27. *Earthquake and Thunderstorm.*

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Relations between the occurrence of earthquake and the status of different meteorological elements prevalent at the time of, or before, the earthquake have been investigated in many details as one of the favourite subjects of seismological statistics. Tidal effects have also been treated by many previous investigators with more or less success.[1] Many years ago, the present author made some study[2] on an apparent relation between the occurrence of earthquake and the mode of distribution of sunspots on the solar hemispheres. In view of the superfluous number of these literatures, it appears rather strange that the possibility of a relation, direct or indirect, between thunderstorm and earthquake has rarely been inquired, at least as far as the knowledge of the author is concerned.[3]

Firstly, the occurrence of a thunderstorm is associated with a certain type or types of barometric pressure distribution and on this account we may expect some statistical relation between thunderstorm and earthquake, as it is already established beyond doubt that there exist some definite relations between the occurrence of earthquake and the barometric gradient prevailing in the region of a certain extent including the epicentral district. Secondly, it is not altogether inconceivable that an electrical effect of thunderstorm may exist which could give rise to an additional mechanical stress in the earth's crust and thus play a sensible role as one of the secondary causes for inducing the seismic activity well ripened for its display. The electrostatic traction normal to the earth's surface due to the atmospheric potential gradient may be shown to be

1) Special mention may be made of the recent investigations by S. Yamaguti, *Bull. E.R.I.*, 9 (1931); N. NASU, F. KISHINOUYE and T. KODAIRA, *ibid.*, 9 (1931), 22; K. HUKUTOMI and Z. KAWASE, *Disin*, 3 (1931), 484.

2) T. TERADA, *Journ. Coll. Sci.*, Imp. Univ., Tokyo, 44, Art. 6 (1923), 1.

3) Aristoteles considered wind, earthquake and thunder to be of the same nature: " Nos autem dicimus eandem esse naturam: super terram quidem ventum; in terra autem terraemotum; in nubibus autem tonitruum. Omnia, enim esse haec, secundum substantiam, idem: exhalationem siccam." (Meteororum lib. II, cap. 9). The same idea seems to have been handed down to the end of 18 century and led l'ab. Bertholon to contrive his para-tremblements-de-terre.

apparently negligible in comparison with the amount of variation of the atmospheric pressure which is considered to be effective in affecting the mechanism of earthquake and thus acting as one of the secondary cause. The effect of the horizontal gradient of this normal stress may, however, be not quite negligible in comparison with that of the barometric gradient as may be seen from an estimation made in the Appendix of this paper. There is also another effect related to the phenomena of electro-endosmose,[4] which must be here taken into account and tested whether its amount may or may not suffice for enlisting this factor as one of the competent secondary causes. A rough estimation made in the Appendix shows that though the effect is generally small, it is not so small that we could discard it as a priori negligible.

These considerations led the author to undertake a preliminary statistical study of the suspected relation between thunderstorm and earthquake, at first with respect to the Kwantô District, for 1915–1930, as this district is characterized by the great frequency of earthquakes. The years before 1915 were excluded because the available data of thunderstorms are not based on the same system of regional classification as for the later years.

The data are exclusively taken from Kisyô-Yôran issued by the Central Meteorological Observatory of Tôkyô. As for thunderstorm frequency, the monthly numbers of thunderstorms observed and recorded within the said district, comprising the Provinces of Musasi, Sagami, Kadusa, Simoosa, Awa, Hitati, Kôduke and Simotuke were taken for the basis of comparison. The three months, July, August and September, were only referred to in the present preliminary study, as the monthly numbers for the other months are generally too small to be subjected to the present method of statistical analysis. As for the earthquake frequency to be compared with the above thunderstorm data, those earthquakes were picked up, of which the epicentres are located in the region within or near the district specified for the thunderstorm data and the intensities are denoted by the usual designations "conspicuous" (顯著) and "rather conspicuous" (稍顯著) in Kisyô-Yôran. It may appear that there is involved a large margin of ambiguity concerning the choice of the extent of the geographical area within which the epicentres are to be picked up for the comparison at hand. From the practical point of view, however, the difficulty is not at all serious, as the number of earth-

