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THE DISTRIBUTION OF THUNDERSTORMS OVER THE GLOBE

BY

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THE DISTRIBUTION OF THUNDERSTORMS OVER THE GLOBE

§1. Introduction.

The investigation described beneath is an attempt to determine, from the materials at present available, the distribution of thunderstorms over the Globe, and from that datum, to calculate, necessarily in a somewhat rough and ready fashion, the total amount of thunderstorm activity which takes place in the course of a single day.

The unit adopted has been the " Day with Thunder Heard." At the meeting of the International Meteorological Committee at Vienna in 1873, the following resolution was adopted :—

> " In order to obtain results which admit of comparison, it is recommended to enumerate only Days of Thunderstorm . . . . Only days on which both thunder and lightning are observed should be counted as days of thunderstorm."

At the meeting at Paris in 1896, this resolution was modified by the following, proposed by M. Angot :—

(1) That the symbol T be added to the international symbols adopted by the Congress of Vienna to indicate the days on which distant thunder is heard.

(2) The symbol < should be reserved for distant or diffused lightning, Wetterleuchten, sheet-lightning.

(3) The symbol ⩤ should indicate all the cases where both thunder and lightning have been observed.[1]

In this study a " Day of Thunder " has been taken as one on which either a thunderstorm or distant thunder was recorded. Lightning alone without thunder has not been included. In such cases as the valuable *Book of Normals* issued by the Brazilian Meteorological Service, where the number of days with distant thunder and the number of days with thunderstorms are given separately, the numbers in the two columns were added. There is no precise instruction that a day of thunderstorm cannot also be a day of distant thunder, but the combined totals fit in well on the charts and the amount of duplication, if any, must be very small.

A more serious difficulty has been the obvious incompleteness of many records in respect of distant thunder. Thunderstorms which pass directly over the station may be noted, but those which occur at a distance of several miles are often ignored ; this is especially the case in tropical stations where thunderstorms are severe but extremely local—at certain times of the day in the rainy seasons distant thunder is so common that it simply does not occur to the observer to enter it in the register—in fact, he may not consciously be aware of its occurrence, in the same way as anyone living within sound of frequent heavy traffic after a time ceases to be consciously aware of it. For this reason the numbers of days with thunder are probably too low at many of the second and third order stations. In some cases the figures were obviously too low and had to be omitted.

[1] *Codex of Resolutions adopted at International Meteorological Meetings*, 1872–1907. English Edition, London, 1909, p. 25.

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As an example of the irregularities which may be met with, the following table of days with thunder heard at the various Dublin stations may be given. All the stations are within a few miles of each other, but the records of thunder differ considerably :—

	1916.	1917.	1918.	1919.	1920.	1921.
Dublin City	11	11	9	9	1	6
Glasnevin	8	12	5	6	0	2
Phœnix Park	7	8	4	8	2	3
Trinity College	–	9	3	–	1	2
Ranelagh	–	4	2	4	0	–

On the other hand, what might have seemed a plausible alternative, namely, to accept only the maximum numbers in each district, would be to go to the opposite extreme. The actual distribution of thunderstorms in most areas is necessarily extremely complex. Considerations of relief, of soil and vegetation, and of geological structure, all combine to give one locality an excess above and another neighbouring locality a deficit below the general average of the district. Any observant person who has lived long in a hilly district is aware of this fact. But in such a broad survey as the present one, it was not possible to take account of these local peculiarities, and it was necessary to assume that the irregularities in the distribution of the figures were due to local distribution and to " accidental " variations and not to omissions in some of the records. Where the records were too numerous to be conveniently plotted on the charts, they were accordingly combined into " district means," which in some cases included more than one hundred stations.

In the case of central Europe the amount of data available was so large that in order to make adequate use of it a special procedure was necessary. In this case the figures were first combined into " district means " as described above, the districts being those which were most conveniently extracted from the various publications. The " district means " for each month were then plotted on a large scale map, lines of equal frequency were drawn, and the mean values of each two-degree square, with intervening points where the variation was greatest, were read off from these charts. These figures are given in Table I.

For Europe, the United States and the Atlantic Coast of South America, the data were amply sufficient for the construction of charts which could be accepted with a considerable degree of confidence, but the charts for the remaining portions of the world mainly depend on ungrouped means for single stations, often based on short periods and widely spaced. This was especially the case with the tropics, and the figures for the latter were in many cases lower than the usual conception of the frequency of electrical phenomena in hot countries would have led us to expect. But since this expectation was based almost entirely on the popular conceptions built up by picturesque descriptions of tropical weather, it was obviously necessary to accept the charted figures as they stood instead of attempting to manipulate them.

Table I.—Monthly Frequency of Thunder over Central Europe.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
55° N.	9° E.	–	0·1	0·1	0·5	2·1	2·4	3·4	3·3	1·4	1·7	0·3	0·1	15·4
	11°	–	0·0	0·1	0·4	2·1	2·3	3·4	3·0	1·2	0·5	0·1	0·1	13·2
	13°	–	0·0	0·1	0·4	2·0	2·5	3·4	2·9	0·9	0·4	0·1	0·1	12·8
	15°	–	0·0	0·1	0·4	2·4	2·6	3·4	3·2	1·0	0·3	0·1	0·0	13·5
	17°	–	0·0	0·0	0·4	2·5	2·6	3·5	3·0	1·0	0·2	0·0	0·0	13·2
	19°	–	0·0	0·0	0·4	2·2	2·6	2·9	2·6	0·9	0·2	0·0	0·0	11·8
	21°	–	0·0	0·1	0·5	2·5	3·0	3·3	3·3	1·2	0·4	0·1	0·0	14·4
	23°	–	0·0	0·0	0·5	2·2	3·2	4·2	2·5	1·0	0·1	0·0	0·0	13·7
53° N.	7° E.	0·1	0·2	0·3	0·8	3·1	3·4	3·5	3·6	1·9	1·1	0·4	0·2	18·6
	9°	0·1	0·1	0·4	1·1	3·2	3·8	5·6	3·5	1·4	0·6	0·2	0·2	20·2
	11°	0·1	0·2	0·4	1·1	2·9	4·4	6·1	4·5	1·6	0·3	0·1	0·2	21·9
	13°	0·0	0·1	0·4	1·6	3·2	4·7	5·5	4·0	1·3	0·3	0·1	0·1	21·3
	15°	0·0	0·1	0·4	1·6	4·0	4·7	6·0	4·6	1·8	0·3	0·1	0·1	23·7
	17°	0·0	0·1	0·3	1·2	3·4	4·7	5·1	4·2	1·5	0·3	0·0	0·1	20·9
	19°	–	0·0	0·1	1·9	3·4	3·5	5·3	4·0	1·3	0·2	0·0	0·0	19·7
	21°	–	0·0	0·1	1·4	3·3	3·4	4·8	3·9	1·2	0·2	0·0	0·0	18·3
	23°	–	0·0	0·1	1·1	3·1	3·5	4·5	3·5	1·0	0·1	–	–	16·9
51° N.	7° E.	0·1	0·2	0·6	1·5	3·4	4·3	4·9	4·2	1·5	0·4	0·1	0·1	21·3
	9°	0·1	0·2	0·4	1·2	3·9	3·9	5·5	3·8	1·5	0·3	0·1	0·0	20·9
	11°	0·1	0·1	0·4	1·0	3·5	4·0	5·3	3·6	1·3	0·2	0·1	0·1	19·7
	13°	0·1	0·0	0·5	1·3	3·2	4·6	5·4	3·4	1·5	0·3	0·0	0·0	20·3
	15°	0·1	0·1	0·4	1·4	4·0	4·9	5·5	3·5	1·5	0·3	0·1	0·1	21·9
	17°	0·1	0·2	0·2	1·5	4·5	4·0	4·3	3·3	1·0	0·2	0·0	0·0	19·3
	19°	0·1	0·2	0·3	2·7	4·5	3·0	4·8	2·8	1·5	0·3	0·0	–	20·2
	21°	0·0	0·2	0·2	1·5	3·6	4·0	4·3	3·7	1·4	0·3	0·1	–	19·3
	23°	–	0·0	0·1	1·2	3·4	4·0	4·3	3·7	1·1	0·3	0·1	–	18·2
49° N.	7° E.	0·1	0·2	0·4	1·2	3·0	4·4	4·3	3·6	1·8	0·5	0·1	0·1	19·7
	9°	0·1	0·1	0·3	1·2	3·5	4·8	4·8	4·0	1·6	0·3	0·1	0·1	20·9
	11°	0·1	0·1	0·4	1·4	3·5	7·0	5·9	3·8	1·7	0·2	0·1	0·1	24·3
	13°	0·1	0·0	0·5	1·4	4·6	6·6	7·0	3·8	1·5	0·4	0·1	0·0	26·0
	15°	0·0	0·0	0·3	1·3	3·3	4·7	5·1	3·4	1·2	0·3	0·1	0·0	19·7
	17°	0·0	0·0	0·3	1·0	2·9	4·3	4·3	3·1	1·1	0·4	0·0	0·0	17·4
	19°	0·0	0·0	0·3	1·4	4·8	6·2	5·6	3·7	1·4	0·3	0·1	0·0	23·8
	21°	0·0	0·0	0·3	1·4	5·1	7·2	5·7	4·2	1·3	0·3	0·1	0·0	25·6
	23°	0·0	0·0	0·3	1·1	5·0	7·1	5·7	4·3	1·2	0·4	0·1	0·0	25·2
48° 30′ N.	9° E.	0·1	0·1	0·3	1·2	3·5	5·0	5·0	3·6	1·7	0·3	0·0	0·1	20·9
	9° 30′	0·1	0·1	0·4	1·9	5·3	8·1	9·4	6·4	2·4	0·4	0·0	0·0	34·5
	11°	0·1	0·1	0·3	1·6	4·3	5·7	9·0	6·2	2·5	0·4	0·0	0·0	30·2
	12°	0·1	0·1	0·4	1·7	5·4	7·6	9·2	6·0	2·0	0·4	0·0	0·0	32·9
	13°	0·1	0·0	0·5	1·5	4·5	7·1	8·0	5·1	1·7	0·4	0·1	0·0	29·0
	14°	0·0	0·0	0·4	1·5	3·9	6·2	7·0	5·0	1·5	0·3	0·1	0·0	25·9
47° N.	5° E.	0·2	0·2	0·3	1·6	4·8	5·5	7·5	5·4	3·1	0·6	0·6	0·3	30·1
	7°	0·0	0·1	0·2	0·8	2·6	3·6	4·0	3·2	1·7	0·4	0·1	0·1	16·8
	9°	0·0	0·0	0·1	0·5	1·4	2·4	4·0	2·7	1·0	0·2	0·0	0·1	12·4
	11°	–	0·0	0·1	0·2	1·0	2·9	5·4	3·8	1·3	0·2	0·0	0·0	14·9
	13°	0·0	–	0·1	0·3	1·2	3·3	5·3	3·8	1·5	0·4	0·0	0·0	15·9
	15°	–	0·0	0·1	1·0	2·9	5·6	6·9	4·6	1·6	0·3	0·1	0·1	23·2
	17°	–	0·0	0·3	1·6	5·4	6·6	6·4	4·3	1·7	0·4	0·1	0·0	26·8
	19°	0·0	0·0	0·2	1·5	5·4	6·5	5·8	4·1	1·5	0·4	0·1	0·1	25·6
	21°	0·0	0·0	0·4	1·5	6·0	7·1	6·0	4·1	1·4	0·4	0·1	0·0	27·0
	23°	0·0	0·0	0·3	1·2	5·9	7·6	6·2	4·3	1·4	0·3	0·1	0·0	27·3
46° 30′ N.	11° E.	–	0·0	0·1	0·1	0·9	2·7	5·0	3·6	1·2	0·3	0·0	0·0	13·9
	12°	–	0·0	0·2	0·2	0·9	3·3	5·3	3·7	1·3	0·5	0·1	0·0	15·5
	13°	–	0·0	0·3	0·4	1·6	4·1	6·2	4·5	1·6	0·7	0·2	0·1	19·7
	14°	0·0	0·1	0·4	0·7	2·6	5·5	7·5	5·4	2·5	1·2	0·5	0·3	26·7
	15°	0·0	0·1	0·2	1·0	2·8	5·5	5·5	4·1	1·8	0·5	0·2	0·2	21·9
	16°	–	0·1	0·3	1·4	4·4	5·5	5·3	4·0	1·6	0·4	0·2	0·2	23·4

The total number of stations employed and their distribution according to continents, is as follows :—

Europe	2,680*
Asia	182
Africa	83
North America	135
South America	133
Australasia	81
Oceanic Islands	21
Total	3,265

In addition to these, the results of various tabulations of marine data were employed for the oceans. The chief sources of the data are given in the following bibliography, but there were also many isolated references which are too numerous to mention specifically. The basis of the work was Klossovsky's magnificent pioneer effort, which included data for 439 stations, of which 72 were in European Russia. Klossovsky published an annual chart which is sufficiently accurate for Europe and Asiatic Russia, but which is based on insufficient information for remaining regions, and in these regions the revised chart for the year differs widely from Klossovsky's.

