Geomagnetic Effects Associated with the High-Altitude Nuclear Explosion

By

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Abstract

Since Aug. 1958, the high-altitude nuclear explosions have been made several times in the Mid-Pacific Ocean and / or the Atlantic Ocean by the United States. Among them, the experiment on July 9, 1962 affected the geomagnetic field over the world. The details of the effects, observed at Kakioka, Memambetsu and Kanoya are described.

The mechanism of this disturbance is discussed from the dynamo theoretical stand point and the effective total conductivity is estimated. The effects of the experiments in November, 1962 are attached.

§ 1. Introduction

The magnetic observatories at Kakioka, Memambetsu and Kanoya have recorded a noticeable and special variation at 09h 00m, July 9, 1962 (U. T.). The changes at three observatories are similar to each other and rather resemble to S. I. (magnetic sudden impulse). While the unusual phenomena at the time, of the ionosphere and the telecommunication have been reported in Japan. These are attributed to a nuclear explosion which the United States experimented near Johnston Island in the Pacific Ocean. At 09h 00m (U. T.), the nuclear devices in the mega-ton range were detonated at the altitude of nearly 320 km.

Since Aug. 1958, the high-altitude nuclear explosions have been made several times in the Mid-Pacific Ocean and/or the Atlantic Ocean by the United States. They are tabulated in the Table 2.

Table 1. Geographic and Geomagnetic Coordinates of Observatories.

Observatory	Geographic Lat.	Geographic Long.	Geomagnetic Lat.	Geomagnetic Long.
Memambetsu	43°55′N	144°12′E	34. 0°	208. 4°
Kakioka	36°14′N	140°11′E	26. 0°	206. 0°
Kanoya	31°25′N	130°53′E	20. 5°	198. 1°

Table 2. Data on Bursts.

	(1)	(2)	(3)	(4)	(5)	(6)
	Teak	Orange	Argus I	Argus II	Argus III	
Nominal yield	?	?	1 ~ 2 kiloton	1 ~ 2 kiloton	1 ~ 2 kiloton	1 ~10 megaton
Time of Burst	Aug. 1, '58 10^h50^m	Aug. 12,'58 10^h30^m	Aug. 27,'58 02^h30^m	Aug. 30,'58 03^h20^m	Sep. 6,'58 22^h10^m	July 9, '62 09^h00^m
Geographic Coordinates	16.7°N 169.4°W	16.7°N 169.4°W	38°S 12°W	50°S 08°W	50°S 10°W	16.7°N 169.4°W
Nominal Altitude	160 km (70~80)	100 km (40)	480 km	480 km	480 km	640 km (320~800)

In Japan, most of these experiments have not any appreciable effects on the geomagnetic field and some of the small effects were observed only by the high-sensitive induction magnetograms. The description and analysis of them are printed by some authorities (1). In this report, the magnetograms at Memambetsu, Kakioka and Kanoya in case of these experiments are reproduced. (Fig. 1. a and Fig. 1. b). The mechanical details of the induction magnetograms should be referred to "Report of the Geomagnetic and Geoelectric Observations I. G. Y. 1957-58 Kakioka Mag. Obs." published by the Kakioka Magnetic Observatory, Kakioka, Japan 1960.

On the other hand, the disturbances on July 9, 1962 were so large that they could be detectable even on the ordinary magnetograms in Japan. In this experiment, the geomagnetic effects seem to be observed all over the world. These