4) T. TERADA, *Proc. Imp. Acad.*, 6 (1930), 401; *Bull. E.R.I.*, 9 (1931), 225, v. footnote (30) in p. 253.

quakes of which the origins are situated outsides of the above specified districts and still so near the margin of this area that it seems not plausible to discard them, is comparatively small. Thus, though the epicentres in the Provinces of Idu, Kai and Iwaki were included in the present statistics, omission of these will not sensibly affect the general feature of the results of comparison which will be shown later. A point which deserves a more serious consideration, is concerned with the question, whether we should include, or not, those earthquakes of which the epicentres are situated in the sea area off the coast of these land districts, in the present statistics. Those earthquakes which are originated in such deep-sea areas as Iwaki-nada, Kasima-nada, Tyôsi-oki, Bôsô-oki, Kuzyûkuri-oki and the sea near Oosima, Idu, are by no means small in comparison with the total number for the entire region in question. Thence, the comparisons were made for the two kinds of data, one including and the other excluding the sea area above mentioned. On the other hand, those earthquakes of which the origins are located at different points within the Bay of Tokyo, such as Uraga Channel, Haneda-oki, Estuary of the R. Naka etc. were enlisted as land earthquakes, as will appear quite natural if we consider the shallowness of this bay.

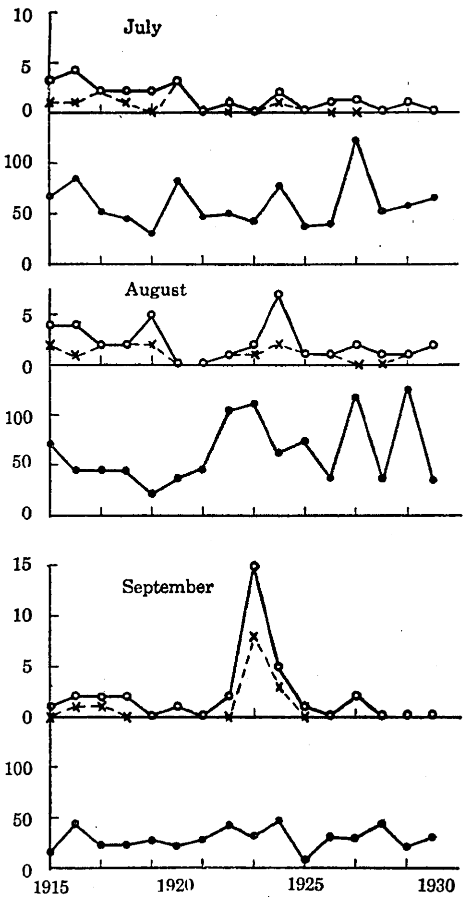

Fig. 1. Yearly Frequencies of Earthquakes and Thunderstorms in Kwantô Region, for July, August and September respectively.
○: Earthquakes, including those originated in sea area.
×: Earthquakes, excluding those originated in sea area.
●: Thunderstorms.

Fig. 1 shows the graphs

of the yearly variations of the frequencies of thunderstorms and earthquakes respectively, for the three months named above separately, while Fig. 2 gives the said variations for the three months taken together.

Referring to Fig. 1, we may notice some parallelism, especially the coincidence of frequency maxima, between the seismic and meteorological data in the case of July. For the other two months, a similar tendency may be traced in some measure, though not quite so conspicuous as in the case of July. It is also to be suggested that the thunderstorm curve in August show some resembrance of its trend with that of the earthquake data in September. Next, referring to Fig. 2 we will see that the suspected relation between the two phenomena is at least not so much improbable as to be discarded without a further investigation, though it will not be safe enough to propose anything further than this negative statements.