§2. Sources of the Data.

General.—Klossovsky, A. " Zur Frage über die Verbreitung der Gewitter auf der Erdoberfläche." *Revue Météor. du Sudouest de la Russie*, 3, 1892, No. 3, p. 37. (Russian with a summary in French.)

Sweden.—Stockholm, Institut Central de Météorologie, *App.* 1 *aux observations météorologiques suédoises*, Vol. 57, 1915. " Fréquence des jours d'orage en Suède, 1730–1915." Par H. E. Hamberg, Upsala, 1917. (Contains tables for 797 stations. These are grouped in " district means " and plotted on large scale charts.)

Norway.—Mohn, H. *Klimatabeller for Norge*, Pt. 8, " Antal dage med nedbor, sne, hagel, taage, klart, overskyet, torden." Kristiania, 1899.

Denmark (Copenhagen).—*Met. Zs.*, 15 p. 426.

Färoes, Iceland and Greenland.—Copenhagen, Dansk Meteorologisk Institut, " Éléments météorologiques des îles Féroé, de l'Islande et du Groenland." *Aarbog*, 1895, 2 pte, App. Copenhagen 1899. (Normals for 16–25 years ending 1895.)

Russia in Europe and Asia.—Klossovsky A. (See above.) Also *Met. Zs.* 35, p. 255.

Germany.—Arendt, T. " Ergebnisse zehnjähriger Gewitterbeobachtungen in Nord–und Mitteldeutschland," *Berlin, K. Preuss, Meteor. Inst., Abhandl.* Bd. 2, No. 2.

Hamburg, Deutsche Seewarte, *Ergebnisse der meteorologische Beobachtungen im Systeme der Deutsche Seewarte*, 1876–1900, 1901–05, 1906–10. Hamburg, 1904, 1910, 1912.

Schreiber, P. *Das Klima des Königreich Sachsens*, H.2, Chemnitz, 1893, p. 60.

Alt, E. und Weickmann, L. " Klimatologie von Süddeutschland. Untersuchungen über Gewitter und Hagel in Süddeutschland (1893–1907)." *München, Beob. meteor. Stat. K. Bayern*, 31, 1909, p. C 1.

Meyer, H. " Die Gewitter zu Göttingen." *Nachs. K. Gesellsch. Wiss., Göttingen*, 1887, No. 9, p. 390. (See also *Met. Zs.* 5, p. 86.)

Also *Zs. f. Met.*, 7, 1872, p. 143, and *Met. Zs.* 5, p. 38, 7, p. 278 and 21, p. 86.

* Including 797 in Sweden.

Holland.—Utrecht, K. Nederl. Meteor. Institut. *Maandelijksch overzicht der weergesteldheid in Nederland,* 1921 (contains long-period normals).

British Isles.—London Meteorological Office, *The Book of Normals,* Section IV.

France.—Paris, Bureau Central Météorologique. " Les orages en France, 1905, 1910." *Annales* 1905, 1910, pte 1, Paris 1909, 1915. (The volume for 1905 contains data for 1901–05, that for 1910 data for 1906–10.)

Also *Met. Zs.,* 5, p. 405 ; 10, p. 273 ; 11, p. 78 ; 13, p. 265 ; 14, p. 179 ; 21, p. 473 ; 23, p. 426.

Spain and Portugal.—Köppen, W. " Die jährliche und räumliche Verteilung der Gewitter und Böen auf dem Nordatlantischen Ozean und an dessen Küsten." *Ann. Hydrogr.,* Berlin, 46, 1918, p. 64. (This also contains data for additional stations in France and in Canada.)

Semmelhack, W. " Beiträge zur Klimatographie von Nordspanien und Portugal." 1 Teil, Niederschlagsverhältnisse. Hamburg, *Arch, D. Seewarte,* 1910, No. 2.

Also *Met. Zs.,* 6, p. 117 ; 7, p. 198 ; 9, p. 72 ; 12, p. 159.

Italy.—No general discussion was available and the data were compiled from a number of separate sources.

Switzerland.—Maurer, J. *et al. Das Klima der Schweiz,* 1864–1900. 2 vols , Frauenfeld, 1905.

Austria-Hungary (former area).—Vienna, K. K. Zentralanstalt für Meteorologie und Geodynamik. *Klimatographie von Österreich.* 9 parts, Vienna, 1904–1919.

Budapest, K. Ung. Reichsanstalt für Meteorologie und Erdmagnetismus. *Jahrbuch,* Vol. 40, 1910, Th. 3, " Ergebnisse der Gewitterbeobachtungen im Jahre 1910," Budapest, 1914. (Contains "Fünfzehnjährige Ergebnisse der Gewitterbeobachtungen in Ungarn aus dem Zeitraum 1896–1910.")

Asiatic Turkey and Mesopotamia, Balkans, Mediterranean Islands.—London, Admiralty War Staff, Intelligence Division. " Notes on climate and other subjects . . . . in Eastern Mediterranean and adjacent countries " (London), 1916.
Hepites, St. C. *Album climatologique de Roumanie,* Bucuresci, 1900.

China.—No general discussion was available and the data were compiled from various sources.

Japan.—Tokio, Central Meteorological Observatory. *Results of Meteorological Observations in Japan for the years* 1906–10. Tokio, 1913.

Korea.—See Japan ; also :

Jinsen, Meteorological Observatory of the Government General of Korea. *Results of Meteorological Observations made at Korea* 1911–15. Jinsen, 1917.

Formosa.—Kondo, H. *The Climate, Typhoons and Earthquakes of the Island of Formosa (Taiwan).* Taihoku, 1914.

Taihoku, Meteorological Observatory. *The Rainfall in the Island of Formosa* . . . . Taihoku, 1920.

India.—Data mainly from Klossovsky.

East Indies.—No general discussion was available and the data were compiled from various sources.

Africa.—Most of the data were compiled from separate sources, or from manuscript records in the Meteorological Office. In addition, data for a number of stations were obtained from the following publications :—

Brussels, Société Royale de Médicin Publique et de Topographie Médicale de Belgique. Congrès nationale d'hygiène et de climatologie médicale de la Belgique et du Congo . . . . 1897. 2 pte, Congo. Bruxelles, 1898.

Castens, —. Klimatafeln. *Pflanzer,* Daressalam, H. 2.

Canada.—A number of stations are given in the paper by Köppen cited above. Other data were collected from various sources, mainly in the *Met. Zs.*

United States.—Alexander, W. H. "Distribution of Thunderstorms in the United States." Washington, U.S. Weather Bureau, *Monthly Weather Rev.* 43, 1915, p. 322.

Mexico, West Indies and Central America.—Various sources were employed. After the maps had been drawn, however, a comprehensive publication dealing with this area was received :—

Kloster, W. "Bewolkungs-, Niederschlags- und Gewitterverhältnisse der Westindischen Gewässer und der angrenzenden Landmassen." Hamburg, *Arch. D. Seewarte*, 40, 1922, H. 1.

The chart for the year was partially re-drawn in accordance with this publication, but it was too late to alter those for the half years.

South America.—The following publications may be mentioned specifically :—

Rio de Janeiro, Directoria de Meteorologia. *Boletim de normaes, Observaçoes meteorologicas feitas no ex-Observatorio Nacional . . . . e nas estaçoes da rede Nacional.* Rio de Janeiro, 1922.

Davis, W. G. *The Climate of the Argentine Republic.* Buenos Aires, 2nd ed., 1910.

Buenos Aires, Oficina Meteorologica Argentina. *Annales*, T. 1–17. (Each volume contains a climatic description of one or more stations.)

Australasia and Oceanic Islands.—Various sources were employed, including unpublished manuscript data.

Oceans.—Köppen, W. "Die jährliche und räumliche Verteilung der Gewitter und Böen auf dem Nordatlantischen Ozean und an dessen Küsten." *Ann. Hydrogr.*, Berlin, 46, 1918, p. 64. (The figures were given in percentage of observations. Since there are six observations a day on board ship, it was necessary to convert these figures to days of thunder and a table based on the theory of probabilities was constructed for the purpose.)

Schlee, P. "Niederschlag, Gewitter und Bewölkung im südwestlichen und in einem Theile des tropischen Atlantischen Ozeans," *Diss*, Halle a. S., 1892.

Danckelman, A. v. "Regen, Hagel und Gewitter im Indischen Ozean. . . ." Hamburg, *Arch. D. Seewarte*, 3, 1880, No. 2.

§3. The Distribution of Thunderstorm Frequency.

The data referred to above were plotted on three charts of the globe, giving the figures for the year, for April to September, and for October to March. On these charts isobronts, or lines of equal frequency of thunder, were drawn. These are shown in Figs. 1, 2 and 3, the data being expressed as percentages of days on which thunder was heard. The percentages for which isobronts were drawn, with the equivalent number of days, are as follows :—

Percentage.	*Days.* *Year.*	*Days.* *Six months.*
1	4	2
3	11	5
5	18	9
10	36	18
20	73	36
30	110	55
50	183	91
75	274	137

In favourable circumstances thunder can be heard for a distance of ten or twelve miles, but it is unlikely that all thunderstorms occurring within this distance of a station will be recorded, and probably we shall be interpreting the data in a sufficiently generous manner if we consider that the numbers represent the thunder occurring within a distance of six miles, i.e., in an area of 113 square miles surrounding the station.

In drawing the isobronts a few areas were found where even the plotted figures (without regard to their reliability) were quite insufficient. The chief cases were the eastern half of the South Atlantic Ocean, the Sahara, the interior of Australia, and the greater part of the Pacific Ocean. In these cases recourse was had to general meteorological considerations. Over the land areas—the Sahara and the interior of Australia—the isobronts were drawn roughly parallel to the isohyets, and it was assumed that the practically rainless central areas were almost without thunderstorm activity. Over the oceans even the rainfall was not available as a guide and the isobronts were based on the pressure and wind direction, the centres of permanent high pressure and the neighbouring steady trade wind regions being considered as stable areas where thunderstorms were probably rare. These isobronts are indicated by broken lines.