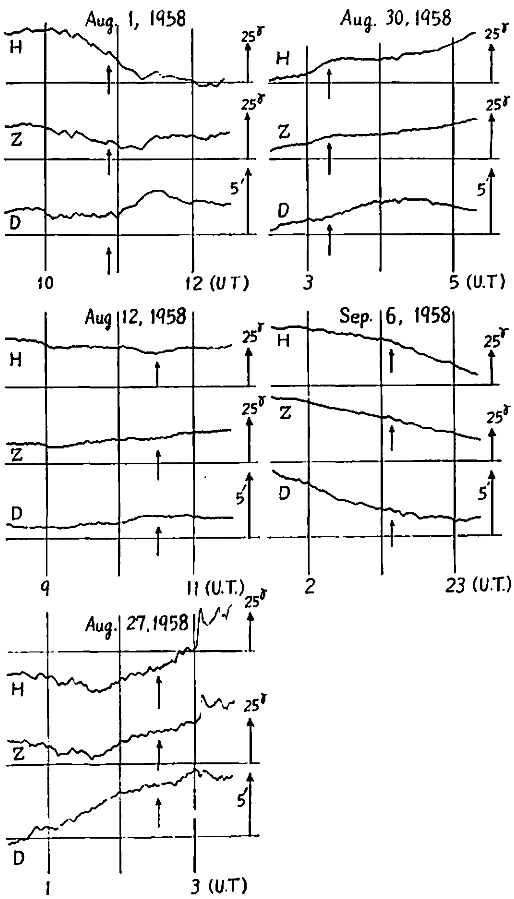

Fig. 1(a). Ordinary magnetograms at Kakioka.

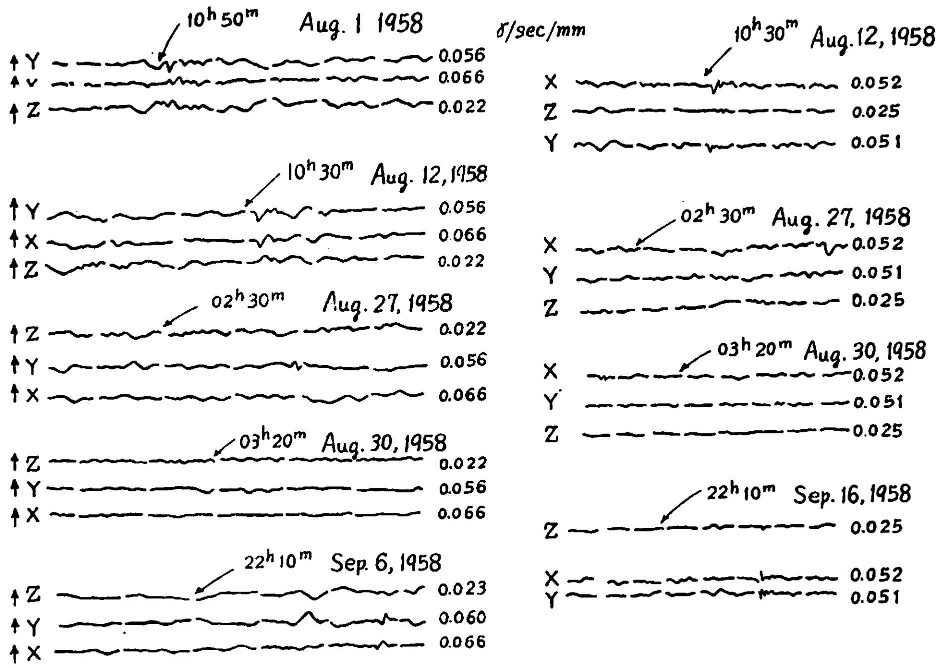

Fig. 1(b). Induction magnetograms at Memambetsu (Left) and at Kanoya (Right). One of Aug, 1, at Kanoya is a missing record. The scale values of the original records are given. On the original records, 1 minute is expressed by the length of 12 mm at Memambetsu and 6 mm at Kanoya.

distinguished effects from other experiments may be attributed to the differences of the yield and to the altitude of bursts etc, although it is difficult to say definitely the very factor in the present state of the researches.

