
27	2008/03/22	21:24:11	52.18 N	178.72 W	132	6.2
28	2008/04/15	22:59:52	51.86 N	179.36 W	11	6.4
29	2008/04/16	05:54:20	51.88 N	179.16 W	13	6.6
30	2008/05/02	01:33:37	51.86 N	177.53 W	14	6.6
31	2008/05/20	13:53:36	51.16 N	178.76 E	27	6.3
32	2008/07/05	02:12:04	53.88 N	152.89 E	632	7.7
33	2008/07/24	01:43:16	50.97 N	157.58 E	27	6.2
34	2008/11/02	13:48:43	51.55 N	174.37 W	36	6.1
35	2008/11/24	09:02:59	54.20 N	154.32 E	492	7.3
36	2009/01/15	17:49:39	46.86 N	155.15 E	36	7.4
37	2009/04/07	04:23:33	46.05 N	151.55 E	31	6.9
38	2009/04/18	19:17:59	46.01 N	151.43 E	35	6.6
39	2009/04/21	05:26:12	50.83 N	155.01 E	152	6.2
40	2009/07/06	14:53:12	50.44 N	176.99 E	22	6.1
41	2009/10/13	05:37:24	52.75 N	167.00 W	24	6.5
42	2009/10/13	20:21:53	52.60 N	167.12 W	14	6.4
43	2009/12/10	02:30:53	53.42 N	152.76 E	656	6.3
44	2010/04/30	23:11:43	60.47 N	177.88 W	12	6.5
45	2010/04/30	23:16:29	60.48 N	177.65 W	14	6.3
46	2010/06/18	02:23:06	44.45 N	148.69 E	28	6.2
47	2010/07/18	05:56:45	52.88 N	169.85 W	14	6.7
48	2010/07/30	03:56:14	52.50 N	159.84 E	23	6.3
49	2010/08/04	12:58:24	51.42 N	178.65 W	27	6.4
50	2010/09/03	11:16:07	51.45 N	175.87 W	23	6.5
51	2010/10/08	03:26:14	51.37 N	175.36 W	19	6.4
52	2010/12/23	14:00:32	53.13 N	171.16 E	18	6.3

type of precursor is shown in Figure 2C and E. Figure 2C shows the initial state of jet stream with high value of speed. In some time the initial shape of the jet stream area changes - an intersection of wind speed contour occurs at a point (Figure 2D), then the jet stream divides in two parts (Figure 2E) and later disappears over the epicenter of the preparing earthquake. Projection of the point of contour' intersection can also correspond to the epicenter of a future earthquake.

Results and Discussion

During the studied period 10 earthquakes with magnitude M>6.0 occurred in the area in the first zone (Table 1) and 52 events with magnitude M>6.0 occurred in the second area (Table 2). One earthquake of the first zone and three events of the second zone weren't preceded by jet streams over 70 days, therefore we carried out our comparison only for 9 earthquakes in the first case and for 49 seismic events for the second. We examined 58 groups of anomalous jet streams as a whole. We were interested in wind speed contour of those groups of jet streams shown on meteorological maps, front or tail ends of which for the certain period of time were almost stationary within the area of earthquake preparation.

Let us take, for example, the earthquake with magnitude M 6.1, which occurred on 5 May, 2007 in China (Table 1). Its epicenter was in the point with coordinates 34.25° N, 81.97° E and the hypocenter's depth was 9 km. The front end of a group of jet streams moving at a speed of 108 km/h (30 m/s) was formed for the first time at noon on 3 April, 2007 (Figure 3A) and remained stationary till 6 p.m. (Figure 3B). Its projection on the Earth's surface (34.5° N, 81.5° E) was located at a distance of about 51 km from the earthquake's epicenter, which occurred 31.6 days after the moment when a group of jet streams remained almost at the same place during 6 h (Table 3).

Table 3 shows the results of processing, characterizing the correlation of jet stream

