CORRELATION IN SEASONAL VARIATIONS OF WEATHER, VIII.

A PRELIMINARY STUDY OF WORLD-WEATHER

BY

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INTRODUCTION.

The relations between weather over the earth are so complex that it seems useless to try to derive them from theoretical considerations; and the only hope at present is that of ascertaining the facts and of arranging them in such a way that interpretation shall be possible. I have therefore in the following paper attempted a preliminary and systematic survey of the field, by selecting seventeen 'centres' which seemed fairly representative, and working out the correlation coefficients between their departures, both simultaneous and when separated in time by intervals, usually of six months.

The previous workers to whom I owe most are H. H. Hildebrandsson, F. M. Exner, C. Braak, Sir Norman and Dr. Lockyer, B. Helland-Hansen and F. Nansen, and R. C. Mossman; and a list of those of their works to which references will be made is given below: an excellent bibliography will be found in pp. 262-267 of Helland-Hansen and Nansen's book.

H. H. Hildebrandsson.—'Quelques recherches sur les centres d'action de l'atmosphère,' K. Sv. Vet. Akad. Hand. Band 29, No. 3, Stockholm, 1897.

II.—La pluie. Band 32, No. 4, 1899.

III.—Sur la compensation entre les types des saisons simultanés en différentes régions de la terre. Band 45, No. 2, 1909.

IV.—Sur la compensation entre les types des saisons simultanés en différentes régions de la terre (Suite). Band 45, No. 11, 1910.

V.—Fin. Band 51, No. 8, 1914.

These will be subsequently referred to as H 1, H 2, H 3, H 4 and H 5.

F. M. Exner.—'Ueber monatliche Witterungsanomalien auf der nördlichen Erdhälfte im Winter,' Sitz. d. k. Akad. d. Wiss. in Wien. Bd. CXXII, Abt. IIa, Juni, 1913.

C. Braak.—'Atmospheric variations of short and long duration in the Malay archipelago and neighbouring regions, and the possibility to forecast them.' Kon. Mag. en Met. Obs. te Batavia, Verh. 5, 1919.

Sir Norman and Dr. Lockyer.—'On some phenomena which suggest a short period of solar and meteorological changes,' Proc. Roy. Soc. Vol. LXX, pp. 500-4, 1902.

'Monthly mean values of barometric pressure,' Solar Physics Committee, London, 1908.

B. Helland-Hansen and F. Nansen.—'Temperatur-schwankungen des Nordatlantischen Ozeans und in der Atmosphäre,' Kristiania, 1917.

R. C. Mossman.—'Southern hemisphere seasonal correlations,' Symons' Meteorological Magazine, Vol. 48, 1913.

Also 'On Indian monsoon rainfall in relation to S. American weather, 1875-1914,' in Vol. XXIII, Part 6 of these memoirs.

2. The first chapter is devoted to the effect of the sun, and I think it is clear that it plays a subsidiary part as a control of weather. The unit of time that has usually been adopted is the month or the year. The latter is clearly unsuitable for the present purpose since relations may be entirely different at different seasons:* but those who have adopted the month have, in view of the considerable irregularities, almost invariably smoothed their data over six or twelve months and thereby run serious risks of being led to wrong conclusions. I have, I think, avoided the main difficulties by working with seasonal values, dividing the year into Dec—Feb, March—May, June—Aug and Sep—Nov. A relationship which holds for one month will in general, by the principle of continuity, hold, to a limited extent at least, during the months before and after; and if the preliminary study of quarterly values brings out relationships of importance there will be no waste of labour in working out monthly values.

3. In the next chapter I have selected a number of 'centres of action' including several areas such as the Indian Peninsula, whose rainfall exercises a more powerful control than some of the places near the hearts of areas of high or low pressure to which the title 'centre of action' was applied by Teisserenc de Bort. I have in this chapter attempted to collect such of the main facts as are brought out by an examination of the relationships of the summer and winter values of pressure or rainfall. These two seasons are probably in general decisive of the character of the year, but it is desirable to examine the data of spring and autumn and this work is now in hand.

4. In chapter III the effect of temperature is briefly discussed, and the conclusion is reached that the variations of temperature are in general governed by those of pressure and rain; and hence with the possible exception of the Atlantic Ocean, a large and much

* Thus the data of the years '79—'15 give a corr. coeff. between pressure in India and at Batavia of +·93 for the quarter Dec—Feb; but for June—Aug it is —·06.

discussed field upon which I have not entered, and the Antarctic region, for which the data are insufficient, it is not as yet necessary to add temperature centres to those of pressure and rain.

5. In chapter IV I have attempted to piece together the facts of chapter II into a more coherent whole. I noticed some ten years ago that a chart of earth-pressure showing those regions of which high and low pressure were favourable to Indian monsoon rainfall was very largely similar to a chart showing the areas where pressure rose or fell with the number of sunspots: but in this chapter I have, I think, established that the latter chart is identical (within the limits of error) with that giving the natural swayings of pressure when the atmosphere is not disturbed by external influences.

I would acknowledge my obligations to Mr. V. Doraiswamy Iyer for his conscientious supervision of the computing involved.

6. I would like to emphasize here the desirability of publishing the results of all examinations of relationships, not merely those which prove to be close: one reason is that until feeble relationships are put on record they will be examined to no purpose by every worker interested in that part of the subject; and another reason is that unless we know that all results are published we do not know how great is the significance of the relationships found. If an investigator works out the correlation coefficients between the contemporary pressures of two places for each of the twelve months and has 45 years' data at his disposal, the probable error of one coefficient selected at random is ·10, but the probable error of the biggest of the twelve, selected because it is the biggest, is ·28*; so if I know that the May coefficient is the largest of the twelve and is ·35 I attach little importance to it; but if I know that he has merely worked out the values for May, there is a high probability that ·35 expresses a physical relationship.

7. I hope shortly to publish a paper containing the application of these new facts to the forecasting of the monsoon and the winter rains. It appears that the character of the coming monsoon in the Peninsula may now be about as well estimated in the first week of February as it was recently in the first week of June; and it would be of great value to India if a reliable anticipation of the general character of the rains could be made available when the financial schemes for the year are being prepared.

I have habitually used abbreviations for the names of months and for the words "pressure," "temperature" and "correlation coefficient" in view of the extreme frequency with which they occur in this paper.

CHAPTER I.

(*a*) Sunspots and pressure.

8. The relationships between the annual numbers of sunspots and press. for 93 stations widely distributed over the earth have been given in Vol. XXI, Part XII of these memoirs; and it was pointed out there that although the results were on the

* See Vol. XXI, Part 9 of these memoirs, p. 15.

whole somewhat favourable to the view that numerous spots were associated with greater solar radiation and more vigorous development of the areas of high and low press., yet the handling of the question must be unsatisfactory unless the data for summer and winter were separately calculated. The coeffs. with annual sunspot numbers of some examples of these seasonal pressures are :—

—	Dec—Feb	June—Aug
Stykkisholm ('74—'18)	+·10	—·06
Central Siberia* ('76—'08)	—·04	—·13
Petrograd ('52—'05)	+·21	+·04
Ponta Delgada ('66—'21)	·00	—·01
Honolulu ('84—'19)	—·06	+·30
India ('56—'11)	—·24	—·02
Port Darwin ('83—'21)	—·21	—·25
Mauritius ('76—'21)	—·09	—·15
South America† ('65—'21)	—·02	+·21

For central Siberia the values for spring and autumn are +·16 and +·09. The only significant coeffs. are those of Port Darwin in summer and winter, of winter in India, Petrograd and South America, and of summer at Honolulu. Now Port Darwin is near the centre of a low press. region in summer and increase of solar radiation might send press. down, but the cause of —·25 in winter is not so clear. We might expect an influence of increased circulation on the high press. in South America in winter when the high press. belt covers the region of 35°S; and, for Honolulu, the north Pacific high press. area is more fully developed in summer. The low press. in India as a part of the heated tropics might also be expected, though in summer rather than in winter. The variations of press. in Petrograd suggest a slight increase of circulation, but those of Siberia do not support this at all.

Using data from 1855—1906 the value of the coeff. of the annual spot number with the annual press. of India two years before is —·11, one before —·28, the same year —·36, one year after —·36, two after —·27 and three after —·06; thus the maximum effect of the spots is felt after a lag of about half a year. For the successive months the spot number of the year has relationships

J	F	M	A	M	J	J	A	S	O	N	D
—·31	—·30	—·16	—·12	—·14	—·06	—·07	+·13	—·35	—·26	—·10	—·07

* Central Siberia stands for the mean of Eniseisk and Irkutsk.
† South America is used as an abbreviation for ⅓ (Buenos Ayres + Cordoba + Santiago).

(b) Sunspots and temperature.

9. The corr. coeffs. between the annual sunspot numbers and the annual departures of temp. have been worked out for 102 representative stations scattered over the earth and the results were published in Vol. XXI, Part XI of these memoirs. In order to make discussion of the annual variations possible the mean monthly temps. of India and of Mauritius have been correlated with the annual sunspot numbers from 1875 to 1906.