§ 2. Disturbances, observed at Kakioka, Memambetsu and Kanoya Magnetic Observatories on 9th July, 1962

At Memambetsu and Kanoya, we operated the induction magnetographs, together with the ordinary magnetographs. The magnetograms at three observatories are similar, with a exception of the opposite sense of the change of the horizontal component at Memambetsu. The ordinary magnetograms at three observatories, the induction magnetograms at Memambetsu and Kanoya are traced in Fig. 2. The summary of the disturbances at each observatory are tabulated in Table. 3. The results of the earth potential gradients are also described in the same table. The aspects of the effects are nearly the same at three observatories. On the ordinary magnetogram, the preliminary impulsive variations with the duration less than 1 minute are observed, just like SSC* and then the main disturbances developed in the opposite direction, which continued for about 2 minutes. At about 09h 02m, the deviations of all the components from the pre-disturbance level became maximum and ceased to develop. To our regret, the time mark of 9 o'clock prevented the perfect recording of the preliminary impulse to scale the quantities of them, but it is certain, especially for the vertical component, that the variations went on before the main disturbances. These disturbances seemed to come to an end at about 09h 10m (U. T.). As a whole, the phenomena seem to be resemble to S. I. (magnetic sudden impulse) at first sight, although the changes of declination and vertical component are somewhat different from the natural S. I. Also the decrease of horizontal component is the same as the variations at observatories near Johnston Island, e. g. Honolulu. The

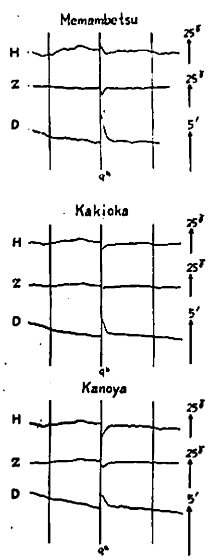

Fig. 2(a). Ordinary magnetograms on July 9, 1962. The scale values are expressed by the length f arrows.

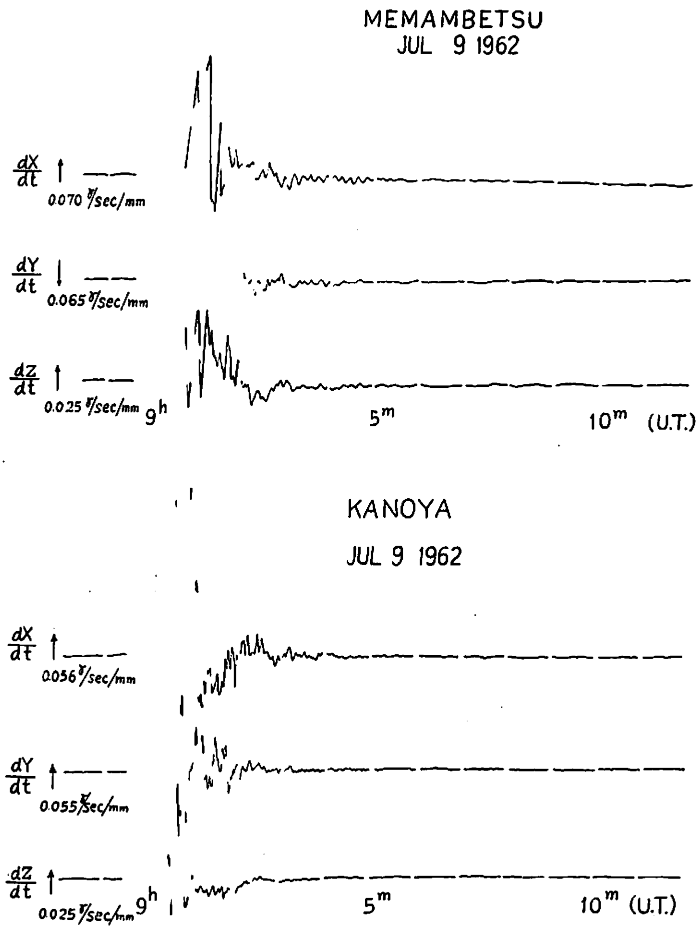

Fig. 2(b). Induction Magnetograms. The given scale values are ones on the original records. On the original record, 1 minute is expressed by the length of 12 mm, at both observatories.

Table 3. The disturbances in geomagnetism and earth current, caused by the high altitude nuclear explosion.

(1) Effects on the ordinary magnetogram and tellurigram.