The chart for the year (Fig. 1) shows six areas of maximum frequency, in four of which the frequency of thunder exceeds 30 per cent. (110 days). These six areas are :—Southern Mexico (39 per cent.), Panama (37 per cent.), Central Brazil (29 per cent.), Central Africa (41 per cent.), Madagascar (26 per cent.), and Java (61 per cent.). The last is probably the most thundery region of the earth and this should be taken into account in planning air routes to Australia.

Strongly opposed to these highly disturbed areas are those where thunder is rarely or never heard. These include in the first place the Arctic and Antarctic regions. The area with less than one thunderstorm a year includes Greenland, the northern half of Iceland, Northern Norway, the whole of the Arctic Ocean and the northern coast of North America. It was long supposed that thunderstorms were practically unknown in Arctic regions, but H. Harries[1] collected a number of records of thunder from high latitudes, the records extending as far as Spitsbergen in about 78° N. It appears that during an Arctic expedition lasting two or three years, thunder may be experienced once or at most twice, but by more than half the expeditions it was not experienced at all. On the west coast of Greenland, both at Godthaab in 64° N. and at Jacobshavn in 69° N., two days of thunder were recorded during the 22 years, 1874–1895, but at Upernivik, in 72° 47′ N., there was not one record of thunder during the same period. Thus, the average frequency of thunder north of the Arctic circle may be taken as about one day in ten years.

Thunder appears to be unknown on the Antarctic continent, but is occasionally recorded on the sub-antarctic islands. Thus, at Laurie Island, South Orkneys (60° 44′ S.), thunder was recorded twice in twelve years, and at Cumberland Bay, South Georgia (54° S.), five times in ten years.

Nearer the equator there are two belts of minimum thunderstorm activity coinciding with the sub-tropical belts of high pressure in about 30° N. and S. In the northern belt the greater part of the Saharan and Arabian deserts has a probable frequency of less than 1 per cent. (four records a year), while there is another minimum area to the west of North America, where the whole coast from Alaska as far south as San Diego (32° N.) has less than 1 per cent. This quiet region probably extends a long distance westward, Honolulu in Hawaii averaging only four storms per annum, but eastward it does not penetrate far on to the continent and storms are much more frequent in the Rocky Mountain belt.

In the Southern Hemisphere there is a well-marked minimum area on the west coast of South Africa, where Walfish Bay and Swakopmund average three days of thunder per annum, and this minimum area seems to stretch some distance northwestward over St. Helena, but does not extend more than a few miles inland to the east. A minimum is indicated by ships' observations in the South Indian Ocean,

[1] Arctic hail and thunderstorms, *Q. J. R. Meteor. Soc.* 22, 1896, p. 251.

situated in about 25° to 30° S., and there is probably another over the dry interior of Australia, but the most marked deficiency of storms in this belt is along the coast of Chile from 16° to 34° S., where the frequency averages less than one a year and at some stations thunder is unknown. This area extends westward to include Juan Fernandez in 79° W., but beyond this the frequency increases towards Easter Island (109° W.), where it is five a year.

There is an interesting local minimum along the east coast of New Zealand, where the average annual frequency is only three, or less than 1 per cent., while on the corresponding west coast it is about 3 per cent. This is probably a " rain-shadow " effect, although in general in temperate regions (Scandinavia and North America); the effect of a range of mountains to windward seems to be to increase the storm frequency. Probably in these latter regions the increase in thunderstorm activity is caused by an increase in the continentality due to the mountain range, while in New Zealand the mountains are not high enough and the westerly winds are too powerful for the development of a continental climate. The distribution in Central Europe is also interesting. The average frequency is 20 days per annum (just over 5 per cent.) with a marked maximum north of the Alps, another maximum along the eastern part of the Alpine ridge and a minimum over Central Germany. There is also a local maximum over the Dutch coast which is due chiefly to the frequency of winter thunderstorms.

The chart for April to September reproduces in the northern hemisphere the essential features of the chart for the year, except that over the northern temperate regions the percentages are nearly doubled, since most of the thunder is experienced in this half-year. The Saharan minimum is more marked and extends in an unbroken belt from the Persian Gulf far out across the Atlantic Ocean, where it turns northward in longitude 30° W. to include the Azores. The minimum over the North Pacific is also greatly extended and the area with less than 1 per cent. extends from the western coast of the United States well beyond Hawaii. The maxima over Southern Mexico, Panama, Central Africa and Java are still well developed, but those of Brazil and Madagascar are much weaker and new maxima are shown in Abyssinia, near Bangkok (Siam) and on the north coast of New Guinea. The minima in the South Pacific and South Indian Oceans are also well marked. This being the winter of the Southern Hemisphere, thunder is very rare south of 50° S.

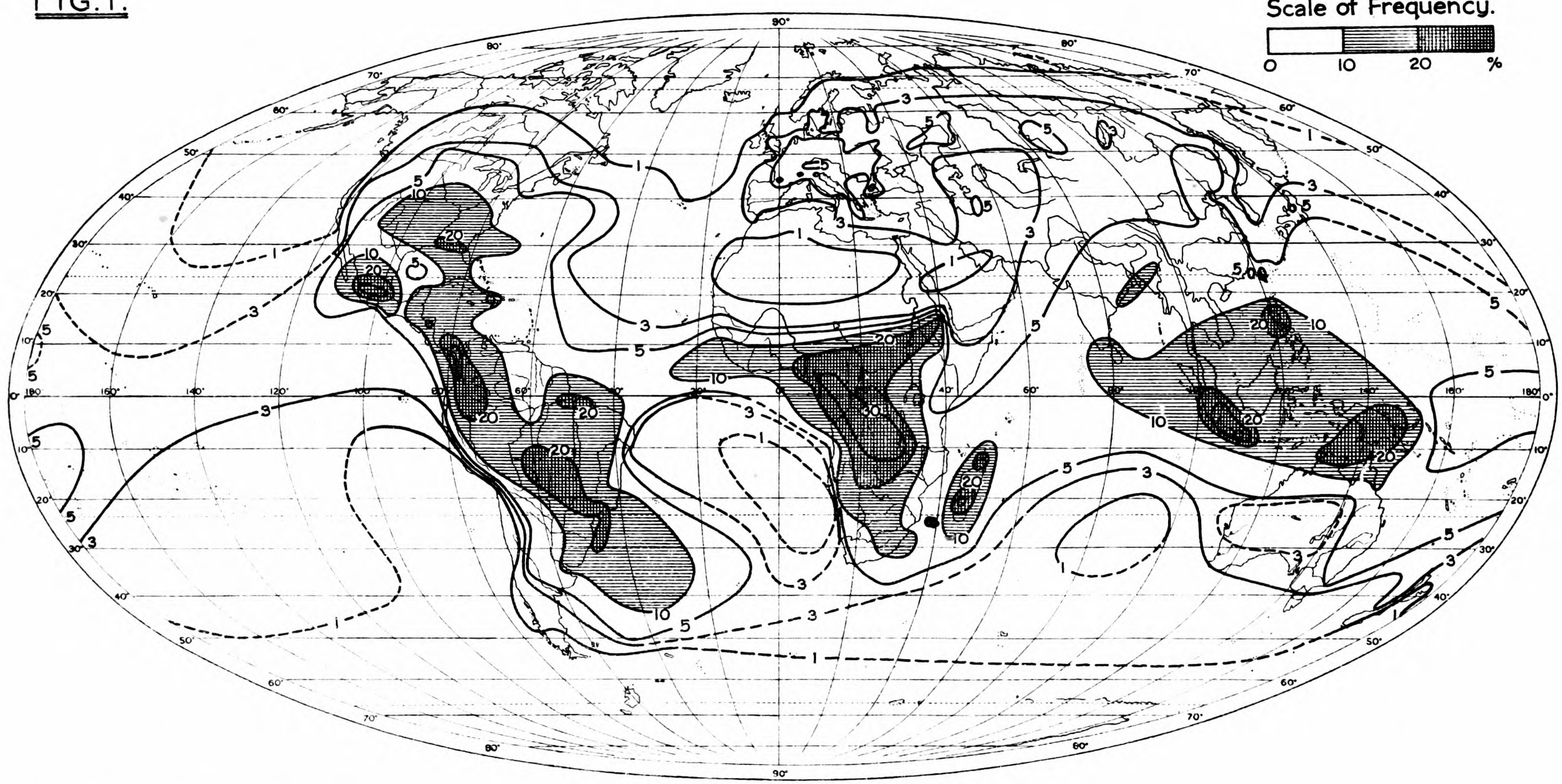
In October to March there is an almost complete absence of thunder north of 50° N., except on the north-west coasts of Europe, where the winter type of thunderstorm is met with. This winter type is associated with line-squalls and occurs most frequently on the west coasts of Southern Norway, Scotland, Ireland, Holland, Belgium and France. At Valencia the frequency is four per half-year and on some parts of the continent it reaches five or six. The relative frequency of winter as compared with summer thunder in this region is shown in Fig. 4, which gives the percentage of the total annual records of thunder occurring in the period October to March. The percentage increases from less than five in Sweden and the interior of Europe to above 30 on the whole stretch of the Atlantic coast (excluding the southern North Sea) and above 50 per cent. in places. The few thunderstorms experienced in Iceland and the Faroes occur almost exclusively in winter.

There is a minor maximum of thunder in the Mediterranean and the minimum in the Sahara is not so well developed as in the summer months. The minimum in the North Pacific is also less sharply defined.

In contrast with the chart for April to September, the maxima in Southern Mexico and Central America are feebly shown, the number of records in the half-year failing to reach 30 (16 per cent.). On the other hand, the maxima in Central Brazil (41 per cent.), Central Africa (74 per cent.), Madagascar (45 per cent.), and Java (70 per cent.), are well developed and there is another maximum area at Port Darwin (38 per cent.). In Central Africa a great area is shown in the interior extending from 8° S. to 23° S., in which more than one hundred storms are recorded at each station during the half-year; this maximum has greatly increased in intensity and moved further southward as compared with the distribution in April to September.

FIG. I.

Chart showing Percentage of days with Thunder heard during the Year.



K2073. H&SP. G227. 24428. 10202 RF 844/135. 625. 3/25.

Fig. 2.

Chart showing Percentage of days with Thunder heard during April to September.