—	J	F	M	A	M	J	J	A	S	O	N	D
India .	−·25	−·32	−·43	−·17	−·11	−·50	−·37	−·22	−·38	−·36	−·29	−·31
Mauritius	−·26	−·12	−·18	−·03	+·01	−·13	+·03	0	−·06	−·05	−·24	−·13

It will be noticed that in India the negative values are greatly reduced during the hot weather. With the annual temp. of India ('75—'21) the coeff. is −·50. For central Australia (Alice Springs and Charlotte Waters) between '79 and '11 the corr. coeff. of temp. in the dry period of winter (June—Aug) is +·22, while in summer (Dec—Feb) it is −·04.

(c) Sunspots and winds.

10. Inasmuch as spot activity expresses variations in the sun's heat radiation the winds should in general show a direct relationship with the number of spots. The most striking relationship of this kind that has been claimed is that of Meldrum, based on data of cyclones in the South Indian Ocean from 1847 to 1873: * I find that these show a coeff. of +·61 with spot numbers. Revised figures of cyclones between 50° and 70°E have been given by Claxton (see Washington M. W. R., Vol. 50, p. 293, 1922†) and for the period 1848 to 1873 yield only +·18 ±·13; from the cyclones for the period 1848 to 1902 as given by Claxton, together with those from 1903 to 1920 as derived from the Mauritius annual reports, I derive a coeff. of only +·02 ±·08; these figures appear fatal to Meldrum's theory. For cyclones in the South Indian Ocean between 70° and 100°E Schück's numbers from 1848 to 1909, as published by Visher in the same Review (p. 293), give a coeff. of +·37. The hurricanes in the South Pacific, 160°E to 140°W, from 1830 to 1921 (p. 289) give −·20; those in the South Pacific, 100° to 160°E, 1839—1921 (p. 290), give −·10; and those in the N. E. Pacific between Hawaii and Mexico, 1832—1921 (p. 295), give −·04. For cyclonic storms in the Arabian Sea and the Bay of Bengal from 1877 to 1921 I find +·06.

These results show that while there may perhaps be in some places a positive connection between the numbers of sunspots and of cyclones, there may be also a negative connection in others. I believe however that they afford no evidence whatever regarding the strength of ordinary winds; for in the Indian seas at any rate

* See British Association report for 1873, pp. 466—478.

† The data for '05, '08, '13 and '16 do not however agree with those of the annual reports, which I have followed.

cyclones are produced in periods of calm weather when the monsoon winds are temporarily weak, and the occurrence of cyclones shows unsteadiness not strength in the monsoon winds. For evidence as to the association of spot activity with increased vigour in the atmospheric circulation we have to take ordinary winds such as those of Scotland where Buchan* shows that the westerly circulation is stronger when spots are numerous, while E winds and calms are more frequent near minimum years. In India the effect is negligible: at Saugor Island, at the mouth of the Hughli, sunspot data from 1880 to 1903 give −·04 for the year, −·04 for Jan and Feb, −·01 for March to May, −·02 for July to Sep and +·02 for Oct to Dec: at Bombay the coeff. of annual mean wind velocity with the annual spot number from '66 to '11 is +·11, at Calcutta ('75—'11) it is −·26, and at Madras ('75—'11) it is +·02. For Zanzibar the relationship of annual spot numbers, '92—'21, with the wind strength from June to Sep is +·06, and for Seychelles ('94—'21) +·44. For St. Helena (25 years) the relations for the four quarters beginning with the summer (Dec—Feb) are −·40, −·11, −·02, −·06. At Colombo the relation with wind velocity, June to Aug, is +·04.

(*d*) Sunspots and cloud.

11. The relationships between the annual spot numbers and cloud in the different months in India from '75 to '06 are :—

J	F	M	A	M	J	J	A	S	O	N	D
+·03	+·12	+·15	−·20	−·13	+·34	+·23	−·07	+·25	+·04	+·14	·00

with the annual cloud the relationship is +·23. The contrast between the diminution of cloud in the hot weather (April and May) and the increase in the rains (June to Sep) calls to mind the contrast between the paucity of moisture of the sea winds of the hot weather and the abundance brought by those that have come from the South Indian Ocean during the south-west monsoon.

(*e*) Sunspots and rain.

12. The corr. coeffs. of the annual rainfall of 150 representative stations with sunspots were given in Vol. XXI, Part X of these memoirs. For the seasonal rainfalls of India the earliest relations were pointed out by Hill; but the data at his disposal were scanty. He rightly pointed out that the monsoon rainfall of northern India increased with the number of spots; but his conclusion,† that the rainfall of the cold weather in northern India and particularly in the United Provinces was decreased by an increase of spots, was erroneous. If we take his own figures for the percentage winter (Nov to April) rainfall of the United Provinces from 1845 to 1878 the relationship with sunspots is −·15 ±·11, but if we extend it to 1921 we find a negligible

* Journ. Scott. Metl. Soc., XII, p. 120, 1903.

† See Vol. I of these memoirs, pp. 192, 208.

coeff. of $-\cdot02 \pm\cdot08$. If however we take the precipitation of north west India a small positive coeff. results: thus the total rainfall of the plains in the United Provinces, Punjab, North-West Frontier Province, Sind, Rajputana and Gujarat from '75 to '21 for the period Jan to March yields a coeff. $+\cdot10 \pm\cdot10$, while the winter snowfall on the mountains of the region Baluchistan, North-West Frontier Province, Kashmir, Punjab and United Provinces, as derived from reports of district officers and actual snow measurements, yields over the same period a value $+\cdot07$.

The monthly rainfall over the whole plains of India ('75—'06) gave values :—

J	F	M	A	M	J	J	A	S	O	N	D
−·05	+·07	+·28	−·05	+·17	+·24	+·14	−·16	+·08	+·25	−·04	−·03

From Dec to March the value was $+\cdot17$; and for the monsoon (June—Sep) it was $+\cdot28$. For the whole year from '75 to '21 we find $+\cdot26$. By comparison with this the coeff. for the Nile floods from 1749 to 1903, excluding 1801 to 1824, was $+\cdot16$ and from 1849 to 1903 $+\cdot28$.

(*f*) **Discussion of the influence of sunspots.**

13. The tendencies associated with an abnormally large number of sunspots may be summarised as follows :—

(*a*) Annual press. is affected irregularly, that over some land and sea areas being increased and that over others diminished : on the whole over the eastern hemisphere we find a decrease and over the west an increase.

(*b*) Annual temp. is in general lowered, particularly in the tropics.

(*c*) The effect on winds is uncertain.

(*d*) On Indian cloud there is apparently a slight stimulation except in the hot weather April and May.

(*e*) Rainfall is affected irregularly, that over parts of a continent being increased and over other parts diminished : in general the relationships of sunspots with rain are opposed to those with press.

Now we may regard solar variations as affecting the weather of an area either immediately, or indirectly through setting up changes in the weather over a large region which will cause changes in the area in question. The second alternative will be discussed in chapter IV; if we consider the first alternative, of an immediate control, we naturally attempt to explain the tendencies associated with sunspots as due to one or more of the following causes :—

(1) An increase of sunspots indicates an increase of solar activity and so of insolation : this means more evaporation at sea and therefore more rainfall on land.

(2) An increase of solar activity will increase the general atmospheric circulation.

(3) An increase of sunspots will cause greater opacity to heat in the atmosphere through some agency not associated with rainfall.

Now (1) presupposes that although the temp. may fall inland owing to increased rainfall it must be higher at sea where the evaporation occurs: and this appears impossible in view of the distinct preponderance of negative coeffs. between sunspots and temp. on the islands contained in the former paper.*

Clearly (2) might give increased rainfall if the air had time to become saturated with moisture over the oceans: its main difficulty is that the press. centres of action show only a slight relationship with sunspots so that a marked effect on wind force is impossible; and such data of winds as are available do not show any appreciable effect. But the coeffs. with temp. in rainy regions in the tropics are in general considerable, and are too large to be accounted for by the cooling effect of the rain and cloud associated with sunspots. For example let us form for India the equation,

$$\left\{ \text{temp.} \right\} = a \left\{ \text{spots} \right\} + b \left\{ \text{rainfall} \right\},$$

where by putting a quantity in brackets we indicate that we consider its *proportionate* departure, *i.e.*, the ratio of the actual to the standard departure: then since the coeff. of temp. with spots is $-\cdot50$ and with rain is $-\cdot32$, while the coeff. of spots with rain is $+\cdot26$, we find $a = -\cdot45$ and $b = -\cdot20$. Thus when the effect of rainfall is eliminated we still have $-\cdot45$ instead of $-\cdot50$; and the puzzle of this marked negative relationship with temp. is unsolved. Also since the corr. coeff. between spots and cloud in India is only $+\cdot23$, the effect of this cannot explain $-\cdot50$ in temp.

The following are the tropical stations for which coeffs. of temp. and of rainfall with spots are given in Parts X, XI of Vol. XXI of these memoirs: the first coeff. is that with temp. and that in brackets is with rainfall; and the association with rainfall will in no case explain temp. coeffs. more marked than $-\cdot10$:—

Bahia $-\cdot29$ ($+\cdot31$), Batavia $-\cdot40$ ($+\cdot24$), Colombo $-\cdot18$ ($-\cdot24$), Honolulu $-\cdot20$ ($-\cdot17$), Madras $-\cdot20$ ($+\cdot19$), Manila 0 ($-\cdot18$), Newcastle (Jamaica) $-\cdot38$ ($-\cdot35$), Para $-\cdot25$ (0), Port Darwin $+\cdot03$ ($+\cdot03$), Mauritius $-\cdot07$ ($+\cdot07$), Recife $-\cdot45$ ($+\cdot26$), Rio de Janeiro $-\cdot25$ ($-\cdot01$), St. Helena $-\cdot17$ ($+\cdot14$), Seychelles $+\cdot10$ ($-\cdot25$), Sierra Leone $-\cdot16$ ($-\cdot14$), Zanzibar $-\cdot22$ ($-\cdot15$).