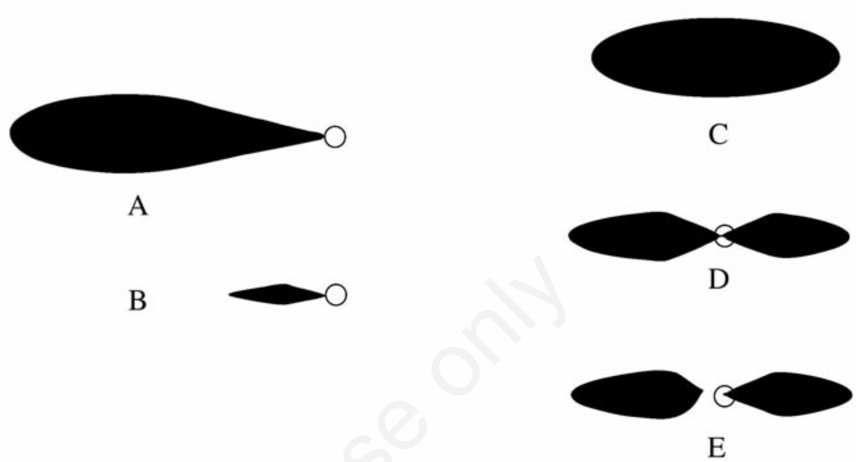


Figure 2. Scheme of two types of anomalous behavior of jet stream on consequent maps, which indicate the possible location of the future strong earthquake (circle). A and B) First type of precursor, when a front end of jet stream remains at the same place during 6 and more hours. Second type of precursor: C) Initial state of jet stream; D) Form of a jet stream's area at the next moment of time (intersection of wind speed contour at a point); E) Division of jet stream in a certain time in two parts and its disappearance over the epicenter of a preparing earthquake.

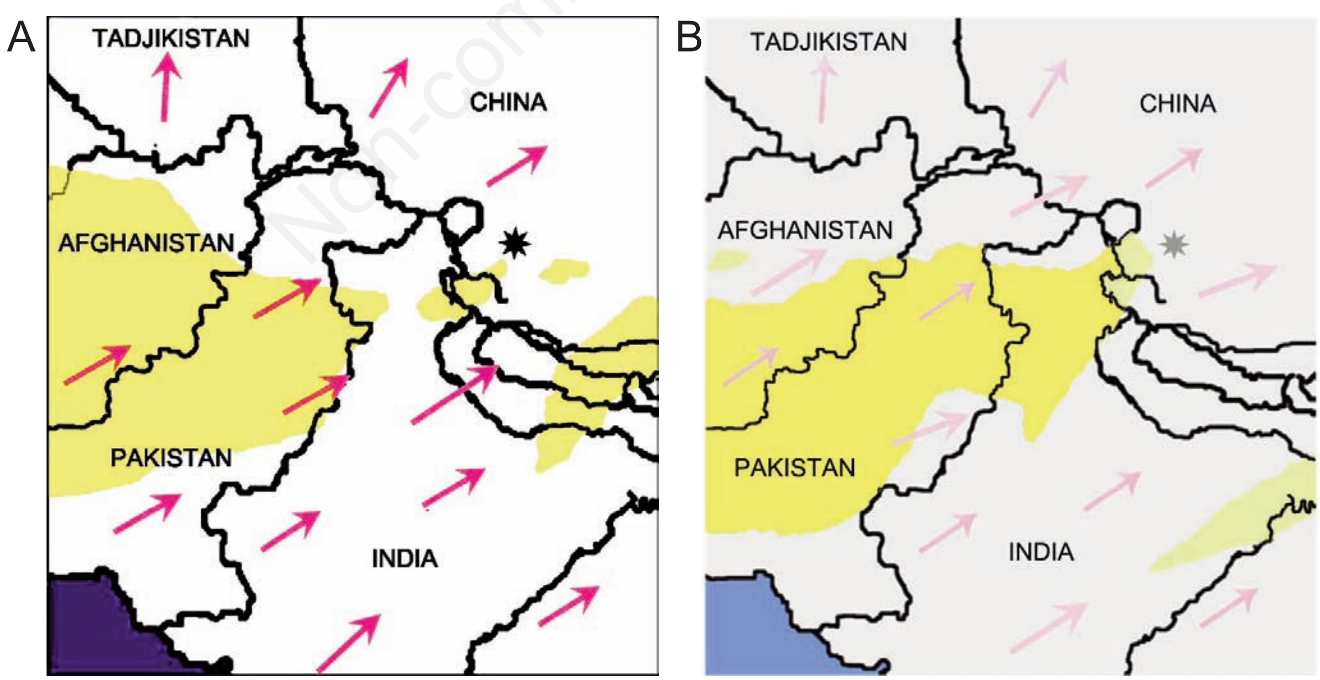


Figure 3. Connection of anomalous behavior of jet stream at a speed of 108 km/h (yellow spots) with preparation of the 5 May, 2007 earthquake with M=6.1 in China (Table 1). A) Position and shape of a jet stream, observed at 12 h 00 min on 3 April, 2007; B) The same after 6 h (at 18 h 00 min on 3 April, 2007); C) Star - location of epicenter of the 5 May, 2007 earthquake.

anomalies in time and space, preceding strong earthquakes of the studied region of China. Analogous data for the second sampling (earthquakes of the north-western part of the Pacific seismic belt) are shown in Table 4. Regardless the different volumes of samplings, it is obvious that there is no significant difference of the values of the *R* parameter (distance between earthquakes epicenters and coordinates of projection of jet stream) for continental and oceanic seismically active regions. The same can be said concerning the *T* parameter (advance time of emergence of anomaly until earthquake's occurrence). Taking into account all that was mentioned above, further the estimates of the *R* parameter from Tables 3, 4 were united in one sampling. The same unified sampling was made for the *T* parameter.