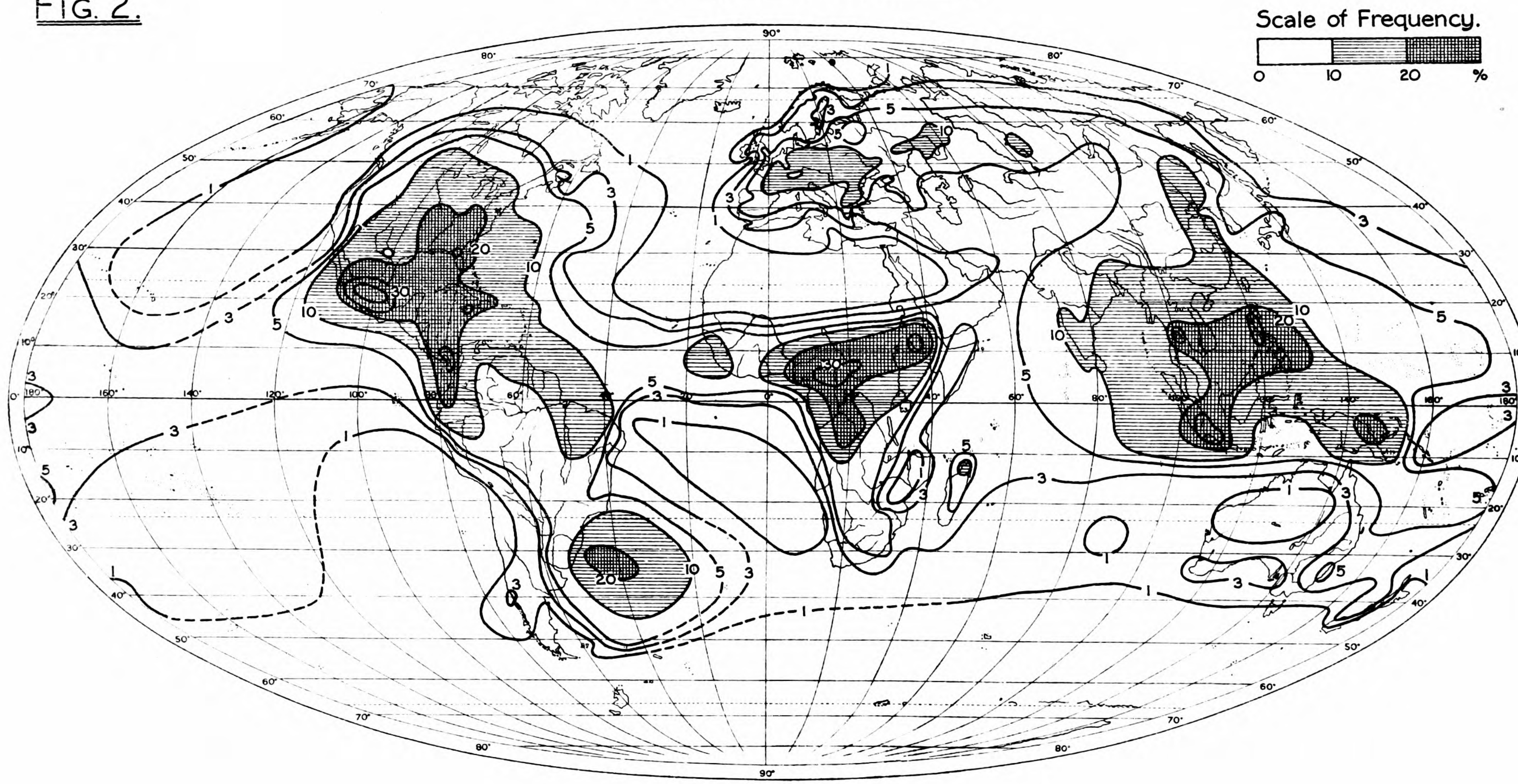
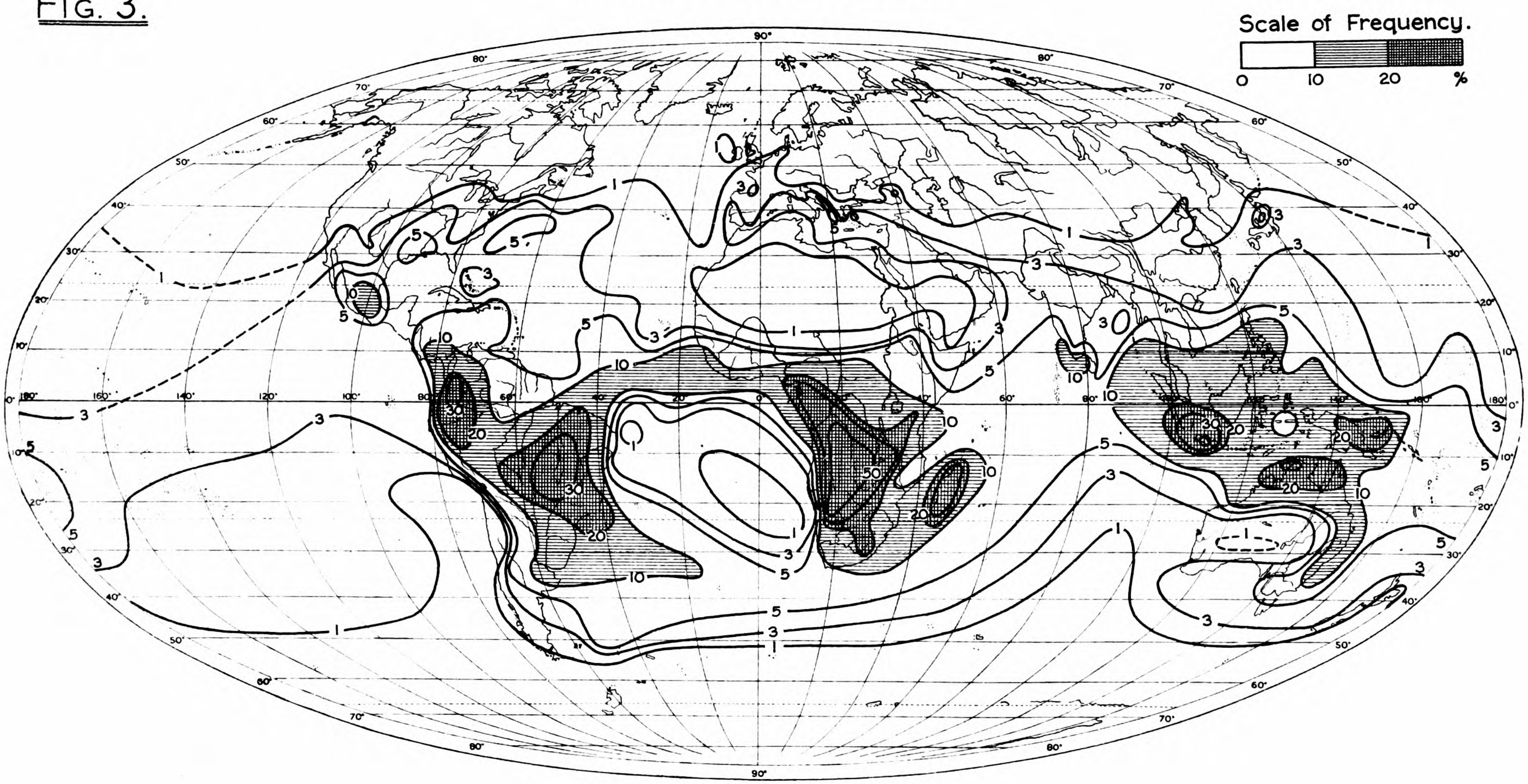


Fig. 3.

Chart showing Percentage of days with Thunder heard during October to March.



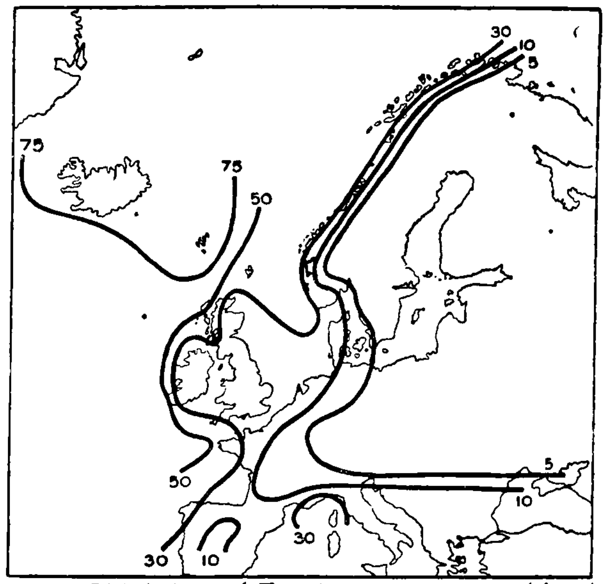


FIG 4. Distribution of Thunder (*in percentages of Annual frequency*) over Europe during Winter (*October to March*)

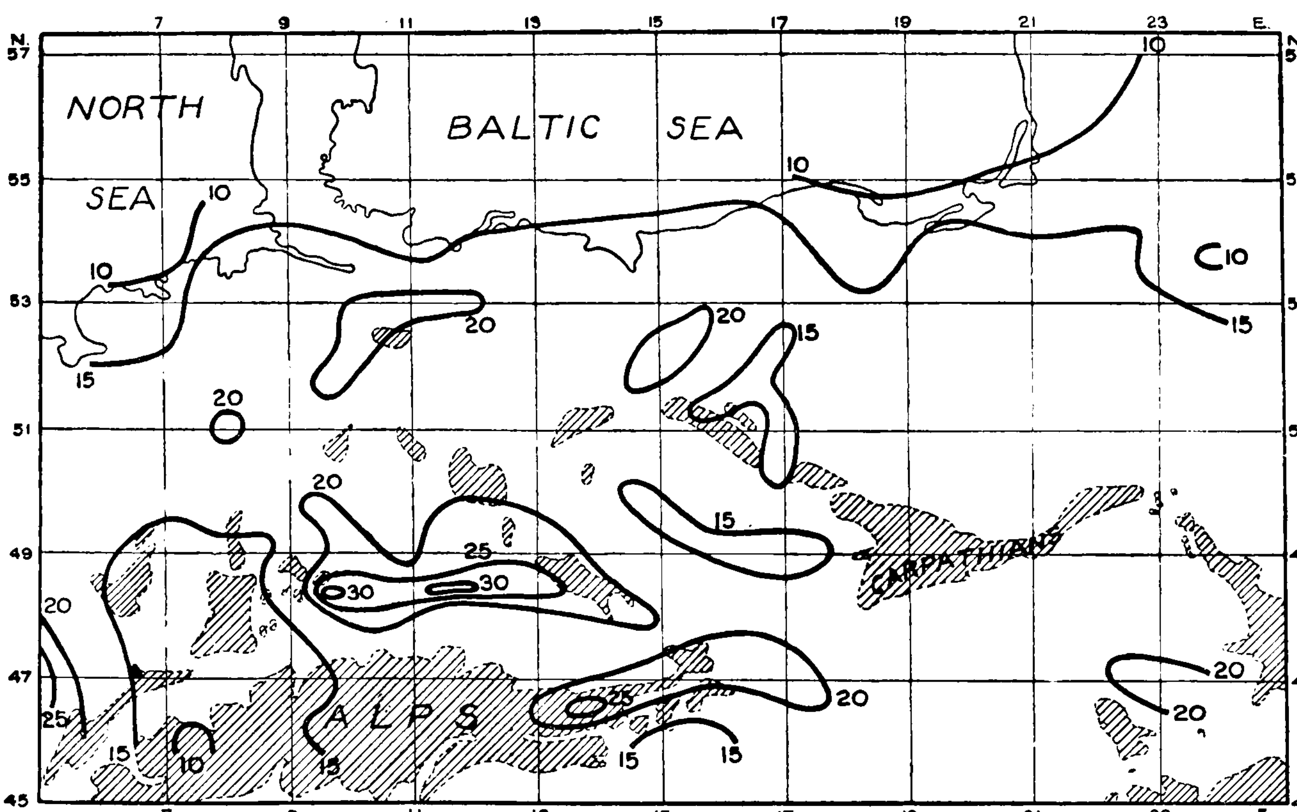


FIG. 5. Distribution of Thunder (*in percentages*) over Central Europe in July.
Shaded areas represent land above 3000 metres.

In order to bring out the distribution over Central Europe, where a great deal of data has been co-ordinated, the chart for July is reproduced in Fig. 5. The mountain areas are shown by shading, the area shaded being that above 3,000 metres (approximately 10,000 ft.). The chief maximum of thunderstorm frequency in Europe extends in a long narrow belt at the base of the northern slopes of the Alps. There is another maximum at the eastern end of that chain and a third is indicated to the east of the Plateau Central district of France.