* Vol. XXI, Part XI of these memoirs. Compare Helland-Hansen and Nansen, Temperatur-schwankungen, p. 175, 1917.

In order to test (3), the hypothesis of increased opacity at times of numerous spots, I have examined the daily range at Colombo and at Lahore, as tropical stations with a marine and a continental climate. For Colombo ('75—'21) the corr. coeffs. with sunspots for the four seasons are :—

—	D—F	M—M	J—A	S—N
Mean temp.	—·31	—·33	—·18	—·29
Daily range	—·18	—·29	—·33	—·34

For Lahore ('75—'21) we find :—

—	D—F	M—M	J—A	S—N
Mean temp.	—·14	—·11	—·03	—·12
Daily range	—·12	—·18	—·22	—·17

The data extend over 46 years, but as the probable error in a coeff. is ·1 some caution is necessary. It will be seen that the relationships with the daily range are as marked as those with mean temp. at Colombo, and more marked at Lahore where the mean of the four quarterly coeffs. is —·10 for mean temp. and —·17 for daily range. On taking into account the standard departures this suggests that while sunspots produce an appreciable lowering of the maximum temp. the effect on the minimum is insignificant except for the period J—A. Now as we have a corr. coeff. of +·64* between spots and the solar constant a diminution of the daily range is as big a paradox as the lowering of the mean temp. : and in both cases the natural explanation lies in an increase of opacity other than that caused by rain or cloud. Since the estimation of the solar activity by means of spot numbers involves confusion between results due to increase of radiation and increase of opacity it is desirable now to make use of measures of the solar constant in spite of the small amount of data available.

(*g*) Solar radiation.

14. Through the kindness of Mr. C. G. Abbot reliable values of the solar constants made at Mt. Wilson, mainly during the summer months, for 15 recent years ('05, '06 and '08—'20) are available. The first use made of them was to ascertain that their corr. coeffs. with the temp. and rainfall of India during the monsoon period are each +·2 with a probable error as large as +·18. For monsoon rain in the

* See the next paragraph.

Peninsula the corr. coeff. is $+\cdot 2$ and in north west India $+\cdot 15$. If now we form for India the equation

$$\left\{ \text{temp.} \right\} = a \left\{ \text{solar constant} \right\} + b \left\{ \text{rainfall} \right\},$$

and note that the corr. coeff. for these years between temp. and rainfall is $-\cdot 75$ we find that

$$\left\{ \text{temp.} \right\} = +\cdot 35 \left\{ \text{solar constant} \right\} - \cdot 8 \left\{ \text{rainfall} \right\}$$

If instead of $-\cdot 75$ we take the coeff. $-\cdot 32$ between temp. and rainfall given by the longer period we find

$$\left\{ \text{temp.} \right\} = +\cdot 25 \left\{ \text{solar constant} \right\} - \cdot 35 \left\{ \text{rainfall} \right\}$$

Thus apart from rainfall the solar constant has a corr. coeff. of about $+\cdot 30$ with temp., and if future data confirm this result the main theoretical difficulty, as far as solar influences on India are concerned, will disappear. There is of course no real contradiction in the temp. of India having a positive corr. coeff. with the solar constant and a negative one with the spot number; for the corr. coeff. between the solar constant for the period June to Aug and the annual spot number is only $+\cdot 56$ for the 15 years, and if the mean of the monthly spot numbers of the period June to Aug is taken the coeff. is $+\cdot 64$.

During the period June—Aug the corr. coeffs. of the solar constant with pressures and temps. at representative centres of action are :—

——	No. of years.	Press.	Temp.
Iceland	14	−·05	+·1 (Grimsey)
C. Siberia	9	−·25	0
Azores	15	−·1	+·15
Honolulu	15	−·1	+·35
India	15	−·3	+·2
Australia	15	+·25	−·05*
Mauritius	15	−·2	+·25
South America	15	−·1	+·6†

For the relationships with the winds we have from June to Sep at Seychelles $+\cdot 2$; and for the quarter June to Aug at Colombo 0, at St. Helena $-\cdot 2$, at Valentia $-\cdot 25$ and at Honolulu $-\cdot 15$. For relationships with rainfall I have chosen

* This is with the mean of Alice Springs and Charlotte Waters.
† This is with Santiago alone.

places whose rainfall mostly occurs during the quarter June to Aug; for rainfall during this quarter at Perth (W. Australia) we have with the solar constant a corr. coeff. of −·2, at Cape Town +·35, at Valdivia +·05, and with the Indian monsoon +·2.

15. It remains to compare the effect of the solar constant on the daily range with that of sunspots, the season being June to Aug for which solar constant data are available. The relationships with maximum and minimum temps. for a marine and a continental station are:—

—	Colombo.		Lahore.	
	Max.	Min.	Max.	Min.
Solar constant	0	+·4	0	+·2
Sunspots	−·3	+·5	0	+·1

The effect on temp. of local rainfall is:—

—	Colombo.		Lahore.	
	Max.	Min.	Max.	Min.
Local rainfall	−·3	−·5	−·8	−·5

while the corr. coeffs. of the local rain with the solar constant and sunspots are:—

—	Colombo.	Lahore.
Solar constant	−·2	0
Sunspots	−·3	0

Hence we can deduce for the separate effects of the solar constant and of rainfall on Colombo:—

$$\left\{\text{Max. temp.}\right\} = -\cdot 1\left\{\text{sol. const.}\right\} - \cdot 3\left\{\text{rain}\right\}$$

$$\left\{\text{Min. temp.}\right\} = +\cdot 3\left\{\text{sol. const.}\right\} - \cdot 4\left\{\text{rain}\right\}$$

and for the effects of spots and rain,

$$\{\text{Max. temp.}\} = -\cdot4\{\text{spots}\} -\cdot4\{\text{rain}\}$$

$$\{\text{Min. temp.}\} = +\cdot4\{\text{spots}\} -\cdot4\{\text{rain}\}$$

Similarly for Lahore

$$\{\text{Max. temp.}\} = 0\{\text{sol. const.}\} -\cdot8\{\text{rain}\}$$

$$\{\text{Min. temp.}\} = +\cdot2\{\text{sol. const.}\} -\cdot5\{\text{rain}\}$$

$$\{\text{Max. temp.}\} = 0\{\text{spots}\} -\cdot8\{\text{rain}\}$$

$$\{\text{Min. temp.}\} = +\cdot1\{\text{spots}\} -\cdot5\{\text{rain}\}$$

After eliminating the rainfall effect the table thus is :—

——	Colombo.		Lahore.	
	Max.	Min.	Max.	Min.
Solar constant	−·1	+·3	0	+·2
Spot number	−·4	+·4	0	+·1

The results of this table have to be treated with much caution since the probable error of the small coeffs. is about ·2. But two deductions are suggested :—(*a*) the effect on the daily range of the opacity effect associated with sunspots is greater in the marine than in the continental station ;* and (*b*) there appears to be some opacity effect with the solar constant although less than with the spot number ; but the effect is not large enough by comparison with the probable error to give any certainty.

In order to see how far these features apply to other places I give the corr. coeffs. of the constant and the spot number with max. and min. temps. at Mauritius as a marine station, and Denver and Alice Springs as continental. I have not eliminated

* I have verified that this diminution in the daily range is not due to increase of wind, for the corr. coeff. of Colombo wind velocity with sunspots and with the solar constant is less than ·05.

the effect of rainfall on these coeffs. since its effect at Colombo and Lahore is not more than half the probable error.

—	Mauritius.		Denver.		Alice Springs.	
	Max.	Min.	Max.	Min.	Max.	Min.
Solar constant . . .	+·3	+·4	−·3	0	−·2	−·2
Spot number	−·1	−·1	−·1	+·1	−·1	+·1

There is here some support for (*a*) and (*b*) above, but it is doubtful whether satisfactory conclusions can be reached until we have more data.

16. In general it appears that for explaining the weather abnormalities of the seasons the variations of the solar radiation are inadequate, and we must seek the reasons in the previous distribution of seasonal features over the earth. In this conclusion we disagree with the widely prevailing idea that such abnormalities are an immediate consequence of changes in the heat given out by the sun. As a definite example I know of nothing in solar physics to explain without reference to previous terrestrial conditions the contrast between the biggest Indian monsoon on record in 1917 and the monsoon in 1918 that has only been surpassed in scantiness twice in the last sixty years.

17. However although the sun's radiation does not dominate seasonal variations, Mr. Clayton's announcement of immediate effects of changes in solar radiation on temp. in Argentina* suggests great possibilities in variations from day to day: and I have therefore looked for similar effects in India. Taking the months of June in 1909, 10, 11 it appears that for Multan, where the mean cloud is only 0·7/10 the vapour tension being ·723″, the relationship of the solar radiation constant at Mount Wilson with the mean air temp. of the same day is −·09, and 8 days later −·15: if clear days alone are considered the values are +·02 and −·31.