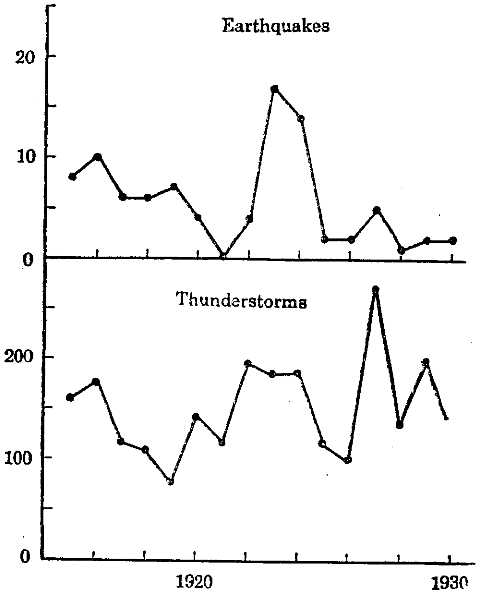

Fig. 2. Yearly frequencies of earthquakes and thunderstorms in Kwantô Region for July, August and September taken together.

On the other hand, the author may be allowed to venture in this place to point out a fact of very singular coincidence between the maxima of frequency of conspicuous summer earthquake and the appearance of a very rare meteorological phenomenon known under the name of "rocket lightnings." At first sight, the coincidence will appear quite accidental, as the two phenomena are apparently too remote in their physical connection, however striking the fact of coincidence may appear even to the majority of scientists. A little consideration will, however, lead us to assume a more cautious attitude than of a hasty negation. If there exist a physical relation between thunderstorm and earthquake, it will be of no wonder if the activity maxima of the latter would coincide with one of the rare modes of display of the former, since as a matter of fact the observation of rocket lightning here referred to happened to be made at, or near, the maxima of thunderstorm frequency, as may be seen from the comparison of Fig. 2 with Fig. 3.

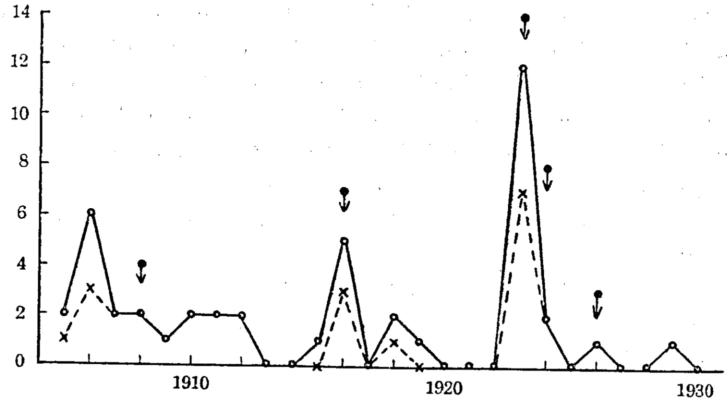

Fig. 3. Summer Earthquakes in Kwantô Region.

○ conspicuous earthquakes including those originated from sea area.
× " " excluding " " " " " .
● ↓ marks the year in which the rocket lightning was observed.

The phenomena of rocket lightning are extremely rare. Though it seems that there are some variety of phenomena among those designated by this name, one of the essential characteristics of this lightning is the comparative slowness with which the foremost extremity of the luminous ribbon is prolonged in its direction of propagation. Examples are rare, however, even among the occidental literatures, of those lightnings of which the descriptions are positive with regard to this latter essential point. We may only cite those observed by Everett,[5] Simpson[6] and Mack.[7] The phenomenon observed by E. Schelle[8] and described as " Schlangenblitzen " belongs probably to the same class, though the velocity of propagation is not positively stated.

Searching for the examples of the rocket lightnings observed in this country, we find the following cases.

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5) J. D. and W. H. Everett, *Nature*, 68 (1903), 599; cited in Humphreys, " Physics of the Air," 376.

6) G. C. Simpson, an abstract of 32nd. Robert Boyle Lecture, delivered before the Oxford Junior Scientific Club, June 7, 1930, in *Month. Weath. Rev.*, 58 (1930), 497.

7) K. Mack, *Met. Zs.*, 18 (1901), 427.

8) E. Schelle, *Met. Zs.*, 16 (1899), 475.