It has not been considered necessary to reproduce the whole of the data employed in preparing the charts, but in Table 2 the data for a series of representative stations are given. The monthly totals are expressed as percentages of the annual frequency which is given in the last column. The maxima are printed in heavy type and the minima in italics. The stations selected and the climatological districts which they represent, are as follows :—

TABLE II.—ANNUAL VARIATION OF FREQUENCY OF THUNDER AT SELECTED STATIONS.

District	Station	Latitude	Longtitude	Height	No. of Years	Reference.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year No.
				Ft.			%	%	%	%	%	%	%	%	%	%	%	%	
NORTH AMERICA..	Portland, Me.	43° 39′ N.	70° 15′ W.	103	43	Mon. Weath. Rev., 1915, p. 326.	*0*	*0*	3	4	11	21	**28**	18	10	4	1	*0*	10·9
	Charleston ..	32° 47′ N.	79° 56′ W.	48	43	,, ,,	*1*	2	4	6	11	19	**23**	21	8	2	2	*1*	52·7
	Duluth ..	46° 47′ N.	92° 6′ W.	1,133	43	,, ,,	*0*	*0*	1	4	13	22	**26**	19	11	4	*0*	*0*	22·3
	Nashville ..	36° 10′ N.	86° 47′ W.	546	43	,, ,,	2	4	7	10	13	**20**	19	13	7	2	2	*1*	44·6
	Salt Lake City.	40° 46′ N.	111° 54′ W.	4,360	43	,, ,,	2	1	4	6	12	15	21	**24**	10	4	1	*0*	18·8
	San Diego ..	32° 43′ N.	117° 10′ W.	59	42	,, ,,	5	9	14	5	4	4	9	**32**	5	9	*0*	4	2·2
	Leon ..	21° 7′ N.	101° 43′ W.	5,902	29	Mexico, Bol. mens., 1907, p. 832.	*1*	*1*	4	5	10	15	**19**	17	15	8	4	*1*	143·0
WEST INDIES ..	San Juan, P R	18° 29′ N	66° 7′ W	82	15	Mon. Weath. Rev., 1915, p. 338.	*0*	*0*	1	3	10	14	14	15	**19**	16	6	2	50·4
CENTRAL AMERICA	Colon ..	9° 23′ N	79° 23′ W	10	8	Isthmian Canal Commission Reports.	*0*	*0*	*0*	2	12	15	13	**16**	**16**	15	9	2	103·6
SOUTH AMERICA..	Quito ..	0° 14′ S	78° 45′ W	9,350	3½	Zs.f. Met. 11, p. 370 and Met. Zs. 18, p. 580, and 19, p. 378.	7	6	9	**13**	12	7	*5*	*5*	6	**13**	9	8	99·5
	Barra do Corda	5° 30′ S	45° 15′ W	266	7	Rio de Janeiro, Boletim de Normaes, 1922.	**16**	15	15	13	5	*1*	*1*	2	2	7	10	13	134·0
	Bahia Blanca	38° 43′ S	62° 20′ W	66	21	Davis, Climate of Argentine, 1902.	11	11	10	7	5	*1*	2	4	6	14	11	**18**	13·8
AUSTRALIA ..	Port Darwin	12° 28′ S	130° 51′ E	97	35	Rainfall Obs. in S. Australia.	16	14	13	5	1	*0*	*0*	*0*	2	10	19	**20**	76·1
	Sydney ..	33° 51′ S	151° 13′ E	146	56	Rainfall Obs. in N.S.W.	10	9	8	8	7	*5*	*5*	7	8	10	11	**12**	48·7
	Perth ..	31° 57′ S.	115° 51′ E.	97	24	M.S. data supplied by Commonwealth Meteor.	7	7	7	*5*	10	14	**15**	11	6	6	*5*	7	12·0
PACIFIC OCEAN ..	Honolulu ..	21° 19′ N.	157° 52′ W.	38	9	Mon. Weath. Rev., 1915, p. 331.	**23**	18	3	3	2	2	*0*	*0*	8	10	8	**23**	3·9
	Apia, Samoa	13° 48′ S.	171° 46′ W.	10	17	Met. Zs. 30, p. 162 ..	14	11	12	11	6	5	2	*1*	3	9	11	**15**	25·0
INDIAN OCEAN ..	Mauritius ..	20° 6′ S.	57° 33′ E.	178	45	Mauritius, Results Obs., Dec. 1918.	21	18	**23**	14	6	1	*0*	*0*	1	1	3	12	20·1
EUROPE— Atlantic Coast ..	Bergen ..	60° 23′ N.	5° 21′ E.	56	20	Mohn, Klimatabeller for Norge.	11	3	3	*0*	6	6	11	**25**	8	11	8	8	3·6
	Valencia Obsy.	51° 56′ N.	10° 15′ W.	30	35	Unpublished data ..	12	9	8	6	8	**11**	8	9	*5*	7	8	9	6·5
	Brest ..	48° 23′ N.	4° 27′ W.	200	10	Köppen, Verteilung... ..	8	7	6	*5*	9	**16**	10	10	13	6	*5*	*5*	6·7
	Lisbon ..	38° 42′ N.	9° 8′ W.	312	20	Lisbon, Annals, App. 1876, p. 12.	9	7	6	7	**15**	9	*2*	3	10	**15**	9	8	13·8
Interior ..	Paris ..	48° 12′ N.	2° 7′ E.	405	30	Annu. Soc. Météor. France, 1905.	*0*	1	3	8	15	**21**	**21**	17	10	3	1	*0*	27·2
	Brunn ..	49° 12′ N.	16° 37′ E.	732	36	Liznar, Klima von Brunn	*0*	*0*	1	4	18	**28**	23	18	6	2	*0*	*0*	15·7
	Ekaterinburg	56° 50′ N.	60° 38′ E	930	34	Klossovsky	*0*	*0*	*0*	1	9	27	**35**	24	4	*0*	*0*	*0*	22·7
MEDITERRANEAN	Rome ..	41° 54′ N	12° 29′ E	208	129	Eredia, Clima di Roma..	*3*	*3*	5	7	9	11	10	12	**14**	13	8	5	22·0
	Tripoli ..	32° 54′ N	13° 11′ E	33	20	Eredia, Clima di Tripoli	4	6	8	7	12	6	*0*	3	16	**19**	12	7	8·4
	Smyrna ..	38° 26′ N	27° 13′ E.	33	6	Köppen, Verteilung... ..	11	7	3	7	13	6	*0*	4	7	6	**20**	16	17·7
	Beirut ..	33° 54′ N.	35° 29′ E.	172	25	Kostlivy, Klimat. Verh. von Beirut.	13	13	12	6	5	1	*0*	*0*	1	12	**20**	17	20·5
ASIA— Continental ..	Barnaoul ..	53° 20′ N.	83° 47′ E.	531	25	Klossovsky	*0*	*0*	*0*	1	12	23	**37**	23	4	*0*	*0*	*0*	22·8
	Tachkent ..	41° 20′ N.	69° 18′ E.	1,569	9	,, ...	*0*	1	9	20	**29**	25	5	5	4	2	*0*	*0*	8·0
Monsoon ..	Vladivostok	43° 7′ N.	131° 54′ E.	57	13	,, ...	*0*	2	*0*	*0*	6	**35**	19	14	16	5	3	*0*	6·3
	Hong Kong	22° 18′ N.	114° 10′ E.	103	30	Claxton, Climate of Hong Kong.	1	1	7	12	14	17	17	**18**	11	2	*0*	*0*	30·3
	Calcutta ..	22° 36′ N.	88° 23′ E.	20	10	Alipore Obs., Reports ..	1	3	8	11	**16**	15	14	12	15	5	*0*	*0*	47·5
	Batavia ..	6° 11′ S.	106° 50′ E.	26	50	Batavia Obs., Report, Vol. 39.	10	9	11	11	8	6	*4*	*4*	6	9	**12**	10	132·7
AFRICA	Cairo (Helwan)	29° 52′ N.	31° 20′ E.	379	45	——	7	7	12	7	7	2	*0*	2	3	19	**22**	12	4·2
	Duala ..	4° 3′ N.	9° 41′ E.	33	8	Deutches Schutzgebiet, 1914, p. 273.	5	8	12	12	**13**	7	4	*3*	9	12	9	6	110·5
	Entebbe ..	0° 5′ N.	32° 39′ E.	3,842	10	Manuscript returns ..	8	7	10	**12**	7	9	8	8	7	*6*	8	10	40·9
	Loanda ..	8° 49′ S.	13° 7′ E.	194	15	Congr. Nat. du Congo, Met. Zs. 24, p. 418.	3	12	20	**35**	4	*0*	*0*	1	2	3	11	9	22·8
	Walfish Bay	22° 57′ S.	14° 26′ E.	10	7	Met. Zs. 13, p. 243 ..	*0*	**26**	12	9	9	3	*0*	2	*0*	18	9	12	3·4
	Tananarivo..	18° 55′ S.	47° 32′ E.	4,593	10	Obs. Météor à Tananarive	18	15	13	6	1	*0*	*0*	1	3	8	15	**20**	93·4

The Atlantic coast of Europe is represented by Bergen, Valencia, Brest and Lisbon, the latter approximating to the Mediterranean type. For the interior of Europe, becoming more and more continental as we pass eastward, we have Paris, Brunn and Ekaterinburg. The western Mediterranean is represented by Rome, with a winter minimum, and the eastern Mediterranean by Tripoli, Smyrna and Beirut, all with their minima in summer. Asia is represented, for the continental interior, by Barnaoul and Tachkent, and for the monsoon regions by Vladivostok, Hong Kong, Calcutta and Batavia (East Indies). In Africa we have Cairo in the northern dry belt, Duala and Entebbe in the equatorial rain region, Loanda and Walfish Bay in the southern dry region and Tananarive in Madagascar. In North America the Atlantic coast is represented by Portland (Maine) and Charleston, the Great Lakes by Duluth, the continental interior by Nashville and Salt Lake City, the Pacific Coast by San Diego and the Mexican plateau by Leon. The West Indies is typified by San Juan, Central America by Colon (Panama), and South America by Quito on the equator, Barra do Corda in the southern tropics and Bahia Blanca in the south temperate region. In Australia we have Port Darwin in the tropical monsoon area to the north, Sydney in the temperate area on the east, and Perth in the winter rain region on the west. The oceanic islands are represented by Honolulu (Hawaii), Apia (Samoa), and Mauritius.

§4. The Total Number of Thunderstorms occurring in a Year.

In order to obtain some idea of the average frequency of thunder over the whole world, the region between 70° N. and 60° S. latitude was divided into a series of "squares" by ten-degree lines of latitude and longitude, and from the working charts the average number of days with thunder was estimated for each square. These figures have been combined in Table III., which gives for each belt of latitude the average frequency of thunder in each half-year and in the whole year. The columns headed "land" refer to ten-degree "squares" which contain more than 33 per cent. of land, those headed "sea" refer to "squares" which are almost entirely occupied by open sea.

Table III.—Average Number of Storms per Station in Various Latitudes.