For Leh, where the altitude of 11,000 feet might be expected to give a less disappointing result, the normal vapour tension in June is only ·171″, the mean cloud being 3·9/10, but the coeffs. are still small: taking all days we have +·04 for the same day and +·02 for 8 days later, while clear days only yield +·09 for the same day and −·02 for 8 days later. Perhaps the success in the Argentine is due to its anticyclonic conditions in the high press. belt and probably drier air over a considerable range of height.

* "Nature," July 29, 1920, p. 673.

CHAPTER II.

Relationships between centres of action.

18. The centres hitherto accepted have been those in the heart of regions of high or low press., whether permanent like the Azores or seasonal, such as the winter high press. of Asia in central Siberia and its summer low press. in north west India. To these must be added places whose rainfall, wind or temp. is found to be an important control, such as the Oct—Feb rainfall of Java, and, perhaps, the June—Aug temps. in the region of the North Cape and the South Orkneys.

The press. centres that we shall examine here are:—

(*a*) the N. Atlantic or Iceland low (Stykkisholm, '75—'21*),

(*b*) the N. Pacific or Alaska low (Juneau, Atlin, Sitka, '82—'87, '06—'15, '17—'20),

(*c*) the central Siberian winter high (Irkutsk+Eniseisk, '76—'15),

(*d*) the N. Atlantic high (P. Delgada, '75—'21, and Charleston, '75—'19),

(*e*) the N. Pacific high (Honolulu, '83—'20),

(*f*) the Asian summer low (Lahore+Karachi, '75—'21),

(*g*) the January equatorial low (Port Darwin, '82—'21),

(*h*) the Indian Ocean high (Mauritius, '75—'21),

(*i*) the S. Atlantic high (St. Helena, '93—'21),

(*j*) the S. tropical Pacific (Apia, Samoa, '90—'10),

(*k*) the Australian winter high (Brisbane+Adelaide+Alice Springs, '76—'21),

(*l*) the S. Africa high (Cape Town, '75—'21),

(*m*) the S. America high (Buenos Ayres, Cordoba and Santiago, '75—'21),

(*n*) the southern low (Laurie Island, S. Orkneys, '03—'16).

Among the precipitation centres are:—

(*o*) the Indian Peninsula,† June—Sep ('75—'21),

(*p*) Java, Oct—Feb ('80—'21),

(*q*) the rainfall of Rhodesia, Oct—March ('00—'22),

(*r*) Zanzibar district, May ('92—'21),

(*s*) Seychelles, May ('92—'21),

(*t*) the western Himalayas and mountain region to their west, with their snowfall accumulation at the end of May ('76—'22).

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* The years given are those of the data used in this analysis.

† By this area is meant Gujarat, the Central Provinces, Konkan, Bombay Deccan, Hyderabad and Madras Coast North.

19. The relationships of (*a*) Iceland press. in winter and summer with conditions in the same quarter of the year, and those six months before and after are :—

ICELAND PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before Icel. J—A	Contemporary. D—F	2 qrs. after Icel. J—A	2 qrs. before Icel. D—F	Contemporary. J—A	2 qrs. after Icel. D—F
Iceland	+·06	+1·00	+·07	+·07	+1·00	+·06
Alaska	+·26	− ·18	0	+·20	+ ·55	+·06
C. Siberia	+·25	+ ·34	+·14	+·19	+ ·22	+·02
Azores	−·07	− ·54	+·02	−·05	− ·49	+·13
Charleston	+·08	− ·33	−·11	−·19	− ·02	−·07
Honolulu	+·02	− ·19	−·07	−·04	− ·34	−·01
N. W. India	−·06	+ ·05	+·04	+·07	+ ·14	+·12
Port Darwin	−·13	+ ·06	+·01	+·12	+ ·23	+·27
Mauritius	+·01	+ ·26	+·05	+·10	− ·29	−·09
St. Helena	−·14	+ ·07	−·02	+·10	− ·13	−·06
Samoa	−·17	− ·13	−·17	−·07	− ·09	−·17
S. E. Australia	−·26	+ ·09	+·13	−·07	− ·11	+·06
Cape Town	−·19	− ·10	+·08	+·01	− ·09	+·03
S. America	−·20	+ ·19	+·04	−·01	− ·05	+·06
S. Orkneys	+·67	− ·14	+·04	−·01	+ ·09	+·14
Rain.						
Peninsula	+·03	...	− ·10	...	+·03	...
Java	...	+ ·26	...	+·19	...	−·04

That press. in Iceland is opposed to press. in the Azores is well known; it is also opposed in winter and summer to that of the corresponding area in the Pacific represented by Honolulu; and it moves in sympathy with Siberia and Mauritius in the north-winter months; in the north-summer it is opposed to Mauritius. In Hildebrandsson's third paper (§4, p. 7) he indicates that he had previously found opposition between Iceland and Siberia, but I cannot trace his evidence for this. During May, 1902-1911, Mossman finds* −·90 ±·12 between press. at Stykkisholm and Laurie Island; when extended to 1916 this becomes −·59 ±·11: for April and June I find +·04 and −·03 respectively; and it seems very unlikely that such discontinuity in the values of consecutive months will be maintained by future data.

* Symons' Metl. Mag., Vol. 48, p. 44 (1914).

20. For Alaska data are available for Fort St. Michael ('75—'84) from Hildebrandsson's 1897 memoir, and for Sitka ('82—'87), Atlin ('06—'15) and Juneau ('17—'20) from official publications: for the first three stations the corr. coeffs. in winter (D—F) are as follows:—

——	Ft. St. Michael.	Sitka.	Atlin.
Iceland	+·03	+·05	+·24
Honolulu	...	−·94	−·64
Siberia	−·80	+·17	+·17

The probable errors are large and the Siberian results throw grave doubt on the reliability of the Ft. St. Michael data. I have thought it advisable to combine the departures for Sitka, Atlin and Juneau as if they referred to the same station; and have thus found for Alaska the coeffs. of the following table:—

ALASKA PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before Alaska. J—A	Contemporary. D—F	2 qrs. after Alaska. J—A	2 qrs. before Alaska. D—F	Contemporary. J—A	2 qrs. after Alaska. D—F
Iceland	+·06	−·18	+·20	0	+·55	+·26
Alaska	+·04	+1·00	−·02	−·02	+1·00	+·04
C. Siberia	−·27	+·18	+·32	+·44	+·27	−·24
Azores	+·09	+·24	−·47	−·13	−·33	−·28
Charleston	0	+·35	−·27	+·02	+·18	−·14
Honolulu	+·23	−·71	−·12	−·03	−·28	−·15
N. W. India	−·28	−·08	−·05	+·03	−·21	+·24
Port Darwin	−·12	−·25	−·23	−·12	+·25	+·18
Mauritius	−·27	+·08	−·21	0	+·22	−·24
St. Helena	+·30	−·23	+·09	−·05	−·10	−·47
Samoa	+·38	−·18	−·23	+·09	−·36	−·36
S. E. Australia	−·04	−·13	−·51	−·33	+·06	+·06
Cape Town	−·18	−·51	+·04	−·01	−·03	+·15
S. America	+·04	−·09	−·03	−·34	−·07	−·05
S. Orkneys	−·01	−·47	+·36	−·09	−·42	+·51
Rain.						
Peninsula	+·51	...	−·38	...	−·11	...
Java	...	+·33	...	+·05	...	−·08

Attention is drawn in 'Weather forecasting in the United States' (1916, p. 344) (reviewed in Met. Zeit. 1922, p. 251) to an opposition between Honolulu and Alaska; but the statement there made that Siberia and the southern Alaska coast show an inversion is not confirmed in the table; and while Alaska and Iceland generally show departures of the same sign, as claimed, in summer, they do not appear to do so in winter. With the South American high press. belt there is no contemporary relationship; but with the South Orkneys Alaska has, both in summer and winter, a marked negative relationship which becomes positive after two quarters.

21. For Irkutsk and Eniseisk, which in winter represent the Asian high press. area, we have

CENTRAL SIBERIA PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before C. Sib. J—A	Contemporary. D—F	2 qrs. after C. Sib. J—A	2 qrs. before C. Sib. D—F	Contemporary. J—A	2 qrs. after C. Sib. D—F
Iceland	+·02	+·34	+·19	+·14	+·22	+·25
Alaska	—·24	+·18	+·44	+·32	+·27	—·27
C. Siberia	+·37	+1·00	+·16	+·16	+1·00	+·37
Azores	—·03	—·03	—·29	—·12	—·27	—·06
Charleston	—·16	—·29	—·19	—·03	—·26	—·36
Honolulu	—·09	—·29	+·07	—·39	—·16	—·20
N. W. India	+·37	+·01	+·36	+·13	+·37	+·07
Port Darwin	—·08	—·07	—·40	—·37	—·07	+·10
Mauritius	+·26	+·28	—·05	+·21	+·09	+·02
St. Helena	+·14	+·12	—·03	—·06	—·22	+·17
Samoa	—·15	+·02	+·11	+·03	—·31	—·24
S. E. Australia	+ 24	+·02	—·23	—·11	+·12	+·20
Cape Town	+·04	+·01	+·04	0	—·27	+·33
S. America	—·17	—·04	+·25	—·03	—·31	—·03
S. Orkneys	—·02	—·24	+·30	—·65	—·02	+·51
Rain.						
Peninsula	—·05	...	+·24	...	—·33	...
Java	...	—·15	...	+·35	...	—·10

It is noteworthy that Siberia's sympathy with the low press. areas of Iceland and Alaska and its opposition to the high press. region of Charleston are shown in winter as much as in summer; and the relations of a low press. region are suggested even in winter.