Observatory	Time (U. T.)		Geomagnetism ※ D	H	Z	Earth current ※ EW	NS	Remarks
	h	m	′/min	γ/min	γ/min	mv/km/min.	mv/km/min.	
Memambetsu	09	00	-3.5/2	5/1	-2/1 11/2	2/1 -8/2	-33/2	
Kakioka	09	00	? -2.2/2	? -10/2	2/1 -5/2	66/2★	-11/2	
Kanoya	09	00	? -1.3/2	3/1 -18/2	1/1 -8/3	14/3	2/2	

The deviation of both geomagnetism and earth current became maximum at 09^h02^m.

※ Upper ; Preliminary impulse Lower ; Main impulse

★ Estimated that it is larger than this numerical value.

The positive signs denote the increase of east declination, downward vertical intensity, eastward current and northward current, respectively.

(2) Effects on the induction magnetograms.

At both observatories, Memambetsu and Kanoya, the changes began before 0901, although the accurate beginning time is questionable on account of the superposition of the time mark and at about 0901, the maximum amplitudes were observed and ended at about 0905. The variations of three components—dX/dt, dY/dt and dZ/dt—were the irregular, damped oscillations of the period of about 10 sec.. The maximum amplitudes are undefinite, owing to the lightened traces.

(3) The general aspects of the effects on the rapid-run tellurigrams are nearly the same as the variations observed by the induction magnetograms. The maximum ranges of EW component at Kanoya is about 23 mv/km and that of NS component is about 15 mv/km. Those at Memambetsu are uncertain.

ordinary magnetogram at Honolulu (Geographic latitude : 21° 18.3′N, Geographic longitude : 201° 54.3′E; Geomagnetic latitude 21.1°N, Geomagnetic longitude 266.5° E) on July 9, 1962 is reproduced in Fig. 3, in comparison with.

The disturbances, observed by the induction magnetogram (loop) at Memambetsu and Kanoya appeared as a severe, irregular, damped oscillation with a period of about 10 sec.. The maximum amplitudes occurred at about 09h 01 m, but their quantities are difficult to be scaled, owing to the lightened traces of the rapid changes. These oscillations ended at about 09h 05m (U. T.). The rough summary of the results by the rapid run tellurigrams are also similar. The numerical values are given in Table 3.

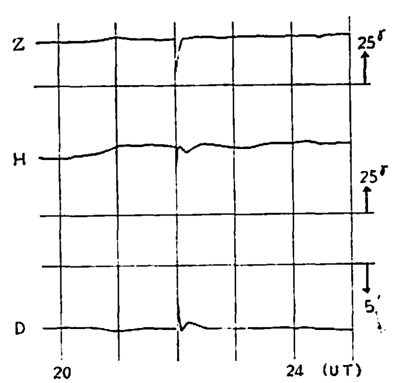

Fig. 3. The magnetogram on July 9, 1962 at Honolulu.

Besides the above mentioned instrumentation, we tested a ultra-rapid run recording for the earth-current-potential gradient at Memambetsu, which recorded the 36 mm traces per minute. And it caught the beginning time of the disturbance of the geomagnetic field at Memambetsu, more accurately. It was 09h 00m 10 sec. (U. T.).

§ 3. Discussions

As stated before, the high-altitude nuclear explosions have been made several times.

Not only the United States, but also U. S. S. R and Great Britain have experimented the bursts of nuclear devices. The details of all the experiments and their effects on the geomagnetic field are not always analyzed and printed. Here we refer to the results of the experiments of Teak, Orange, Argus and the nuclear explosion, conducted by the British in the vicinity of Christmas Island (Geogra. lat. 3° 00′N; Geogra. lon. 160°15′W) (2). The last one was detonated on 28th April, 1958 and are believed to have occurred at relatively low altitudes in the lower ionosphere. The geomagnetic effects, observed at Jarvis (Geogra. lat. 0°23′S; Geogra. lon. 160°02′W), Fanning (3°55′N; 159°23′W) and Palmyra (5°53′N; 162° 06′W) are similar in type to those of other tests, except the absence of any observable disturbance of horizontal intensity, corresponding to the major disturbances of declination and vertical intensity. But, in this case, any geomagnetic effects have not been found at Apia, Guam and Honolulu. In each case, the domains where the effects can be observed are different, but the effects have the same features in common. From them, the difference of the area where the effects can be observed, may be attributed to the differences of the altitude of detonations, the yield and/or the nature of the nuclear devices. And it may be said the secondary mechanism of the geomagnetic effects are in common. The secondary mechanism may be divided into the following three basic ones and either of them is predominant, corresponding to the time after detonaion, geographic coordinates and the relative location of the observatory to the shot point. Thus the disturbance, observed at each observatory, may be a combination of them and appear in a complicated aspects. As described by many researchers, there are several evidences to believe that the three, basic causes are as follows;