Latitude	Proportion of Area	April to September			October to March			Year		
		Land	Sea	Land and Sea	Land	Sea	Land and Sea	Land	Sea	Land and Sea
70°—60° N.	·037	3·5	—	3·5	0·1	—	0·1	3·6	—	3·6
60°—50° N.	·050	9·5	1·7	8·0	0·2	0·1	0·2	9·7	1·8	8·2
50°—40° N.	·062	13·5	2·7	9·9	1·3	0·8	1·1	14·8	3·5	11·0
40°—30° N.	·071	13·9	5·3	10·3	4·0	3·2	3·7	17·9	8·5	14·0
30°—20° N.	·079	15·9	5·9	12·6	4·1	4·1	4·1	20·0	10·0	16·7
20°—10° N.	·084	23·1	10·8	16·9	7·3	6·3	6·8	30·4	17·1	23·7
10° N.—0	·087	26·6	11·2	18·5	23·0	9·9	16·1	49·6	21·1	34·6
0 —10° S.	·087	22·9	6·4	12·8	37·8	9·0	20·2	60·7	15·4	33·0
10°—20° S.	·084	8·1	4·0	5·3	38·2	7·4	17·6	46·3	11·4	22·9
20°—30° S.	·079	7·8	3·6	5·3	18·5	6·9	11·1	26·3	10·5	16·4
30°—40° S.	·071	6·0	5·8	5·9	10·3	7·9	8·5	16·3	13·7	14·4
40°—50° S.	·062	2·0	3·3	3·1	4·4	4·6	4·6	6·4	7·9	7·7
50°—60° S.	·050	0·5	0·5	0·5	2·0	1·0	1·1	2·5	1·5	1·6
Northern Hemisphere	·500	—	—	11·8	—	—	5·3	—	—	17·1
Southern Hemisphere	·500	—	—	5·3	—	—	10·1	—	—	15·4
Whole Earth	1·000	—	—	8·5	—	—	7·7	—	—	16·2

The average frequency of thunderstorms over the land and coastal waters is much greater than over the sea, especially in the tropics, but it must be remembered that the data are much more reliable in the former case than in the latter. The only latitudes in which the frequency of thunder over the sea exceeds that over the land are between 40° and 50° S. in both seasons, but in 30° to 20° N. the figures are equal during the period October to March. In April to September the maximum is reached over both land and sea between 10° N. and the equator; in October to March the land reaches its maximum between 10° and 20° S., the sea between 10° N. and the equator, and the land and sea together between the equator and 10° S. The distribution according to latitude is shown in Fig. 6, which brings out the equatorial maximum and also the effect of the sub-tropical high pressure belts in interrupting by slight depressions the regular decrease towards the poles. On the average, the Northern Hemisphere is slightly more stormy than the Southern Hemisphere (17·1 days a year compared with 15·4), but each hemisphere has the greatest thunderstorm frequency during its respective summer, when it is about double that during the winter. It should be noted in examining Table III., that in calculating the figures in the last three lines the regions north of 70° N. and south of 60° S. have been regarded as free from thunder. The storms here are very few and as the areas are relatively small their omission will not appreciably affect the figures.

On page 00 it was estimated that each station on the average recorded the thunderstorms occurring within an area of 113 square miles surrounding the station. Many storms have a broad front and most of them drift for a longer or shorter distance while they are in progress; hence, we may enlarge this area and consider that on the average a station will record thunderstorms the *centre* of whose track (both as regards length and breadth) falls within area of 200 square miles surrounding the station. Thus, we can say that if we imagine the whole of the earth to be divided into segments each with an area of 200 square miles, on the average 16 thunderstorms will occur each year within each segment. The area of the surface of the earth is approximately 197,000,000 square miles, so that there are very nearly one million sections of area 200 square miles each, and on the whole the earth will experience 16,000,000 thunderstorms per annum or 44,000 per day.

These figures can be looked at in another way. The duration of thunderstorms is very variable, but a moderate estimate of the average duration will be one hour. Then, again speaking in averages, there will be in progress at any one moment about 1,800 thunderstorms in different parts of the world.

What does this mean in terms of lightning flashes? During a thunderstorm at West Norwood, the late W. Marriott[1] counted 98 lightning flashes in 28 minutes, which is at the rate of approximately 200 per hour. A photographic plate exposed for four minutes during a thunderstorm at Sydney, NSW.[2], shows five flashes. This is at the rate of 72 per hour, but the photograph obviously covers only a small part of the storm and we may consider that Marriott's figure of 200 per hour is approximately correct for a severe temperate or an average tropical storm. Then 1,800 storms will give us 360,000 lightning flashes over the whole globe in an hour, or an average of 100 per second.

§5. The Annual Variation of Thunderstorm Frequency.

In preparing Table III., it was possible to make use of the working charts on which the thunderstorm frequencies had been plotted, and to integrate the figures over each ten-degree square. For the separate months this process could not be followed without plotting all the figures separately. In order to obtain an idea of the annual variation from month to month in different parts of the world, the working

[1] *Q.J.R. Meteor. Soc.*, 34, 1908, p. 210.
[2] Hann, *Lehrbuch der Meteorologie*, 2 ed. opposite p. 478.

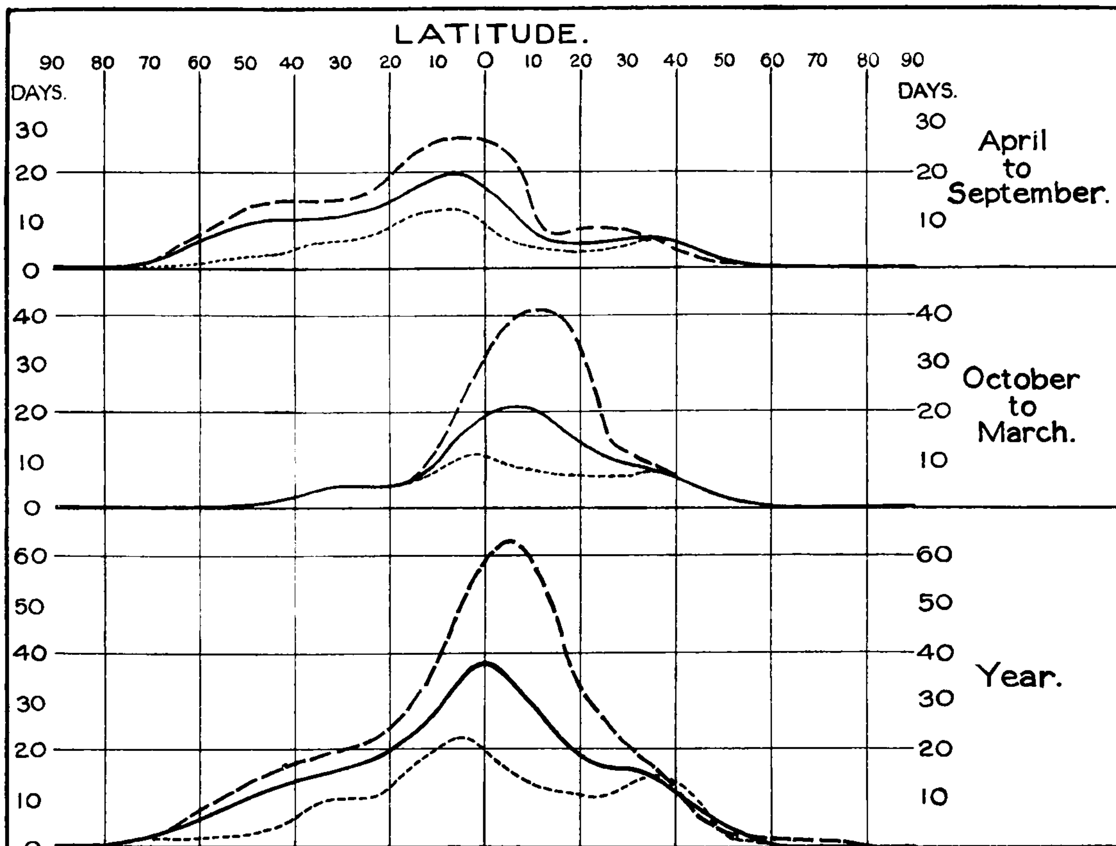


FIG. 6. Variation of Thunder with Latitude.

Land — — — *Sea* ...... *Land and Sea* ———

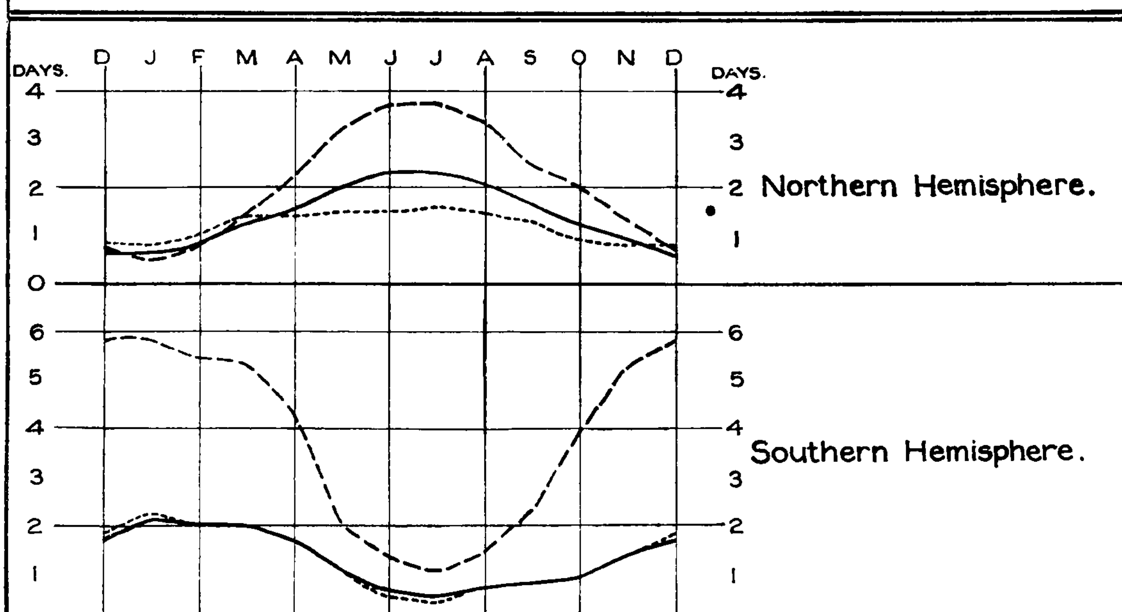


FIG. 7. Annual Variation of Thunder.

Land — — — *Sea* ..... *Whole Hemisphere* ———

tables were divided into a number of geographical units and the actual figures for each unit were averaged. The results are shown in Table IV., which should give a sufficiently good approximation. From this table it appears that the maximum frequency occurs in summer over the greater part of the world. In Europe, northern and eastern Asia, Canada, Alaska, and the United States, the maximum falls in July and the minimum near the middle of the winter. Nearer the equator this simple distribution is disturbed, thus southern Asia and North Africa have two maxima, the greatest in May and a secondary maximum in October, i.e., at the beginning and end of the rainy season. In Central America and the West Indies there is a single maximum in August, near the middle of the hurricane season. The oceans vary greatly ; in the North Atlantic the maximum falls in August, in the part of the Indian Ocean north of the equator in May, and at Honolulu in the North Pacific in mid-winter.

The equatorial regions in general show great thunderstorm activity over the land in all months. The East Indies show two approximately equal maxima in May and October ; Central Africa has a chief maximum in March and a secondary peak in December. The equatorial Pacific has an irregular distribution with a maximum in September. South of the equator Africa and America have their maxima in January, Australasia in December, and the oceans in January to March.