With too scanty materials at his disposal Blanford was misled into postulating a negative relationship between Siberia and India*: the corr. coeff. between the annual

* Report on the Meteorology of India, 1878, p. 2.

pressures ('76—'03) is +·16 : while between the pressures of C. Siberia and N. W. India ('76—'15) for D—F it is +·01 and J—A +·37.

The coeff. of —·37 with Seychelles rain of the succeeding May is surprising as the coeff. with Mauritius autumn press. is only +·03. I find that the coeff. with Seychelles press. in May is —·09, which throws no light on the difficulty.

It might be thought that the press. difference Azores *minus* Iceland might have a closer corr. with Siberia than either Azores or Iceland; but it is not so, the coeff. being —·25.

With the J—S monsoon rainfall of N. W. India* C. Siberia has during the contemporary quarter J—A a coeff. of —·52 : this suggests a dominating influence, but other centres exercise considerable control. Reference to the table of coeffs. with Peninsula rainfall (§ 34 below) shows five between ·40 and ·55, that with Siberia being only —·33.

22. With press. at the Azores in summer and in winter the relations are :—

AZORES PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before Azores. J—A	Contemporary. D—F	2 qrs. after Azores. J—A	2 qrs. before Azores. D—F	Contemporary. J—A	2 qrs. after Azores. D—F
Iceland	+·13	—·54	—·05	+·02	—·49	—·07
Alaska	—·28	+·24	—·13	—·47	—·33	+·09
C. Siberia	—·06	—·03	—·12	—·29	—·27	—·03
Azores	+·17	+1·00	—·01	—·01	+1·00	+·17
Charleston	—·11	+·35	+·01	+·13	+·25	—·04
Honolulu	—·09	+·15	+·07	+·21	+·20	+·15
N. W. India	+·07	—·02	—·10	—·03	—·26	+·03
Port Darwin	+·12	—·07	—·19	+·15	—·08	—·08
Mauritius	+·08	—·04	—·25	—·01	+·11	+·06
St. Helena	+·03	+·27	—·12	—·01	+·22	+·04
Samoa	+·18	—·08	+·15	+·11	+·34	—·04
S. E. Australia	+·19	+·10	—·33	+·27	—·05	—·04
Cape Town	+·05	+·09	0	—·09	+·03	—·18
S. America	+·04	+·05	+·38	+·06	+·17	—·04
S. Orkneys	—·04	—·57	+·19	+·36	—·14	+·16
Rain.						
Peninsula	—·06	...	+·21	...	+·10	...
Java	...	—·15	...	—·18	...	—·03

* The areas included are United Provinces West, Punjab, Kashmir, N. W. F. Province and Rajputana.

It is interesting that the variations of press. in the S. Atlantic seem to resemble those in the N. Atlantic: with the high press. belt of S. America the Azores have a small positive relationship and with the low press. region of the S. Orkneys a marked opposition D—F.

Between press. at the Azores and rain at St. Helena (Oct—Mar) an opposition was found by Hildebrandsson* during the years '90—'07: this is in accordance with the relationship of +·27 between their pressures D—F. As however Nov—Jan is the driest period, I examined the relationship between the Azores D—F and rain at St. Helena of M—M following; the coeff. is only +·11.

The similarity between pressures at the Azores and Hawaii, which is pointed out in 'Weather forecasting in the United States' p. 344, is shown in winter and summer, but is not close.

23. The relationships of Charleston are:—

CHARLESTON PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before Charl. J—A	Contemporary. D—F	2 qrs. after Charl. J—A	2 qrs. before Charl. D—F	Contemporary. J—A	2 qrs. after Charl. D—F
Iceland	—·07	—·33	—·19	—·11	—·02	+·08
Alaska	—·14	+·35	+·02	—·27	+·18	0
C. Siberia	—·36	—·29	—·03	—·19	—·26	—·16
Azores	—·04	+·35	+·13	+·01	+·25	—·11
Charleston	—·11	+1·00	+·17	+·17	+1·00	—·11
Honolulu	+·30	—·20	+·10	+·21	—·08	+·09
N. W. India	—·02	—·52	—·31	—·14	—·51	+·24
Port Darwin	—·31	—·52	—·23	+·04	+·12	+·25
Mauritius	—·01	—·12	+·06	—·21	+·09	—·06
St. Helena	+·03	—·15	+·09	—·09	+·49	—·35
Samoa	+·20	+·28	0	+·32	—·22	—·09
S. E. Australia	—·23	—·30	—·21	—·04	—·12	+·11
Cape Town	+·07	—·25	+·17	—·10	—·16	+·02
S. America	+·21	—·08	+·08	+·06	+·04	+·45
S. Orkneys	—·25	—·51	+·32	+·25	+·11	+·04
Rain.						
Peninsula	+·21	...	—·09	...	+·01	...
Java	...	+·20	...	—·10	...	+·06

* H 3, p. 10. In his text it is erroneously stated that the pressure at St. Helena is involved: see Fig. 11, plate 4.

The opposition between the high press. belt of N. America, as represented by Charleston, in winter and contemporary press. in India and Australia is based on 37 years' data and is strong; as we shall see it is more marked than the well known opposition during June to Aug between the high press. belt of S. America and the countries bordering the Indian Ocean.

As we should expect there is in winter, when the Iceland low is most strongly developed, an opposition between it and Charleston: but between Alaska and Charleston the coeff. is +·35, while a negative value might have been expected.

Like the Azores Charleston has during D—F a big negative coeff. with the S. Atlantic low at the S. Orkneys.

24. With press. at Honolulu we find:—

HONOLULU PRESS.

	Dec to Feb			June to Aug		
	2 qrs. before Honol. J—A	Contemporary. D—F	2 qrs. after Honol. J—A	2 qrs. before Honol. D—F	Contemporary. J—A	2 qrs. after Honol. D—F
Press.						
Iceland	—·01	—·19	—·04	—·07	—·34	+·02
Alaska	—·15	—·71	—·03	—·12	—·28	+·23
C. Siberia	—·20	—·29	—·39	+·07	—·16	—·09
Azores	+·15	+·15	+·21	+·07	+·20	—·09
Charleston	+·09	—·20	+·21	+·10	—·08	+·30
Honolulu	—·17	+1·00	+·13	+·13	+1·00	—·17
N. W. India	+·08	+·13	+·13	—·27	0	—·30
Port Darwin	+·46	+·39	+·11	—·33	—·67	—·64
Mauritius	+·30	—·25	—·18	—·31	—·22	—·10
St. Helena	+·04	+·12	+·08	—·12	—·12	—·40
Samoa	+·08	+·19	+·03	+·45	+·73	+·50
S. E. Australia	+·28	+·33	+·21	—·25	—·28	—·54
Cape Town	+·16	+·29	0	—·29	—·07	—·43
S. America	+·12	+·07	+·19	—·01	+·52	—·05
S. Orkneys	+·01	+·37	—·46	+·16	—·07	—·01
Rain.						
Peninsula	—·42	...	+·23	...	+·46	...
Java	...	—·32	...	—·14	...	+·41

Representing as Honolulu and Samoa do an enormous expanse of ocean under fairly uniform conditions, it is natural that they should exert a more effective and wide-spread control than any other centre of action over the general weather distribution: but until these tables had been worked out it seemed that S. America would occupy the chief place. In fact however while S. America has five contemporary coeffs. exceeding ·35 Honolulu has seven and Samoa thirteen; it is singular that while these relationships with S. America and Honolulu occur almost entirely in the quarter J—A those at Samoa, not very distant from Honolulu, occur as often D—F as J—A. It is also curious that Honolulu press. D—F should have positive coeffs. with Port Darwin and S. E. Australia at that time and two quarters before and after, while the J—A press. should have all negative coeffs.