a. The motion of charged particles, trapped by the geomagnetic field.
b. Hydromagnetic waves, propagated through the high atmosphere from explosion point.
c. The dynamo current in the ionosphere.

To our regret, we have now the unsatisfactory data in hand, to discuss the first two. Then, in this section, we treat the third one only.

The conductivity in the ionosphere may be enhanced owing to what, caused by the detonation of nuclear device. Here the mechanism of the enhancemement of the conductivity will be first ignored.

Table 4. List of the observatories.

Observatory	φ	λ	Φ	Λ
Sodankyla	67° 22′ N	26° 39′ E	63. °8N	120. °0
College	64 51. 6N	212 09. 8E	64. 5N	255. 4
Lerwick	60 08 N	1 11 W	62. 5N	88. 6
Churchill	58 44. 7N	265 46 E	60. 6N	322. 6
Sitka	57 03. 5N	224 40. 5E	60. 0N	275. 4
Witteveen	52 49 N	6 40 E	64. 2N	91. 0
Göttingen	51 33 N	9 58 E	52. 3N	93. 8
Hartland	50 59. 7N	4 29. 0W	54. 6N	79. 0
Victoria	48 30 N	236 36 E	54. 2N	293. 0
Memambetsu	43 55 N	144 12 E	34. 0N	208. 4
Onagawa	38 26 N	141 28 E	28. 3N	206. 8
Fredericksburg	38 12. 3N	282 37. 6E	49. 6N	349. 8
Kakioka	36 14 N	140 11 E	26. 0N	206. 0
Simosato	33 35 N	135 56 E	23. 0N	202. 4
Aso	32 53 N	131 01 E	22. 1N	198. 1
Tucson	32 14. 8N	249 10. 0E	40. 4N	312. 2
Kanoya	31 25 N	130 53 E	20. 5N	198. 1
Honolulu	21 18. 3N	201 54. 3E	21. 1N	266. 5
Teolyucan	19 45 N	99 11 W	6. 0N	327. 1
Alibag	18 38 N	72 52 E	9. 5N	143. 6
San Juan	18 22. 9N	293 52. 9E	29. 9E	3. 2
Muntinlupa	14 22. 5N	121 00. 9E	3. 0N	170. 3W
Guam	13 27 N	144 45 E	3. 9N	212. 8
Annamalainagar	11 24 N	79 41 E	1. 8N	149. 4
Addis Ababa	09 02 N	38 46 E	5. 3N	109. 2
Trivandrum	08 29 N	76 57 E	0. 9S	146. 3
Bangui	04 26 N	18 34 E	4. 8N	88. 5
Holland	02 50 S	140 30 E	12. 5S	210. 3
Luanda	08 49 S	13 13 E	7. 1S	80. 5
Port Moresby	09 24 S	147 03 E	18. 7S	215. 0
Huancayo	12 02. 7S	75 20. 4W	0. 6	353. 8
Apia	13 80 S	188 2 E	16. 0S	260. 2
Gnangara	31 47 S	115 56 E	43. 2S	185. 8
Hermanus	34 25 S	19 13. 5E	33. 3S	80. 5
Amberley	43 09 S	172 43 E	47. 7S	252. 5

If we think the geomagnetic variation as caused by the stationary current in the ionosphere, we can deduce the current system in the ionosphere, corresponding to the distribution of the geomagnetic variation at the surface of the earth. The observatory, of which data we used are tabulated in Table 4. We assume the current function J of the equivalent current system as follows;

$$J_n = -\frac{10}{4\pi} R \left(\frac{a}{R}\right)^n \frac{2n+1}{n+1} \sum_{m=0}^{n} P_n^m(\cos\theta)(A_n^m \cos m\varphi + B_n^m \sin m\varphi) \qquad (1)$$

where Jn is expressed in amp. and a and R are the radii of the layer in which the assumed current system flows and of the earth, respectively.