The figures for the hemispheres in the lower section of Table IV. were obtained by weighting the various continents and oceans according to their areas. The weighted totals for land and sea were then combined to give the frequency of storms in each hemisphere, but in order to take account of the Arctic and Antarctic regions, these were divided, not by the aggregate of the areas included, but by the area of a hemisphere. The resulting figures for the year for the two hemispheres showed slight divergencies from those found in Table III., and they were adjusted by multiplying the monthly means for the Northern Hemisphere by 1·09 and for the Southern Hemisphere by 0·90.

These differences are due to the paucity of observations over the oceans and especially the Pacific, which is represented by only twelve island stations, four in the north and eight in the south. In the upper part of the table the North Pacific is represented solely by Honolulu, the Equatorial Pacific by six, and the South Pacific by five stations, but in the lower part these stations have been re-divided. Considering the enormous area of this ocean, the uncertainty introduced by the paucity of stations must be considered as affecting the reliability of the means for the oceanic areas in both hemispheres and also the means for the whole hemispheres and for the earth. The means for the land areas in the lower part of the table are based on a large number of stations and should be reliable.

Accepting the figures as they stand, we find that in the Northern Hemisphere the land has a maximum in June and July and a minimum in January, while the sea has a maximum in March and April (spring) and a minimum in October, which is very much what we should expect. For the whole hemisphere the maximum falls in July and the minimum in December and January. The Southern Hemisphere land shows a maximum in December and January and a minimum in July, but the water areas have their maxima and minima at the same time as the seas of the Northern Hemisphere. The latter is a curious result which may be due to paucity of observations, especially as the different oceans show very great differences in this respect. Owing to the great preponderance of the water areas in the south, the annual variation for the whole hemisphere is very similar to that for the oceans, but owing to the inclusion of the Antarctic and Southern Ocean the figures are in general lower.

The excess of thunderstorms in the land areas of the Southern over those of the Northern Hemisphere is merely due to the shapes of the continents, which expand northwards but contract southwards, thus giving a very much greater land area in the cold temperate zone of the north than in that of the south.

The figures for the whole earth show a maximum in March and April and a minimum from October to December, but the annual range is small and the differences may have no significance.

TABLE IV.—MONTHLY FREQUENCY OF THUNDERSTORMS OVER CONTINENTS, OCEANS AND HEMISPHERES.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Greenland, Iceland, Faroes	0·1	0·1	0·0	0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·1	0·7
Europe	*0·2*	*0·2*	0·4	0·9	2·5	3·6	**3·8**	2·9	1·5	0·7	0·4	*0·2*	17·3
Asia, North	*0·0*	*0·0*	*0·0*	0·3	1·3	2·9	**3·5**	2·1	0·7	0·1	*0·0*	*0·0*	10·9
,, East	0·2	*0·1*	0·7	1·1	1·9	3·2	3·9	**4·0**	2·0	0·7	0·3	0·2	18·3
,, South	*0·6*	0·9	2·5	4·3	4·8	2·7	1·7	2·0	2·6	**3·3**	2·2	0·8	28·4
East Indies	7·2	6·7	8·6	9·9	10·2	8·1	7·2	*6·4*	7·0	10·0	**10·4**	8·8	100·5
Africa, North	*1·4*	2·3	4·2	5·0	5·3	**4·6**	3·5	3·3	3·4	**4·6**	3·3	2·2	43·1
,, Central	7·7	8·0	**8·9**	8·3	3·0	1·3	*0·9*	1·5	2·8	4·4	7·3	8·1	62·2
,, South	**8·9**	7·6	7·6	3·8	1·5	0·2	*0·1*	0·6	2·2	5·3	7·2	7·9	52·9
Canada, Alaska	*0·0*	*0·0*	0·1	0·5	0·9	1·7	**2·1**	1·7	0·7	0·3	0·1	*0·0*	8·1
U.S.A.	*0·3*	0·6	1·4	2·3	4·3	6·0	**6·7**	6·0	3·1	1·0	0·5	*0·3*	32·5
Mexico, West Indies and Central America.	*0·9*	1·0	1·6	3·0	6·2	7·4	8·2	**8·9**	8·3	6·7	3·9	1·8	57·9
Brazil, Bolivia, Peru ..	**6·1**	5·5	4·6	3·7	1·6	1·2	*1·0*	1·8	2·4	4·2	5·0	5·5	42·6
Chile, Argentine, Uruguay	1·7	1·4	1·2	0·7	0·6	*0·5*	*0·5*	0·7	0·6	1·2	1·4	**1·8**	12·3
Australasia	3·2	2·5	2·4	2·2	1·6	1·7	*1·2*	1·3	1·9	2·5	3·4	**3·9**	27·8
Pacific, North	**0·9**	0·7	0·1	0·1	0·1	0·1	*0·0*	*0·0*	0·3	0·4	0·3	**0·9**	3·9
,, Equatorial ..	0·9	*0·8*	1·1	0·9	1·0	1·1	1·5	1·4	**1·7**	0·9	1·3	*0·8*	13·4
,, South	**3·4**	3·2	3·1	2·8	1·1	1·4	0·4	*0·2*	0·4	0·7	1·1	1·0	18·8
Indian Ocean, North ..	2·9	3·5	4·7	4·1	**6·9**	0·3	4·1	0·9	1·5	*0·0*	*0·0*	3·1	32·0
,, ,, South ..	1·9	**2·4**	**2·4**	1·5	1·4	0·7	1·1	1·4	0·4	*0·1*	0·6	1·5	15·4
North Atlantic	*0·8*	0·9	1·1	1·2	1·0	1·0	1·4	**1·5**	1·2	1·1	1·0	1·0	13·2
South Atlantic	1·8	2·2	**3·3**	3·0	2·5	1·6	1·3	1·3	*1·2*	*1·2*	1·6	1·5	22·5
Northern Hemisphere.													
Land	*0·5*	0·7	1·4	2·2	3·2	**3·7**	**3·7**	3·3	2·4	2·0	1·3	0·7	25·2
Sea	1·1	1·2	**1·4**	**1·4**	1·3	1·2	1·3	1·3	1·3	*0·9*	1·0	1·1	14·5
Land, Sea and Arctic ..	*0·8*	0·9	1·2	1·5	1·9	**2·1**	**2·1**	2·0	1·6	1·2	1·0	*0·8*	17·1
Southern Hemisphere.													
Land	**5·8**	5·4	5·3	4·3	2·0	1·3	*1·0*	1·4	2·3	3·9	5·3	**5·8**	43·8
Sea	2·1	2·3	**2·6**	2·1	1·5	1·2	1·0	1·1	0·8	*0·7*	1·1	1·2	17·7
Land, Sea and Antarctic ..	1·9	1·9	**2·0**	1·7	1·1	0·8	*0·7*	0·8	0·8	0·9	1·3	1·5	15·4
Whole Earth	1·4	1·4	**1·6**	**1·6**	1·5	1·4	1·4	1·4	1·2	*1·1*	*1·1*	*1·1*	16·2

NOTE.—It should be noted that the means for October to March and April to September taken from Table IV. do not coincide with those from Table III. Thus we have :—

	October to March		April to September	
	Table 3	Table 4	Table 3	Table 4
Northern Hemisphere	5·3	5·9	11·8	11·2
Southern Hemisphere	10·1	9·5	5·3	5·9
Whole Earth	7·7	7·7	8·5	8·5

If, as is probable, these differences are to be attributed to the uncertainty of the oceanic figures, we may perhaps correct them by adjusting the figures over the oceans by means of a cyclic curve. When this is done we obtain the following revised figures for the sea areas :—

TABLE V.—REVISED MONTHLY MEANS FOR HEMISPHERES.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Northern Hemisphere :												
Sea	*0·8*	1·0	1·4	1·4	1·5	1·5	**1·6**	1·5	1·3	0·9	*0·8*	*0·8*
Whole Area ..	*0·6*	0·8	1·2	1·5	2·0	**2·3**	**2·3**	2·1	1·6	1·2	0·9	*0·6*
Southern Hemisphere :												
Sea	**2·2**	2·0	2·0	1·7	1·0	0·5	*0·4*	0·7	0·8	0·9	1·4	1·8
Whole Area ..	**2·1**	2·0	2·0	1·7	1·0	0·6	*0·5*	0·7	0·8	0·9	1·4	1·7

These figures give variations over the oceans in the same direction as those over the land in the same hemisphere but of lesser amplitude. The corrections balance in the two hemispheres, so that the means for the whole earth remain as in Table IV. These revised figures for the oceans and for the hemispheres and those for the land from Table IV., are shown graphically in Fig. 7.

§6. THE DIURNAL VARIATION OF THUNDERSTORM FREQUENCY.

Table VI. shows the diurnal variation in the frequency of thunderstorms at a few selected stations or districts, the time unit employed being two hours. Over the land the maximum generally occurs during the afternoon, when convection is strongest, and the minimum during the night or early morning. Thus, at Edinburgh, the maximum occurs at 14–15h., and 46 per cent. of the storms occur between 12h. and 16h. The mean for a large number of stations in Germany also shows a maximum between 14h. and 15h., with 47 per cent. of the reports between 12h. and 16h. In Hungary the maximum is somewhat later, both 14–15h. and 15–16h. experiencing 11·0 per cent. of the thunder ; 42 per cent. occur between 13h. and 17h.

TABLE VI.—DIURNAL VARIATION OF THUNDERSTORMS.

	Hours											
	0–2	2–4	4–6	6–8	8–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24
Edinburgh[1]	2	2	1	2	5	14	22	24	12	9	5	2
Germany[2]	2	2	2	2	4	17	25	22	12	7	3	2
Hungary[3]	2	2	2	2	3	10	17	22	18	12	7	3
Batavia[4]		18			6			50			26	
Buenos Aires[5] ..		18			26			27			29	
Cordoba (Argentine)[5]		29			15			27			29	

[1] Mossman, R. C. Meteorology of Edinburgh, London, *Phil. Trans. R. Soc.*, 39 pt. 1, No. 6, p. 166. Mean of 1770 to 1896.

[2] Langbeck, K. Der Tagesgang in der Entstehung der Gewitterzuge, *Met. Zs.*, 39, 1922, p. 300. Mean of 1901–1910.

[3] Budapest, K. Ung. Reichsanstalt für Meteorologie und Erdmagnetismus, *Jahrbuch*, 40 Bd., 1910, Teil. 3. Mean of 1896–1910.

[4] Batavia, R. Magnetical and Meteor. Observatory. *Annual Report*, 39, 1916, p. 84. Mean of 1867–1916.

[5] Davis, W. G. *Climate of the Argentine Republic.* Buenos Aires, 1902, p. 131.

At Batavia, Buenos Aires and Cordoba, the figures are given only for six-hourly intervals ; Batavia shows a well-marked maximum (50 per cent.) between 12h. and 18h., and a minimum (6 per cent.) between 6h. and 12h. At the two South American stations the distribution is different. Buenos Aires, on the estuary of the Rio de la Plata, has a maximum at 18–24h. and a minimum at 0–6h., but the diurnal range is not very marked. Cordoba, in the interior, has the unusual feature for a land station of a night maximum and day minimum ; in each of the six-hour periods 19h. to 24h. and 0–6h., 29 per cent. of the thunder is recorded, while the minimum falls in the period 6h. to 12h. with 15 per cent.

Over the ocean[1] the diurnal variation of thunderstorm frequency is reversed, the maximum falling between 0h. and 4h. The explanation given by W. J. Humphreys[2] is that the diurnal range of temperature of the ocean surface is very small, usually a small fraction of 1° C., while that of the atmosphere at a height of 500 to 1,000 metres is several times as great. Hence, over the ocean, the temperature gradients favourable to rapid vertical convection are most frequent during the early morning hours.