1) July 31, 1908.[9] The phenomenon was observed from the summit of Mt. Huzi (Fujiyama) towards NNE. The lightning started from the base of a mass of cumulo-nimbus and proceeded towards E with a downward inclination of about 45°. The track of propagation was sinuous. The mode of motion reminded the observer of a railway train running through a wooded land or of a pyrotechnic show of rocket. A number of round knots (?) of luminosity were seen in different points of the track. The time required from the beginning to the end of the progressive motion amounted to about 10 sec. Similar phenomena were repeated with a nearly constant period (of which the length is not mentioned).

2) September 5, 1916.[10] Prof. Kiyoo Nakamura, the former Director of the Central Meteorological Observatory, observed violent lightning discharges towards NW while walking on the street, Huzimityô, at about 8h 30 m. The unusual form of discharges, which were observed twice, attracted his attention. The sky was covered with cloud from SW to NE (via N?) up to an altitude of 30°. The discharges were frequent and sometimes the whole sky was illuminated. A large mass of cumulo-nimbus was seen towards NW, from behind of which a lightning of extraordinary form emerged towards right. It reminded the observer of the sprinkles of fire thrown up into the air on the occasion of a conflagration. Seven or eight such "particles of fire" were seen to fly off towards NE covering an area of about five or six degrees. Another similar phenomenon was observed after two or three minutes. No thunder was heard at that time, but a distant roaring was noticed after he had returned home (his residence was at Minamityô, Usigome). Though the slow motion is not positively stated, the comparison with the sprinkles of fire above mentioned may be taken as an indirect evidence for this point.

3) August 26, 1923. It was just one week before the Great Kwantô Earthquake of Sept. 1, when this unusual phenomenon was observed by the present author and his family in his dwelling Akebonotyô 24, Komagome, Tôkyô. Unfortunately, no detailed note was recorded at that time so that the following description is drawn from his sheer memory. It was near the time of sunset and the sky was not yet quite dark when the phenomenon was detected towards the western sky. A

9) *Journ. Met. Soc. Jap.*, **27** (1906), 399, among the miscellaneous articles, with the name of the author given in initials only as R. W.

10) K. NAKAMURA, *ibid.*, **35** (1916), 360.

number, five or six, of luminous tape or band were seen to start from somewhere towards W or NW and to be prolonged towards E expanding to a "fan" subtending an angle of 20 or 30 degrees. The luminous tracks were irregularly sinuous with knots and kinks which appeared especially bright. The general appearance reminded the observer of a striking resemblance to the unwinding of rolled up paper tapes thrown nearly horizontally through the disturbed air. The altitudes of the tracks were 40°—60°. The horizontal extent of track nearly amounted to 70°—90°. The time required for covering this total length may be estimated at about 3 or 4 sec. in the least. The similar display was repeated with irregular intervals comparable with that of the ordinary lightnings in the cases of average thunderstorms. No sensible thunder was heard as far as the memory of the observers is concerned. The mother of the author who was at the age of just eighty years at that time told him to the effect that she has never seen such unusual form of lightnings. The duration of the display was of the order of half an hour.

4) August 30, 1924. An extraordinary form of lightning was observed and photographed by Mr. Takayama in this evening. The phenomenon was described and discussed as "Bead and Rocket Lightnings?" by Prof. S. Fujiwhara,[11] in English, so that the readers may be referred to the original paper. In this case also the velocity of motion of the luminous spot is not stated, but comparing the photograms reproduced with the verbal descriptions of Nakamura's case we may suppose that the two cases may probably be counted under the same class of phenomena.

5) The exact date of the last example is unfortunately lacking, but it was a few days after July 27 and certainly before Aug. 7 of 1926. One of the observers is Dr. U. Nakaya, now in Hokkaidô University, who lately wrote to the author describing the details of the phenomena observed, at the author's inquiry. Dr. Chûji Tsuboi of our Institute and also Mr. R. Yamamoto of the Institute of Physical and Chemical Research were the witnesses of the same phenomena on the same occasion, and they also took the trouble of writing down the descriptions of their own observations. According to these most reliable descriptions, the phenomena seem to have been an almost exact facsimile of what were observed by the present author in the summer of 1923 and described in

11) *Journ. Met. Soc. Jap.*, ii, 2 (1924), 189, (in Japanese), 197, (in English). Mr. T. TAKAYAMA, who is the Member of our Institute, was as that time in C.M.O.

the above paragragh. The three witnesses state independently that the track of lightning was branched, and judging from the sketches drawn by Nakaya and Tsuboi, the mode of branching was not unlike that of a tree, or of some usual branched sparks. The characteristic feature was the unusually long time of development. Nakaya and Tsuboi state that the motion could be followed with ease by the eyes. Tsuboi estimates the duration at 2 or 3 sec. and Yamamoto at 5 or 6 sec. whereas Nakaya's estimation seems to have been much shorter (1/2 sec.), though his description on this point is not positive.