Figure 4 presents the distribution of the *R* parameter according to the data of a unified sampling. The median of this distribution corresponds to *R*=36.5 km. In 76.7% of cases the value of the *R* parameter does not exceed 90 km. Only in four cases from 60 the estimate of distance between earthquake's epicenter and jet stream projection to the Earth's surface exceeded 200 km. Such results should be considered rather encouraging for the practice of prediction of earthquakes with *M*>6.0. The proof to that is the testing of the most successful algorithms *M*8 and MSc of the intermediate-term prediction,[22-24] confirmed by practice during several decades. Thus, even at retrospective prediction of the 1995 *M* 7.2 Kobe (Japan) earthquake the spatial area of alarm, verified by algorithm MSc, was equal to 175×175 km.

Data in Tables 3, 4 answer to the question: how often a precursor can be observed in a researched territory before an earthquake with magnitude *M*>6.0 (stationary behavior of jet streams) on one and two adjacent maps. The estimated probability is: in 93.6 % of cases on one map and in 26.7 % of cases on two adjacent 6-h maps.

Figure 5 shows the dependence of estimate of cumulative probability of realization of forecasting (in days): 6.4% for 5 days, 24.2% for 10 days, 48.4% for 20 days, 66.1% for 30 days, 87.1% for 40 days, 93.5% for 50 days and 100% during 70 days. This graph displays a clear link between the time of precursor's appearance and the time of earthquake's emergence. These terms differ from time of manifestation of ionospheric precursors lasting 1-5 days[12] or time of manifestation of thermal precursors

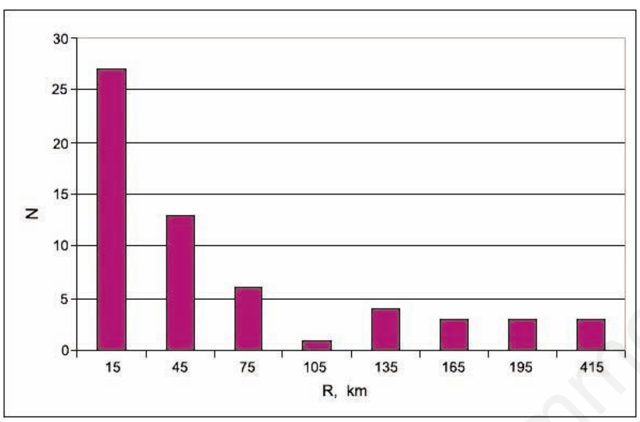


Figure 4. Distribution of parameter *R* (distance between earthquakes epicenters and coordinates of jet stream projection) according to the data of two samplings.

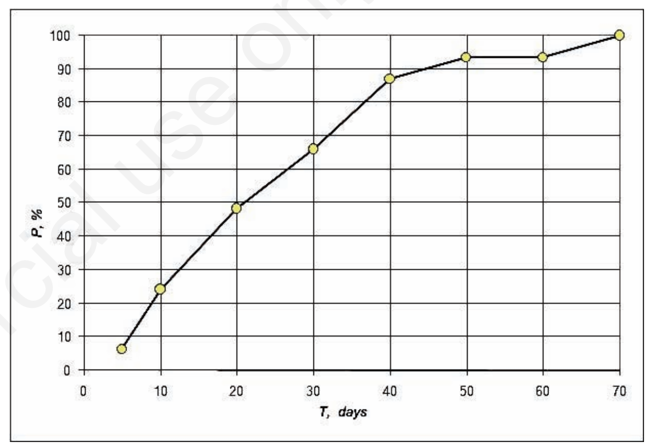


Figure 5. Dependence of estimate of cumulative probability of prediction within 70 days.

Table 3. Data on earthquakes, abnormal manifestations of jet stream and its relationship in space and time for the studied area of China.