K. Langbeck (see Table VI.) discusses the peculiarities of the diurnal variation in different parts of Germany. He finds that the coastal regions have a greater tendency than the interior for early morning thunder, between 6 h. and 9 h., owing to the contrast between the temperatures over land and sea, which is greatest at this time. During the hours of 9 h. to 12 h. thunder appears more regularly in the mountain lands, and in isolated parts of the sea coast such as the Oder mouth. Over the whole country the maximum frequency of thunder occurs between 12h. and 15h., and on the average 37·7 per cent. of the records fall in this period. The percentage exceeds 40 in the central and eastern parts of the country, from the neighbourhood of Rostock eastward and south-eastward and approaches 50 on the eastern Pomeranian coastal plain. On the other hand, the percentage occurring within these hours is less than 35 over the western mountain regions, in Westphalia, Harz Mountains and Thuringer Wald, and also on the Mecklenberg coastal plain and the mouth of the Elbe. Thus, thunder is more closely limited to the middle of the day as one goes eastward towards a more continental climate.

In Hungary it was found that in the eastern and north-eastern highlands the maximum falls between 13 h. and 14 h., on the Little Hungarian Plain between 14 h. and 16 h., and on the Great Hungarian Plain between 15 h. and 16 h. In Hungary, as well as in Germany, the relative frequency in the morning hours increases from the plains to the highlands.

§7. Variation in Thunderstorm Frequency with Height.

In collecting the figures of thunderstorm frequency, occasional data for high levels came to hand and it soon became evident that height had remarkably little effect in determining the incidence of thunder. For instance, the mean of 15 years' observations at the observatory on Pike's Peak, Colorado, at a height of 14,133 ft., gave an annual frequency of 39·7, or 10·9 per cent., and the value read off from the annual map, in which the Pike's Peak data were not included, was 40, or 11 per cent. At Sonnblick in Austria (10,180 ft.), the annual frequency during 13 years was 14·1, or 3·9 per cent., while the number from the chart was 16, or 4·4 per cent. This agreement extends even to the individual months, July being the month of maximum frequency at high as well as low levels in both cases. At Pike's Peak this month has a mean of 39 per cent. compared with a mean for the whole of Colorado of 35 per cent. At Sonnblick the July mean is identical with the mean read off from the chart, viz., 17 per cent.

[1] W. Meinardus, "Zur täglichen und jährlichen Periode der Gewitter auf dem Ozean." Hamburg, *Arch. D. Seewarte*, Vol. 16, 1893.

[2] W. J. Humphreys, "The Thunderstorm and its Phenomena." Reprinted from the *Journal of the Franklin Institute*, November and December, 1914.

H. E. Hamberg, in his investigation of the frequency of thunder in Sweden[1], arrived at an almost identical conclusion. Up to 1,000 or 1,300 ft. the means for different levels in each of the principal parts of the country present such small differences that one can say that at least within these limits the altitude does not exercise any appreciable influence on the number of days of thunder. Above 1,000 ft. stations become few and far between and the data become irregular, showing in some cases an increase and in others a decrease in the frequency of thunder with increasing altitude, and Hamberg concludes that between 1,000 and 2,600 ft. (300 and 800 metres) the frequency on the whole increases slightly. Above 2,600 ft. he has no data.

In the Alps a different conclusion is reached. A special investigation of the distribution of thunder in Switzerland[2] shows that the isobronts are extremely complicated, but apart from a general increase from south-west to north-east are intimately related to the orography of the country. The frequency is greatest in the great valleys of the interior, somewhat less in the Jura district and the Alpine foothills and much less in the high Alps. Thus, a notable diminution with height is found. Examining their chart in detail, they find a close connection between maxima of thunder and surface moisture (lakes, rivers or swamps). In the great Alpine valleys the storms tend to travel along the valleys without crossing the mountain walls which bound them.

In order to obtain a numerical estimate of the decrease with height, the stations, to the number of 93, given in the tables were classified according to height, and the annual average frequency of thunder in each group, together with the maximum and minimum at individual stations, were found. The results are shown in Table 7, the frequencies being expressed in percentages.

TABLE VII.—FREQUENCY OF DAYS WITH THUNDER (PER CENT.) AT VARIOUS HEIGHTS IN SWITZERLAND.

Height (Metres)	No. of Stations	Mean per cent.	Highest per cent.	Lowest per cent.	Range per cent.
0—500	31	4·4	7·0	2·2	4·8
500—1,000 ..	30	3·6	7·3	0·5	6·8
1,000—1,500 ..	20	2·8	8·0	0·8	7·2
1,500—2,000 ..	7	2·5	4·2	1·7	2·5
2,000—3,000 ..	5	2·4	4·5	0·8	3·7
All Stations ..	93	3·6	8·0	0·5	7·5

The result does show a real decrease of thunder with height in Switzerland. This is partly to be accounted for by the fact that a large proportion of the low-level stations lie in the north. Without a special investigation, however, it is impossible to say whether there is a real northward increase of thunder apart from height, or whether the increase shown on the maps is merely an expression of the lower level of the northern stations. In any case, the northward increase cannot account for more than half of the observed diminution of thunder with elevation.

In one respect the results are curiously similar to those obtained in Sweden, namely, in the much greater variability of thunderstorm frequency above 500 metres. The greatest annual frequency of thunder in Switzerland, 8·0 per cent., occurs at Braggio, north-east of Lake Maggiore, at a level of 1,313 metres (4,305 ft.).

A similar calculation was carried out for different parts of Austria, with the result shown in Table 8.

[1] *Meteor. Iakttagelser i Sverige*, Vol. 57, 1915, Bihang, p. 36.
[2] *Das Klima der Schweiz*, Bd. 1, Anhang, pp. 265–284.

TABLE VIII.—FREQUENCY OF DAYS WITH THUNDER AT VARIOUS HEIGHTS IN AUSTRIA.

Height (Metres)	0—500		500—1,000		1,000—1,500		Greater than 1,500	
	No. of Stations	Mean per cent.	No. of Stations	Mean per cent.	No. of Stations	Mean per cent.	No. of Stations	Mean per cent.
Tirol	9	5·1	11	4·5	5	3·4	3	4·2
Salzburg	1	6·0	6	4·3	3	4·1	1	4·8
Karnten	4	6·2	14	6·3	3	5·7	1	6·3
Upper Austria ..	6	6·6	3	6·6	1	5·9	1	4·1
All Districts ..	20	5·8	34	5·4	12	4·4	6	4·6

In this table the means are expressed in percentages and in the lowest line the means for all districts are weighted according to the number of stations. The results agree closely with those for Switzerland in that each separate district shows a decrease in thunderstorm frequency with height. The decrease is, however, not so rapid as in Switzerland, the ratio of the frequency above 1,500 metres to that below 500 metres being 0·79 in Austria and only 0·57 in Switzerland, i.e., in the latter country the relative decrease is twice as rapid as in the former.

There is very little information readily available for the variation of thunder frequency with height in the tropics, since the stations are rarely sufficiently close together for other factors to be eliminated. With reference to the mountain stations in Java, C. Braak writes[1] :—

> " Thunder is seldom observed on the high tops, the thunderclouds, which originate on the lower slopes, repelled as it were by the mountain, taking their course towards the plain. It often occurs that on all sides high clouds tower above the summit, whereas the latter remains free and still basks in the sun."

Generalisation from these conflicting results is difficult. Too much importance must not be given to the cases of Pike's Peak and Sonnblick, because at these stations trained observers are on the watch to record all instances of phenomena, whereas at the average voluntary station the observer has other occupations which may cause him to miss some instances of thunder. Nevertheless, the curious agreement with the results at low-level stations does indicate that the rate of decrease cannot be very great. The absence of any recognisable effect in Sweden probably shows merely that the mountains there, although lofty from an English standpoint, are not of sufficient elevation or extent to affect seriously the meteorological processes giving rise to thunder. On the other hand, in the Alps there appears to be a real diminution towards the high interior, indicating that the storms tend to be limited to the lower ground which is more level and also more moist. It is impossible to make any numerical estimate of the decrease, however, partly because of the irregularities in the observed figures and partly because in a mountainous district it will seldom happen that the level of the ground immediately beneath a thunder cloud is the same as the level of the observing station which records it, and there must be a considerable smoothing out of the results. Also the phenomena in a deep and narrow valley must differ considerably from those in a broad level plain, although the actual elevation may be the same in each case.

[1] *The Climate of the Netherlands Indies.* Vol. 1, pt. 1, Batavia, K. Magn. en Meteor. Observatorium, Verh. No. 8, English Summary, p. 17.

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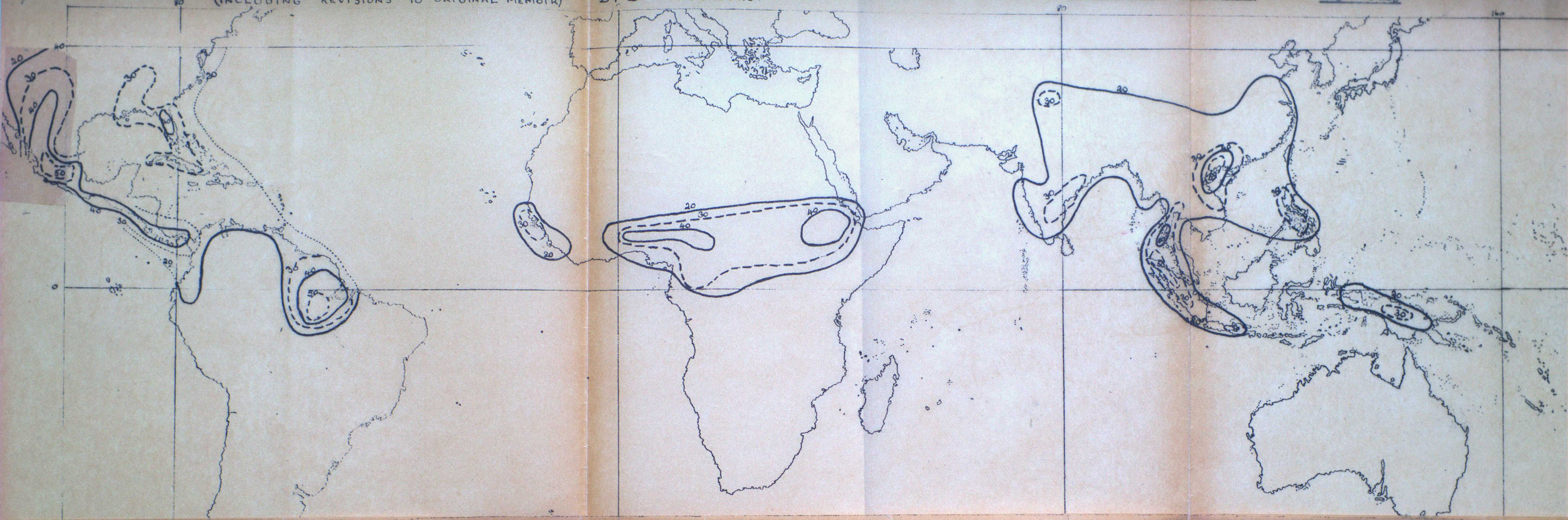
DAYS with THUNDER May - July



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DAYS with THUNDER August ---- October

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DAYS with THUNDER Nov - Jan

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DAYS with THUNDER
Feb - April