25. With N. W. India the relationships are:—

N. W. INDIA PRESS.

	DEC TO FEB			JUNE TO AUG		
Press.	2 qrs. before N. W. Ind. J—A	Contemporary. D—F	2 qrs. after N. W. Ind. J—A	2 qrs. before N. W. Ind. D—F	Contemporary. J—A	2 qrs. after N. W. Ind. D—F
Iceland	+·12	+·05	+·07	+·04	+·14	—·06
Alaska	+·24	—·08	+·03	—·05	—·21	—·28
C. Siberia	+·07	+·01	+·13	+·36	+·37	+·37
Azores	+·03	—·02	—·03	—·10	—·26	+·07
Charleston	+·24	—·52	—·14	—·31	—·51	—·02
Honolulu	—·30	+·13	—·27	+·13	0	+·08
N. W. India	+·05	+1·00	+·20	+·20	+1·00	+·05
Port Darwin	+·45	+·67	+·49	+·05	+·03	—·06
Mauritius	+·27	+·21	—·01	+·12	+·23	+·20
St. Helena	+·22	—·12	—·07	—·07	—·14	+·04
Samoa	—·11	—·39	—·18	—·01	+·18	+·12
S. E. Australia	+·39	+·47	+·33	+·06	+·27	+·05
Cape Town	+·05	+·56	+·07	+·17	+·17	+·27
S. America	—·46	+·20	—·14	+·04	—·25	—·20
S. Orkneys	+·02	—·01	—·45	—·25	—·17	+·31
Rain.						
Peninsula	—·16	...	—·03	...	—·11	...
Java	...	—·32	...	+·10	...	—·16

The corr. coeff. of N. W. India, J—A, with press. at Jacobshavn in the same quarter is +·14 and two quarters later —·01, with Vardo these coeffs. are —·19 and —·20, with Tashkend +·16 and —·01, with Manila +·15 and +·09, with Batavia +·27 and +·03, and with Punta Arenas —·41 and —·05. In support of the contention that a place is not an influential 'centre of action' merely because it is at a maximum or minimum of press., it may be pointed out that for J—A, when N. W. India covers the minimum of the Asiatic low, the only coeff. exceeding ·4 is that with Charleston; but in winter when N. W. India is not a maximum or a minimum it has four coeffs. exceeding ·4.

26. Associated with press. at Port Darwin we find:—

PORT DARWIN PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before P. Dar. J—A	Contemporary. D—F	2 qrs. after P. Dar. J—A	2 qrs. before P. Dar. D—F	Contemporary. J—A	2 qrs. after P. Dar. D—F
Iceland	+·27	+·06	+·12	+·01	+·23	—·13
Alaska	+·18	—·25	—·12	—·23	+·25	—·12
C. Siberia	+·10	—·07	—·37	—·40	—·07	—·08
Azores	—·08	—·07	+·15	—·19	—·08	+·12
Charleston	+·25	—·52	+·04	—·23	+·12	—·31
Honolulu	—·64	+·39	—·33	+·11	—·67	+·46
N. W. India	—·06	+·67	+·05	+·49	+·03	+·45
Port Darwin	+·83	+1·00	+·34	+·34	+1·00	+·83
Mauritius	+·21	+·11	—·11	+·03	+·25	0
St. Helena	+·11	+·11	—·14	+·14	+·16	—·04
Samoa	—·62	—·57	—·28	—·23	—·55	—·29
S. E. Australia	+·48	+·75	+·17	+·09	+·73	+·58
Cape Town	—·06	+·59	+·04	+·39	+·17	+·53
S. America	—·57	+·15	—·06	+·15	—·46	0
S. Orkneys	+·03	+·30	—·39	+·13	—·25	+·17
Rain.						
Peninsula	—·46	...	—·03	...	—·41	...
Java	...	—·46	...	+·17	...	—·50

It will be noticed that although Port Darwin press. D—F has a contemporary coeff. of +·39 with that at Honolulu it has negative relationships of —·64 and —·33 with press. there two quarters before and two after; and there are similar changes of sign between S. America and C. Town, given in § 32 below. The coeffs. —·64, —·62 and −·57 show that press. at Port Darwin D—F is very largely determined by conditions in the Pacific Ocean six months before.

The coeff. of winter press. at P. Darwin with that of the following summer is +·83, a relationship which shows remarkable persistence: the next persistence to this has only +·37 as coeff. and occurs both for C. Siberia and Samoa.

A good forecast of P. Darwin summer press. can obviously be got from the pressures at Honolulu, P. Darwin, Samoa and S. America, and the Indian Peninsula rain, all six months in advance; and a forecast for the monsoon rainfall of north east Australia would appear to be an immediate corollary.

27. For Mauritius the relationships are:—

MAURITIUS PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before Maur. J—A	Contemporary. D—F	2 qrs. after Maur. J—A	2 qrs. before Maur. D—F	Contemporary. J—A	2 qrs. after Maur. D—F
Iceland	−·09	+·26	+·10	+·05	−·29	+·01
Alaska	−·24	+·08	0	−·21	+·22	−·27
C. Siberia	+·02	+·28	+·21	−·05	+·09	+·26
Azores	+·06	−·04	−·01	−·25	+·11	+·08
Charleston	−·06	−·12	−·21	+·06	+·09	−·01
Honolulu	−·10	−·25	−·31	−·18	−·22	+·30
N. W. India	+·20	+·21	+·12	−·01	+·23	+·27
Port Darwin	0	+·11	+·03	−·11	+·25	+·21
Mauritius	+·33	+1·00	+·05	+·05	+1·00	+·33
St. Helena	+·14	+·06	+·02	−·20	+·41	−·01
Samoa	−·08	−·36	+·04	+·27	+·17	−·09
S. E. Australia	+·17	+·25	−·02	+·05	+·43	+·49
Cape Town	−·05	−·03	+·25	0	+·15	+·29
S. America	−·49	−·06	−·21	−·09	−·38	−·05
S. Orkneys	−·05	−·54	+·38	−·10	−·09	+·10
Rain.						
Peninsula	−·12	...	+·08	...	−·52	...
Java	...	−·05	...	+·03	...	−·38

With Java rain, O—F, the corr. coeff of Mauritius press. of the quarter before, S—N, is −·04; of press. two quarters before, J—A, it is −·38; three before, M—M, is −·51; four, D—F, is −·28; and five, S—N, is −·36. With Mauritius press., M—M, one quarter later than the Java rain, the coeff. is −·16; and for J—A, two quarters later, +·03.

With Port Darwin press., D—F, which is opposed to Java rain (the corr. coeff. being —·46), press. at Mauritius has a corr. coeff. of +·21 two quarters before, —·11 three quarters before and +·03 four quarters before. With S. E. Australia press. J—A press. at Mauritius has a relationship of +·43 the same quarter, of +·30 one quarter before and of —·02 two before. Hence although Mauritius has a marked influence on the subsequent Java rain* it does not appear to exert it through the agency of local press.

With India Peninsula rain (J—S), which is opposed to the previous Java rainfall, we accordingly find with Mauritius press. of six quarters before, D—F, +·25; for five quarters before it is +·12, and four, +·15.

There is, I think, no doubt that Sir John Eliot was misled in his view that normally there is opposition between Mauritius and India.† The corr. coeff. of the annual pressures of India and Mauritius is +·28: during the quarter D—F the coeff. is +·21, and during the quarter J—A +·23; the data in all cases extend over 45 years.

28. With press. at St. Helena there are the following relationships:—

St. Helena press.

	Dec to Feb			June to Aug		
Press.	2 qrs. before St. Hel. J—A	Contemporary. D—F	2 qrs. after St. Hel. J—A	2 qrs. before St. Hel. D—F	Contemporary. J—A	2 qrs. after St. Hel. D—F
Iceland	—·06	+·07	+·10	—·02	—·13	—·14
Alaska	—·47	—·23	—·05	+·09	—·10	+·30
C. Siberia	+·17	+·12	—·06	—·03	—·22	+·14
Azores	+·04	+·27	—·01	—·12	+·22	+·03
Charleston	—·35	—·15	—·09	+·09	+·49	+·03
Honolulu	—·40	+·12	—·12	+·08	—·12	+·04
N. W. India	+·04	—·12	—·07	—·07	—·14	+·22
Port Darwin	—·04	+·11	+·14	—·14	+·16	+·11
Mauritius	—·01	+·06	—·20	+·02	+·41	+·14
St. Helena	—·23	+1·00	—·28	—·28	+1·00	—·23
Samoa	—·37	—·53	—·34	+·45	+·17	+·03
S. E. Australia	—·23	+·28	+·33	—·07	+·13	+·21
Cape Town	+·06	+·20	+·18	—·17	+·29	+·12
S. America	—·23	+·09	+·15	—·01	—·06	—·12
S. Orkneys	+·31	—·11	—·01	+·24	—·05	+·03
Rain.						
Peninsula	—·36	...	+·11	...	+·27	...
Java	...	—·05	...	—·24	...	—·25

* This was pointed out in H 5, p. 5.

† Indian Meteorological Memoirs, Vol. XVI, Part 2, p. 273.

Although its latitude is only 15° 55′ S, St. Helena resembles the Cape in that its summer press. is in opposition to that of S. America, Samoa and Honolulu six months earlier; but its corr. coeff. with the Cape is small. It also has a positive coeff. J—A with Mauritius, which occupies a somewhat similar position in 20° 5′ S in the Indian Ocean; with press. at Honolulu J—A the strength of the wind at St. Helena has a corr. coeff. of +·29 in the contemporary quarter, +·14 one quarter later and 0 two quarters later; similarly with the press. of N. W. India J—A the coeffs. of St. Helena winds are +·38 in the contemporary quarter and +·19 six months later.

29. We find that the press. of Samoa (Apia) has the following relationships:—

Samoa press.