Origin time (UTC)		Time of map issuing with the anomaly jet stream Date, hour	Coordinates of the jet stream anomalies Latitude (degree)	Longitude (degree)	*R* (km)*	*T* (days)°
2007/05/05	08:51:39	2007/04/03, 12, 18	34.5 N	81.5 E	51.3	31.6
2008/01/09	08:26:45	2008/01/04, 06 2008/01/08, 18	32.0 N	85.0 E	36.1	5.1
2008/03/20	22:32:58	2008/03/10, 00, 06	35.0 N	81.5 E	54.6	10.7
2008/05/12 2008/05/12	06:28:02 11:11:02	2008/04/29, 00, 12	31.5 N	103.0 E	63.4 67.1	12.8 13.0
2008/08/25	13:21:59	-	-		-	-
2008/11/10	01:22:03	2008/10/15, 06	37.5 N	95.5 E	29.9	25.8
2009/08/28	01:52:07	2009/07/22, 18 2009/07/23/, 00	38.5 N	95.0 E	108.9	36.3
2010/04/13 2010/04/14	23:49:38 01:25:16	2010/03/11, 18	33.0 N	96.5 E	19.5 21.7	33.2 33.3

*This column contains the coordinates of the projection of the jet stream anomalies to the surface of the Earth; *R* is the distance between the epicenter of the earthquake and the coordinates of the projection of anomalies of the jet stream to the surface of the Earth in km; °*T* is the time interval between the occurrence of a precursor anomaly and the time of occurrence of a strong earthquake in days.

Table 4. Data on earthquakes, abnormal manifestations of jet stream and its relationship in space and time for the Kuril Islands, Kamchatka and the Aleutian Islands.

Origin time (UTC)		Time of map issuing with the anomaly jet stream Date, hour	Coordinates of the jet stream anomalies Latitude (degree)	Longitude (degree)	*R* (km)*	*T* (days)°
2006/05/22	11:12:01	2006/05/09, 00, 06	60.7 N	165.7 E	8.1	13.5
2006/05/22	13:08:03	2006/05/04, 12	54.3 N	158.5 E	4.7	18.0
2006/06/14 2006/06/27	04:18:43 02:39:33	2006/05/08, 18 10.05.2006, 00	51.8 N	177.0 E	7.8 74.6	36.4; 35.2 49.3; 48.1
2006/07/08	20:40:01	-	-		-	-
2006/08/24	21:50:37	2006/08/08, 06, 12	51.2 N	157.5 E	5.7	16.7
2006/09/30 2006/10/01	17:50:23 09:06:02	2006/09/09, 06	46.5 N	154.0 E	65.9 58.4	21.5 22.1
2006/11/15 2006/11/15 2006/11/15 2006/11/15 2006/12/07	11:14:14 11:29:23 11:34:58 11:40:55 19:10:22	2006/11/04, 06	48.0 N	155.0 E	205.3 185.8 152.0 170.5 211.3	11.2 11.2 11.2 11.2 33.5
2007/01/13	04:23:21	2007/01/12, 18	46.4 N	154.2 E	30.4	0.4
2007/04/29	12:41:57	2007/03/25, 18	52.0 N	179.9 W	4.9	34.8
2007/05/30	20:22:13	-	-		-	-
2007/07/15	13:08:02	2007/07/08,12, 18	52.3 N	168.0 W	21.3	7.0
2007/08/02	02:37:42	2007/07/26, 06 2007/07/28, 18	47.0 N	147.8 E	454.7	6.9; 4.4
2007/08/02	03:21:43	2007/07/17, 18 2007/07/18, 00	51.3 N	179.5 E	36.9	15.4; 15.1
2007/08/15	20:22:11	2007/08/08, 18	50.2 N	177.4 W	17.1	7.1
2007/09/03	16:14:54	2007/08/06, 18 2007/08/09, 06 12	45.8 N	150.0 E	6.4	27.9; 25.4
2007/10/25	13:50:04	2007/10/10, 00	46.0 N	154.4 E	13.2	15.6
2007/12/19	09:30:28	-	-	-		-
2007/12/21	07:24:34	2007/10/20, 18 2007/10/21, 00	51.4 N	179.8 W	57.1	61.6; 61.3
2007/12/26	22:04:55	2007/12/23, 12, 18	52.5 N	168.0 W	16.3	3.4
2008/03/03	09:31:02	2008/02/24 00, 06	46.5 N	151.0 E	167.6	8.4
2008/03/22	21:24:11	2008/03/14, 06	52.5 N	178.4 E	199.8	8.6
2008/04/15 2008/04/16 2008/05/02	22:59:52 05:54:20 01:33:37	2008/03/01 00, 06	51.5 N	179.5 W	41.2 48.3 141.2	46.0 46.2 62.1
2008/05/20	13:53:36	2008/05/03 06, 12	51.0 N	179.5 E	54.7	17.3
2008/07/05	02:12:04	2008/06/28, 18 2008/06/29, 00	54.5 N	152.9 E	69.0	6.3; 6.1
2008/07/24	01:43:16	2008/06/22, 06	50.9 N	157.6 E	7.9	31.8
2008/11/02	13:48:43	2008/10/19, 18	51.5 N	174.3 W	7.4	13.8
2008/11/24	09:02:59	2008/10/26, 06	54.2 N	154.0 E	20.8	29.1
2009/01/15	17:49:39	2008/12/23, 12	46.8 N	155.0 E	13.2	23.2
2009/04/07 2009/04/18	04:23:33 19:17:59	2009/03/19, 06	46.0 N	149.8 E	135.3 126.0	18.9 30.5
2009/04/21	05:26:12	2009/04/08, 18	49.7 N	155.0 E	125.8	12.5
2009/07/06	14:53:12	2009/06/14 06, 12	56.0 N	177.1 E	619.0	22.4
2009/10/13 2009/10/13	05:37:24 20:21:53	2009/10/05, 06	53.0 N	167.0 W 45.3	27.8 8.6	8.0
2009/12/10	02:30:53	2009/11/14, 00	53.4 N	152.7 E	4.6	26.1
2010/04/30 2010/04/30	23:11:43 23:16:29	2010/03/22, 12	60.5 N	177.0 W 35.7	48.4 39.5	39.5
2010/06/18	02:23:06	2010/06/05 00, 06, 18	45.0 N	148.5 E	63.1	13.1
2010/07/18	05:56:45	2010/06/28, 00	52.8 N	169.6 W	19.0	20.2
2010/07/30	03:56:14	2010/07/04, 06	52.5 N	159.7 E	9.5	25.9
2010/08/04	12:58:24	2010/07/31, 18	51.4 N	178.5 W	10.7	3.8
2010/09/03 2010/10/08	11:16:07 03:26:14	2010/08/01, 00	51.5 N	175.5 W	26.3 17.4	33.5 68.1
2010/12/23	14:00:32	2010/12/18, 06	53.0 N	171.0 E	18.0	5.3