From the spherical harmonic expansion of the observed, disturbances of the geomagnetic field, A_n^m's and B_n^m's can be obtained. Assuming that $R=6368$ km, $a=6468$ km and the outer origin part of the disturbance field is two-thirds of the total one, A_n^m's and B_n^m's are attempted to be calculated.

Table 5.

	A_n^m			B_n^m	
n \ m	0	1	2	1	2
1	8.079	−4.716		−16.905	
2	−0.315	−1.312	−0.989	5.086	0.726
3	−4.509	−0.954	0.256	−0.895	0.392

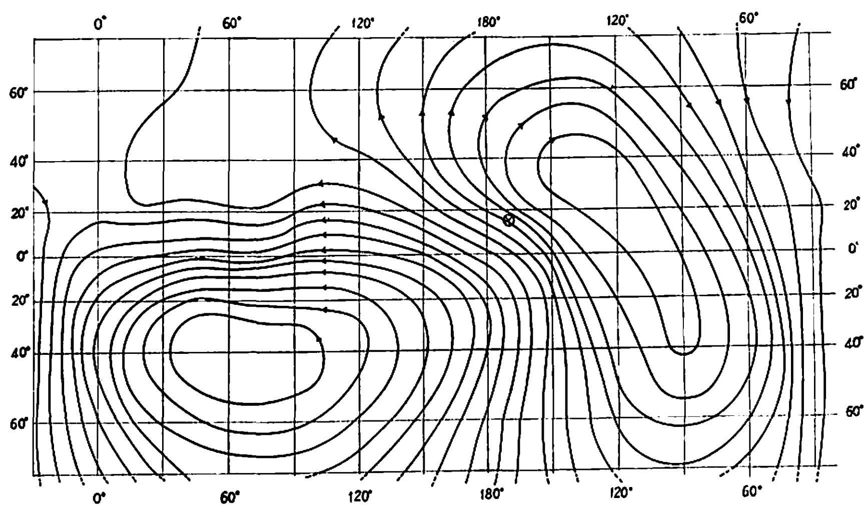

Fig. 4. The equivalent current system for the geomagnetic disturbances at 09h 02m, caused by the nuclear detonation on Johnston Island on July 9, 1962.
The current of 4.8×10^3 amp. flows between the adjacent stream lines.
⊗ is Johnston Island.

Table 5 and Fig. 4 are corresponding to the variation at 09h 02m (U. T.), based on the ordinary magnetograms of the tabulated observatories in Table 4. Untill the time, the oscillations of the period 10 sec. or less survive on the induction magnetogram in Japan, but on the ordinary magnetogram, the maximum deviations of traces from the pre-disturbance level occurred just before the time, with somewhat inequality, according to elements and observatories.

In the Figure, the current of 4.8×10^{3} amp. flows between the adjacent stream lines. Near Johnston Island, it may be resemble to the assumed ones in case of the other tests, which was explained by the dynamo action, caused by the shock wave. (3) However, a part over Europe and Africa, of the equivalent current system is not a mere magnification of the current vortex over Johnston Island. Thus it may be difficult to think the wind contributing to the dynamo action as the dynamical shock wave caused by the detonations. And it will be deduced from the fact that the variation occurs nearly all over the world. Therefore, it may be reasonable to attribute any other wind system. Actually, the current system in Fig. 5 can be obtained under some assumptions, following the usual dynamo equation after S. Chapman, S. K. Chakrabarty and R. Pratap. (4)

We take the followings;

1. Wind assumption that it has the velocity potential of second harmonic.
2. Conductivity assumption that it is expressed as

$$\Delta\sigma=\frac{K}{\sqrt{2a}}(1+\frac{1}{2}\cos\Psi+\frac{3}{8}\cos^{2}\Psi) \qquad (2)$$

where $\Delta\sigma$: the increase of the total effective conductivity, caused by the burst,