	Dec to Feb			June to Aug		
Press.	2 qrs. before Samoa. J—A	Contemporary. D—F	2 qrs. after Samoa. J—A	2 qrs. before Samoa. D—F	Contemporary. J—A	2 qrs. after Samoa. D—F
Iceland	−·17	−·13	−·07	−·17	−·09	−·17
Alaska	−·36	−·18	+·09	−·23	−·36	+·38
C. Siberia	−·24	+·02	+·03	+·11	−·31	−·15
Azores	−·04	−·08	+·11	+·15	+·34	+·18
Charleston	−·09	+·28	+·32	0	−·22	+·20
Honolulu	+·50	+·19	+·45	+·03	+·73	+·08
N. W. India	+·12	−·39	−·01	−·18	+·18	−·11
Port Darwin	−·29	−·57	−·23	−·28	−·55	−·62
Mauritius	−·09	−·36	+·27	+·04	+·17	−·08
St. Helena	+·03	−·53	+·45	−·34	+·17	−·37
Samoa	+·37	+1·00	+·23	+·23	+1·00	+·37
S. E. Australia	−·13	−·54	−·07	−·30	−·37	−·41
Cape Town	+·24	−·37	−·37	−·47	0	−·46
S. America	+·48	+·24	−·01	+·11	+·49	−·35
S. Orkneys	−·75	−·02	+·29	+·37	−·13	+·09
Rain.						
Peninsula	+·49	...	−·19	...	+·36	...
Java	...	+·45	...	−·08	...	+·25

The relationships of Samoa are for the period J—A much like those of Honolulu and like those of S. America; but for D—F, while gently opposed to the northern low press. regions, Iceland and Alaska, it is definitely opposed to N. W. India, Port

Darwin, S. E. Australia, Cape Town and St. Helena, with which at this time Honolulu shows sympathy. The coeff. of +·73 with Honolulu J—A is big considering their separation by 38°.

30. The corr. coeffs. with S. E. Australia (Brisbane, Adelaide and Alice Springs) are :—

S. E. AUSTRALIA PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before S. E. Aus. J—A	Contemporary. D—F	2 qrs. after S. E. Aus. J—A	2 qrs. before S. E. Aus. D—F	Contemporary. J—A	2 qrs. after S. E. Aus. D—F
Iceland	+·06	+·09	—·07	+·13	—·11	—·26
Alaska	+·06	—·13	—·33	—·51	+·06	—·04
C. Siberia	+·20	+·02	—·11	—·23	+·12	+·24
Azores	—·04	+·10	+·27	—·33	—·05	+·19
Charleston	+·11	—·30	—·04	—·21	—·12	—·23
Honolulu	—·54	+·33	—·25	+·21	—·28	+·28
N. W. India	+·05	+·47	+·06	+·33	+·27	+·39
Port Darwin	+·58	+·75	+·09	+·17	+·73	+·48
Mauritius	+·49	+·25	+·05	—·02	+·43	+·17
St. Helena	+·21	+·28	—·07	+·33	+·13	—·23
Samoa	—·41	—·54	—·30	—·07	—·37	—·13
S. E. Australia	+·36	+1·00	+·09	+·09	+1·00	+·36
Cape Town	—·07	+·52	0	+·38	+·25	+·48
S. America	—·57	+·08	+·01	+·09	—·33	—·17
S. Orkneys	+·17	+·04	—·28	+·29	—·31	—·08
Rain.						
Peninsula	—·62	...	+·04	...	—·31	...
Java	...	—·42	...	0	...	—·52

As might be expected the relationships of S. E. Australia have a material resemblance to those of P. Darwin. In winter it allies itself with Mauritius to a greater extent than does Port Darwin in summer, when the latter is near the centre of the equatorial centre of low press. With Cape Town six months before and after also S. E. Australia has in winter considerable affinity; as will be seen in § 31, winter press. at the Cape has little, but summer press. much resemblance with Australian press. Australian relationships are more marked with regions in the southern than the northern hemisphere.

31. With Cape Town we find :—

CAPE TOWN PRESS.

	Dec to Feb			June to Aug		
Press.	2 qrs. before C. Town. J—A	Contemporary. D—F	2 qrs. after C. Town. J—A	2 qrs. before C. Town. D—F	Contemporary. J—A	2 qrs. after C. Town. D—F
Iceland	+·03	—·10	+·01	+·08	—·09	—·19
Alaska	+·15	—·51	—·01	+·04	—·03	—·18
C. Siberia	+·33	+·01	0	+·04	—·27	+·04
Azores	—·18	+·09	—·09	0	+·03	+·05
Charleston	+·02	—·25	—·10	+·17	—·16	+·07
Honolulu	—·43	+·29	—·29	0	—·07	+·16
N. W. India	+·27	+·56	+·17	+·07	+·17	+·05
Port Darwin	+·53	+·59	+·39	+·04	+·17	—·06
Mauritius	+·29	—·03	0	+·25	+·15	—·05
St. Helena	+·12	+·20	—·17	+·18	+·29	+·06
Samoa	—·46	—·37	—·47	—·37	0	+·24
S. E. Australia	+·48	+·52	+·38	0	+·25	—·07
Cape Town	+·08	+1·00	+·08	+·08	+1·00	+·08
S. America	—·48	+·12	—·16	—·14	+·10	—·38
S. Orkneys	+·01	+·44	—·16	+·09	—·22	+·22
Rain.						
Peninsula	—·51	...	+·01	...	+·10	...
Java	...	—·33	...	—·13	...	—·16

During the summer period, D—F, Cape Town lies on the edge of the African continental low; its press. at this time varies with that of Northwest India, P. Darwin and S. E. Australia, and is opposed to that of Samoa. But in winter it lies within the southern high press. belt so that its relationships with low press. areas are weakened and with Samoa it ceases to be in opposition.

It is rather curious that Cape Town should show during D—F a marked opposition to press. six months earlier on the high press. belt of S. America as well as to that at Honolulu and Samoa. Another surprise is that the effect of the Peninsula rain six months earlier is much more marked (—·51) than that of India press. (+·27), a paradox of which we shall find other examples.

The corr. coeff. of O—F rain at Java with press. at Cape Town of the previous quarter S—N is +·16, for the quarter J—A before this it is —·16, for M—M it is

+·24, for D—F (a year before the Java rain) —·18 and 5 quarters before, S—N, it is —·15. This contradicts Hildebrandsson's strong opposition (H 5, p. 5) between the Cape Oct—Mar press. and the Java rain of a year later: the corr. coeff. given by Hildebrandsson's figures for '81 to '03 is —·31, but on taking the official Java figures I find —·19 for the period '81—'03, and for '80—'21 only —·08. With the Cape press. of the season, M—M, after the Java rain its coeff. is —·04.

32. The corr. coeffs. with S. America (B. Ayres + Cordoba + Santiago) are :—

S. AMERICA PRESS.

Press.	Dec to Feb: 2 qrs. before S. Am. J—A	Dec to Feb: Contemporary. D—F	Dec to Feb: 2 qrs. after S. Am. J—A	June to Aug: 2 qrs. before S. Am. D—F	June to Aug: Contemporary. J—A	June to Aug: 2 qrs. after S. Am. D—F
Iceland	+·06	+·19	—·01	+·04	—·05	—·20
Alaska	—·05	—·09	—·34	—·03	—·07	+·04
C. Siberia	—·03	—·04	—·03	+·25	—·31	—·17
Azores	—·04	+·05	+·03	+·38	+·17	+·04
Charleston	+·45	—·08	+·06	+·08	+·04	+·21
Honolulu	—·05	+·07	—·01	+·19	+·52	+·12
N. W. India	—·20	+·20	+·04	—·14	—·25	—·46
Port Darwin	0	+·15	+·15	—·06	—·46	—·57
Mauritius	—·05	—·06	—·09	—·21	—·38	—·49
St. Helena	—·12	+·09	—·01	+·15	—·06	—·23
Samoa	—·35	+·24	+·11	—·01	+·49	+·48
S. E. Australia	—·17	+0·8	+·09	+·01	—·33	—·57
Cape Town	—·38	+·12	—·14	—·16	+·10	—·48
S. America	+·02	+1·00	+·09	+·09	+1·00	+·02
S. Orkneys	+·15	—·14	0	+·23	+·25	+·17
Rain.						
Peninsula	+·03	...	—·09	...	+·44	...
Java	...	+·28	...	—·18	...	+·37

The press. in the high press. belt of S. America is remarkable not only for its marked inverse effect with press. in the Indian Ocean six months later, but also for the smallness of the influence exercised by the summer press. compared with that of winter: the largest of the summer relationships is that of ·24 with Samoa, while in winter there are four over ·40. Its summer relationship with Honolulu also is only +·07 contrasted with +·52 in winter.

Another feature is that if the quarterly departures of press. are plotted for S. America and for Cape Town, and if the data be also smoothed and plotted, then while the general character of the smoothed line shows a clear opposition there is a marked similarity in the simultaneous quarterly irregularities. If we take the press. J—A of S. America its coeff. with press. at Cape Town two quarters before is —·16, for one quarter before it is —·08, the same quarter +·10, one quarter later —·11 and two quarters after —·48.