*This column contains the coordinates of the projection of the jet stream anomalies to the surface of the Earth; R is the distance between the epicenter of the earthquake and the coordinates of the projection of anomalies of the jet stream to the surface of the Earth in km; °T is the time interval between the occurrence of a precursor anomaly and the time of occurrence of a strong earthquake in days.

during 4-20 days.[5-6] By our estimates the advance time of emergence of this precursor in the form of jet stream varies from 0 to 67 days. The reason of the time difference of its manifestation in comparison with other abovementioned precursors is still unclear.

Therefore, the existence of close (by seismological standards) correlation between jet streams and earthquakes in space and time revealed certain prospects of use of this precursor for short-term prediction of strong earthquakes.

According the physics, it is possible to suppose that jet streams are result of the pressure difference between the beginning and the end of the stream. In this regard it looks interesting that sometimes the epicenter position coincides the tail of the stream what means that over the epicenter could be both the positive and negative pressure extremum. As it was already mentioned above, a number of researchers apply various models of lithospheric-atmospheric-ionospheric links for a possible explanation of this phenomenon. The authors of this article cannot judge, how plausible the suggested models are. This matter is not a subject of our research.

Conclusions

We studied possible connections between two natural phenomena - strong earthquakes and jet streams for the two regions (China and the Northwestern part of the Pacific seismic belt). The unified analysis of two types of phenomena was implemented for the period of 4.6 years observations (from 22 May, 2006 to 23 December, 2010). We established that front or tail ends of groups of a jet stream maintain their position over 6 and more hours in vicinities of epicenters of strong (magnitude M>6.0) earthquakes, preceding such events for a period from several days to two months. The specified precursory anomaly was observed both in continental regions, and in the regions of subduction of tectonic plates. The probability of observation of such stationary behavior of a jet stream was estimated at 93.6% of cases on one 6-h map and in 26.7% of cases - on two adjacent maps. We revealed a relatively stable correlation between locations of epicenters of the strong earthquakes and coordinates of projections of stationary jet stream on the terrestrial surface. The median of distribution of distances between epicenters and the relevant positions of jet stream corresponds to 36.5 km. Estimates of cumulative probability of realization of prediction were 24.2% for 10 days, 48.4% for 20 days, 66.1% for 30 days, 87.1% for 40 days, 93.5% for 50 days and 100% during 70 days. These estimates testify to the existence of connection in space and time between the specified natural phenomena.

Though the mechanisms of emergence of such links between jet streams and earthquakes are still unclear, the precursory effect should be studied, in our opinion, more carefully, and then we advise to apply it for real short-term prediction of strong earthquakes.

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