K : constant

a : radius of the current layer

$\cos\Psi$: $\cos\theta\cdot\cos\theta_0+\sin\theta\cdot\sin\theta_0\cos(\varphi-\varphi_0)$

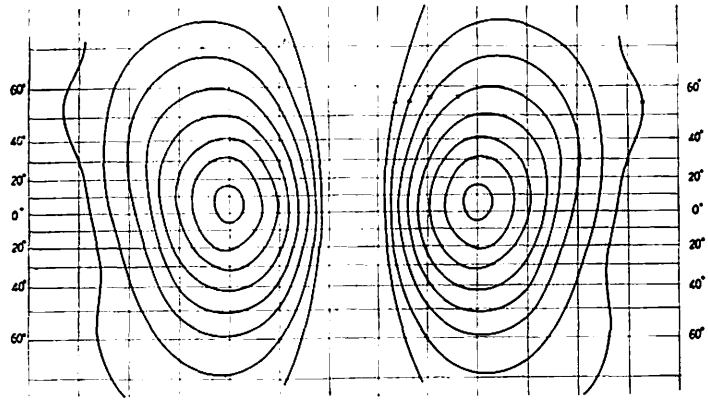

Fig. 5. The current system, under some assumptions. The width between the adjacent vertical lines corresponds to the geographical longitude 30°.

θ, φ : colatitude and logitude of the observatory

θ_0, φ_0 : colatitude and longitude of the point in the current layer, under the shot point.

Although the obtained current pattern is not sufficient to explain the equivalent current system for the actual disturbances all over the world, it may be said that, near Johnston Island, both of the current systems coincide very well. That is, the geomagnetic disturbances near Johnston Island (shot point) may be able to be caused by the dynamo action of the second harmonic type wind in the ionosphere (E layer, perhaps). This is a suggestion of the dynamo current in the ionosphere as one of the causes of the disturbance, together with McNISH's, Matsushita's and others' discussions. (5), (6)

Well, if all the quantity of the equivalent current is assumed to be attributed to the dynamo action of the second harmonic type wind, the distribution of the effective total conductivity by the nuclear explosion can be obtained. If, in the usual dynamo theory, before stated, the contribution of only one component of the velocity potential of the wind is taken, the ratios A_n^m's to B_n^m's is the phase angle of the wind and is free from m and n. Depending actually on m and n on account of the contributions of any other components, here, the mean of the values is adopted. It is 4° 31′, with the deviation ±45°. Next, we assume the enhancement of the effective total conductivity as follows;

$$\Delta\sigma = a_0 + a_1 \cos\Psi + a_2 \cos^2\Psi \qquad (3)$$

where $\Delta\sigma$ and Ψ are the same notations in Equation (2) and the distance between

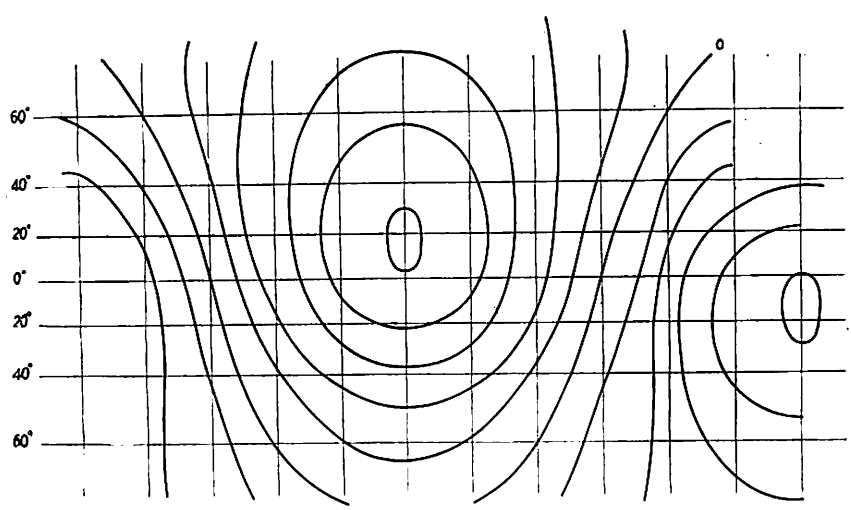

Fig. 6. The deduced distribution of the disturbance of the effective total conductivity, from the dynamo theoretical stand point.