The altitudes of the tracks were 20° to 40° above the southern horizon and its horizontal extents, W to E, were 50°–90°, taking the data of the three observers together. The hour of observation was 8h or 9h p.m. Nakaya saw the similar discharge repeated two or three times, and heard the thunders which appeared not quite remote. Tsuboi states that the discharges were repeated with an interval of about 5–10 sec. and continued for about 20 min. gradually decreasing in frequency towards the end of the display. He describes the colour of the luminosity as greenish blue. The progressing end or tip of the track was brighter than the other part which did not disappear instantly but seemed to remain luminous for a considerable time. Tsuboi considers this latter duration too long to be attributed to the usual persistence of image by retina.

Fig. 3 shows the yearly fluctuation in the frequency of the "conspicuous" earthquakes of which the origins were located in the region above specified. The full line curve refers to the total number of earthquakes including those originated in the sea area as above mentioned, while the dotted line represents those earthquakes originated in the land area. The arrow with black circle marks the year in which the rocket lightning was observed. Though the material is still too scanty to allow us any definite conclusion, it seems nevertheless interesting to observe that the unusual electric phenomema occurred at the period of enhanced seismic activity.

In the case of Example (1) of rocket lightnings, a conspicuous earthquake occurred on August 12, i.e. 12 days after the day of the lightning, in the northern part of Simôsa and also in the sea off Awa. For (2), a conspicuous earthquake is recorded on Sept. 15, i.e. 10 days after the lightning in SE part of Bôsô Peninsula. For (3), we have the Great Kwantô Earthquake six days after the lightning observed by the author. Lastly, for (4) a conspicuous shock was felt in Tôkyô of which the origin was located in the Bay of Tôkyô near Haneda, on August 3, i.e. very near the day of the extraordinary lightning for which the exact date is wanting but falls certainly within a definite period of ten days.

Of course, the occurrence of conspicuous earthquakes in the region here in question is rather frequent as may be judged from the graphs above shown, so that the probability of some accidental phenomenon occurring within a few days before or after the earthquake, is by no means negligibly small and therefore, the above apparent coincidence might be of no significance further than arousing our curiosity. Still, it seems to the present author of some interest to point out this mere fact, either significant or not, and to draw the attention of seismologists towards a domain of research which has been left unnoticed inspite of the physical possibility underlying the nature of the problem.

A further statistical investigation is now going on.

Appendix.

The normal tension acting upon the earth's surface due to the Faraday-Maxwell stress of the earth's electric field prevailing on the surface is given by $\varepsilon E^2/8\pi$ per cm^2., where E is the potential gradient and ε the dielectric constant which may be put equal to unity for the present case. If E be $A \times 100$ volts/cm. the normal tension per unit area amounts to $A^2/226$. In the case of a thunderstorm E may attain 10 000 volts/cm. so that $A=100$, for which the tension becomes 44·3 dynes/cm^2. On the other hand, the atmospheric pressure of 1 mm. Hg is $1{\cdot}33 \times 10^3$ dynes/cm^2. Thus, the electric tension may attain at most a few per cent. of one mm. barometric pressure in its absolute magnitude and may be safely neglected in comparison with the variation of the atmospheric pressure as far as its direct mechanical effects in affecting the stress and strain of the earth's crust is in question.

On the other hand, it is well known that the barometric *gradient* of a few mm. per 100 km. may affect the occurrence as a significant secondary cause. Hence, if the above traction be applied at a locally limited area, a gradient of an amount may be produced which is comparable with the above atmospheric pressure gradient. For example, 44·3 for 3·33 km. corresponds to 1330 per 100 km. Such a steep horizontal gradient of the earth's electric field cannot be quite exceptional in the case of thunderstorm weather.

Hence, we cannot *a priori* reject the possibility of some earthquake being connected with thunderstorm phenomena, though it will be equally absurd to draw any positive conclusion from the above hypothetical consideration.

As to the horizontal pressure gradient due to the phenomenon of electro-endosmose, it is difficult at present to make any reliable estimation based upon observed data as these are utterly wanting. We may, however, show that the effect is at least worth a further investigation.

The hydrostatic pressure difference between the two ends of a capillary tube is given by

$$p = \frac{2\varphi D \Delta V}{\pi r^2} \times \frac{1}{(300)^2} \text{ dynes/cm}^2.$$

where φ (volts) is the kinetic potential, ΔV (volts) the potential difference, D the dielectric constant and r (cm.) the radius of the capillary. p is independent of the length of the tube. Assume $\varphi = 0{\cdot}03$, $D = 81$, $\Delta V = 10^4$ volts[12] and $r = 10^{-2}$ cm. Then $p = 1{\cdot}72 \times 10^3$ dynes per cm²., i.e. attains the same order of magnitude as 1 mm. Hg.

The assumption tacitly made above that the rock material consisting the wall of the capillary is of an infinite specific resistance does not hold. However, it seems that the conductivity should rather enhance the pressure effect under the given potential difference. The assumption as to the dimensions of the capillary is a matter of great uncertainty. When, however, a distance of some ten or hundred km. along the earth's crust is involved, we may scarcely conceive any larger canal of subterranean water communication, so that it seems rather natural to assume such an effective radius of the order as above tentatively chosen, or perhap still less.

To avoid misunderstanding it must be emphasized that the above estimations were made only to demonstrate the plausibility of undertaking a statistical study of the relation between earthquake and thunderstorm, which may sound at first sight rather too fantastic. At least there is no reason to disprove such a relation from the beginning.

It must be remarked also that even if some relation between the two phenomena may actually exist, the relation cannot be necessary so simple as to allow an immediate explanation.

It may occur that the monthly frequencies run parallel, whereas the

12) A P.D. of this order of magnitude may easily be established for a distance of some 100 km. on the occasion of thunderstorm, at least for a short duration of time.

daily frequency does not. The relation might again depend upon seasons as well as localities. Before we may say anything definitive about these points the statistical materials must be gradually accumulated. For the latter purpose, the cooperation is desirable of as many investigators as possible.

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27. 地震と雷雨との關係

地震研究所 寺田寅彦

地震と氣象要素との關係の統計的研究は從來少くないが、地震と雷雨との關係に就ては文獻が少いやうである。著者は理論上から考へて此の二現象間に關係があるかも知れないと思つたので、試に關東地方だけに就て、1915-1930 の期間に就き、七、八、九の三箇月に於ける顯著及稍顯著地震の月回數と雷雨の月回數との年變化の模様を對應させて見た。其結果は幾分でも著者の豫想を確かめるやうに見える。本文第二圖だけを見ても、少くも、此關係が初めから全然否定は出來ないものだといふことを示すには十分であらうと思ふ。

火箭電光 (rocket lightning) と稱する稀有の現象が雷雨の盛な年、又顯著地震の多い年に起るのではないかといふ疑問を提出して置く爲に第三圖を作つた。

附錄として、空中電位による地面に直角な力、又毛管電氣現象に歸因する水平方向の壓力差の大さに關する概算を行つた結果を示す。此等の電氣的直接影響も一概に初めから否定することは出來ないことだけは分ると思ふ。併し、實際上地震と雷雨との統計的關係が確立したとしても、それは雷雨の發生を促がす氣壓配置狀態が地震に影響する爲として、それだけで說明されるか、或は又上記の電氣的作用も參加するか、此れに就ては將來十分の調査をしなければ何事も云はれない。唯地震と雷雨との關係といふ從來余り注意されなかつたことが將來一つの研究題目として採用する價値のあるものだといふことは今回の豫備的調査だけでも明になつたことと思はれる。