(θ, φ) and (θ_0, φ_0) on the sphere, of which radius is a, is expressed by $\sqrt{2a(1-\cos\Psi)}$. a_0, a_1, and a_2 are the quantities to be evaluated.

Taking $K_2^2=20\times10^{-7}$ in e. m. u. (amplitude of the second harmonic of the velocity potential of the wind) and $a=6468$ km, we can obtain by the usual dynamo theory the following;

$$\Delta\sigma=2\times10^{-8}(1-0.339\cos\Psi-1.397\cos^2\Psi) \quad (4)$$

in e. m. u.

This is shown by the equi-conductivity contour in Fig. 6. and may be roughly reasonable as the enhancement of the conductivity, caused by the nuclear detonation, although it must be compared with other data. In the figure, the distance between the adjacent vertical lines corresponds to geographical longitude 30°, with standard of the meridional line through Johnston Island, which goes through the center of the vortex.

The contours without 0—0 will be physically meaningless and the approximation will be limitted with in 0—0 contour. Moreover, only the second harmonic of the velocity potential is taken into consideration in this section and so taking the first harmonic and/or others, which will be thought to be predominant in the ionosphere, may give some modifications to the distribution in Fig. 6. But, even the distribution may be able to give some contributions, in order to research the mechanism of the enhancement of the conductivity.

§ 4. Conclusions

The wind contributing to the dynamo action will be the same as the wind for Sq field and not the hydrodynamic schock wave. The enhancement of the conductivity, deduced from the same stand point may be reasonable, although it is a rough approximation, taking into consideration of only the second harmonic of the wind velocity potential.

The ionospheric observations seem to support the approximate value.

More exact treatment of this subject and the discussions on the other two, basic causes are in progress.

Acknowlegments

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Appendix

The nuclear explosion were made at about 12h 10m Nov. 1, '62 and 07h 30m Nov. 4, '62 at Johnston Island by the United States. The summaries of the effects on geomagnetism and earth potential gradient are preliminarily given.

In case of the detonation at 12h 10m, Nov. 1, 1962, the ordinary magnetograms at three observatories-Memambetsu, Kakioka and Kanoya-did not record any distinct effect and the ordinary tellurigrams also did not.

The induction magnetogram at Memambetsu recorded oscillations of the period less than 5 sec., for a minute from 12h 10.1m, The maximum amplitude of the Y-component is about 0.5 γ/sec. At Kanoya, also the induction magnetogram caught the damped type oscillations of the period less than 4 sec. for a minute from 12m 10.1m. The maximum amplitude of X-component is about 0.3 γ/sec. Although the rapid run tellurigram at Memambetsu recorded only vestiges at the corresponding time, one at Kanoya did the oscillations such as those observed by the induction magnetogram and the maximum amplitude of EW-component is about 0.2 mV/km. The deduced beginning time of the disturbances of the geomagnetic field at Memambetsu by the ultra-rapidrun recording (36 mm/minute) is 12h 10m 07 sec.

The effects of the experiment at 07h 30m Nov. 4, 1962 could not be detected at any observatories and by any magnetic and earth potential gradient techniques.

超高空核爆発による地磁気変化

山口又新

概要

米国の行なった高空核爆発実験は，1958年以来数回に及んでいる，1958年中に行なわれた実験に際しては，日本附近の地球磁場は，極く僅かの影響を認めたに過ぎなかったが，1962年7月9日の実験に際しては，驚くべき大きさに達した。本稿では，柿岡，女満別，鹿屋で観測された地磁気擾乱の概要を述べ，次に汎世界の資料に基き，この擾乱の主要部は，電離層の電気伝導度増大によるものとし，予備的考察をした。