33. With press. at the South Orkneys we find the following relationships :—

S. ORKNEYS PRESS.

	DEC TO FEB			JUNE TO AUG		
Press.	2 qrs. before S. Ork. J—A	Con-tempo-rary. D—F	2 qrs. after S. Ork. J—A	2 qrs. before S. Ork. D—F	Con-tempo-rary. J—A	2 qrs. after S. Ork. D—F
Iceland	+·14	—·14	—·01	+·04	+·09	+·67
Alaska	+·51	—·47	—·09	+·36	—·42	—·01
C. Siberia	+·51	—·24	—·65	+·30	—·02	—·02
Azores	+·16	—·57	+·36	+·19	—·14	—·04
Charleston	+·04	—·51	+·25	+·32	+·11	—·25
Honolulu	—·01	+·37	+·16	—·46	—·07	+·01
N. W. India	+·31	—·01	—·25	—·45	—·17	+·02
Port Darwin	+·17	+·30	+·13	—·39	—·25	+·03
Mauritius	+·10	—·54	—·10	+·38	—·09	—·05
St. Helena	+·03	—·11	+·24	—·01	—·05	+·31
Samoa	+·09	—·02	+·37	+·29	—·13	—·75
S. E. Australia	—·08	+·04	+·29	—·28	—·31	+·17
Cape Town	+·22	+·44	+·09	—·16	—·22	+·01
S. America	+·17	—·14	+·23	0	+·25	+·15
S. Orkneys	—·17	+1·00	—·29	—·29	+1·00	—·17
Rain.						
Peninsula	—·52	...	+·34	...	+·08	...
Java	...	—·13	...	+·33	...	+·14

The coeffs. for this centre have a probable error of about ·18 and must therefore be treated with considerable caution. It is striking that while the contemporary relationship of Alaska with S. America is only —·09 for D—F and —·07 for J—A, it is —·47 with S. Orkneys for D—F and —·42 for J—A. Again while the monsoon rainfall of the Peninsula has no appreciable effect on the D—F press. in S. America six months later, the corresponding coeff. with the S. Orkneys is —·52.

Eight coeffs. of ·30 or more are available for a six months' forecast of the winter press. at S. Orkneys.

The coeffs. of +·67 and −·75 with Iceland and Samoa two quarters after S. Orkneys' winter are striking and of the signs that would be expected; it will be interesting to see whether they are borne out by future data.

34. The corr. coeffs. with monsoon rainfall (J—S) in the Indian Peninsula are:—

PENINSULA RAIN.

	June to Sep		
Press.	2 qrs. before Penin. D—F	Contemporary. J—A	2 qrs. after Penin. D—F
Iceland	−·10	+·03	+·03
Alaska	−·38	−·11	+·51
C. Siberia	+·24	−·33	−·05
Azores	+·21	+·10	−·06
Charleston	−·09	+·01	+·21
Honolulu	+·23	+·46	−·42
N. W. India	−·03	−·11	−·16
Port Darwin	−·03	−·41	−·46
Mauritius	+·08	−·52	−·12
St. Helena	+·11	+·27	−·36
Samoa	−·19	+·36	+·49
S. E. Australia	+·04	−·31	−·62
Cape Town	+·01	+·10	−·51
S. America	−·09	+·44	+·03
S. Orkneys	+·34	+·08	−·52
Rain.			
Peninsula	...	+1·00	...
Java	−·38	...	+·21

The detailed examination of the effect on Peninsula rainfall of previous conditions must be postponed to a future memoir, and we shall now pay attention to the effect of that rainfall on subsequent conditions elsewhere. Of the seven coeffs. of this type exceeding ·4 those of Alaska* and the S. Orkneys are slightly doubtful in view

* Alaska is however supported by Honolulu with which its contemporary coeff. D—F is −·71.

of the scantiness of the data. But the negative relationships with Port Darwin and S. E. Australia are confirmed by the coeff. of +·37 found by me in 1909 between the Indian monsoon rainfall and that of Australia in their subsequent summer: with the more complete data now available the coeff. of the Peninsula rainfall, J—S, and that of the total monsoon rainfall of Northern Territory (Upper Division) and Queensland is +·25. The negative relationship with Cape Town press. is confirmed by the marked control of the Indian monsoon rainfall over that of the succeeding summer in S. Africa,* including the northeast of Cape Colony, Natal, Rhodesia and British Central Africa: I have just been informed by Mr. C. L. Robertson of the Dept. of Agriculture, Salisbury, Rhodesia, that the coeff. between the total monsoon rainfall of India, J—S, and that of Rhodesia during the following Oct—Mar ('99—'21) is +·35 ±·18.

35. Associated with the rainfall of Java (the sum of the percentage monthly amounts from October to February) we find:—

	Java rain. Oct to Feb		
Press.	2 qrs. before Java. J—A	Contemporary. D—F	2 qrs. after Java. J—A.
Iceland	—·04	+·26	+·19
Alaska	—·08	+·33	+·05
C. Siberia	—·10	—·15	+·35
Azores	—·03	—·15	—·18
Charleston	+·06	+·20	—·10
Honolulu	+·41	—·32	—·14
N. W. India	—·16	—·32	+·10
Port Darwin	—·50	—·46	+·17
Mauritius	—·38	—·05	+·03
St. Helena	—·25	—·06	—·24
Samoa	+·25	+·45	—·08
S. E. Australia	—·52	—·42	0
Cape Town	—·16	—·33	—·13
S. America	+·37	+·28	—·18
S. Orkneys	+·14	—·13	+·33
Rain.			
Peninsula	+·21	...	—·38
Java	...	+1·00	...

* See D. E. Hutchins in nature, Feb 9, 1905, p. 343, and Hann's Klimatologie, III, p. 463 (1911).

The first to draw attention to the importance of the rain of Java was Hildebrandsson (H 3, p. 10). The monthly rainfall data of the island are published officially as percentages of the normal and Hildebrandsson pointed out that there was from '80 to '03 a very close parallelism between the sum of the monthly percentages of rain from Oct to March with the press. at Bombay April—Sep afterwards: the relationship has fallen off since 1903 when its coeff. was +·66, and the period 1880 to 1921 yields only +·26, though with the press. of all India it is +·31. In H 5, p. 5 it is also pointed out that from '81—'03 there is a marked opposition between the Java rain and press. at Cordoba and Santiago of the April—Sep after: this relationship also has not been maintained; as seen in the table the coeff. of Java rain, O—F, with S. America 2 quarters later, J—A, is —·18; and extending the interval we find with S. America three quarters later +·13, and four quarters later +·11.

The negative relationship found by Hildebrandsson between Java rain and contemporary press. at Sidney and Melbourne (H 5, p. 5) is what we should expect: the coeff. between the rain and D—F press. at Batavia is markedly negative, as usual, and its amount ('80—'21) is —·40; with Port Darwin in the same area of low pressure it is —·46. As we should anticipate, this implies a positive association with the summer monsoon rainfall of Australia, and with the rainfall of the three stations (P. Darwin, Daly Waters and Katherine) the coeff. proves to be +·31.

The forecast for Java rain (O—F) given by pressures at Honolulu, S. E. Australia and S. America two quarters before, with coeffs. +·41, —·52 and +·37, and by press. at Mauritius three quarters before with a coeff. —·51, is clearly good. Though logically connected with Braak's method of variations of Batavia press.* it seems easier and is more definite. Moreover it could be improved by examining the coeffs. of press. month by month for the four areas and selecting those groups of months, not necessarily D—F, M—M, J—A or S—N, which have the best coeffs.

36. Some of the relationships of the May rainfall of the Zanzibar district are:—

RAIN OF MAY, ZANZIBAR DISTRICT.

—	Before.	Contemporary.	After.
C. Siberia press., D—F,	+·16	...	+·06
Peninsula rain, J—S,	...	...	—·45
N. W. India rain, J—S,	...	...	—·17
Java rain, O—F,	+·04	...	...
Western Himalayas snowfall accumulation, May,	...	+·15	...

* Atmospheric variations of short and long duration, etc. Kon. Mag. en Met. Obs. te Batavia, Verhand. No. 5. §§ 11, 22 (1919).

For a number of years the May rainfall of Zanzibar has been used in monsoon forecasting and it is remarkable in view of the usual irregularity of rainfall distribution that the records of a single gauge should have with Peninsula rainfall as high a corr. coeff. as −·50 : in order however to increase the reliability of the indication it became necessary to include data from a wider region.

The near stations are, travelling northwards, Pemba, Shimoni, Mombasa, Takaungu and Malindi, while Daressalam lies to the south ; and for the series of stations the corr. coeffs. of May rainfall with the monsoon rainfall of the Peninsula are Malindi (20 years) −·17, Takaungu (13) −·19, Mombasa (32) −·12, Shimoni (26) −·33, Pemba (24) −·42, Zanzibar (31) −·50 and Daressalam (19) −·41 : it is surprising that in the 150 miles between Zanzibar and Mombasa the closeness of the relationship should diminish so rapidly. For the May rainfall of {Daressalam + Zanzibar + Pemba + ½ (Shimoni)} we find from '93 to '21 a coeff. of −·45, and this rainfall is accordingly taken as representing the district.

Upon Indian rainfall Zanzibar rainfall after May exercises little influence : but that of April is appreciable. With the Nile floods the Zanzibar rainfall of April and May has a coeff. of −·44, based on data of 27 years.

In May the coeff. of Zanzibar rain with Mauritius press. is positive, +·40.

37. Some of the relationships of the May rainfall at Seychelles are :—

SEYCHELLES RAIN, MAY.

—	Before.	Contemporary.	After.
C. Siberia press., D—F,	−·37	...	+·09
India „ , May,	...	+·38	...
N. W. India rain, J—S,	...	...	−·38
Java „ , O—F,	−·40	...	...
Snowfall accumulation (India, May),	...	+·34	...

The importance of Seychelles rain to India lies in its position in the heart of that part of the S. E. trades which becomes the Bay monsoon current after it has crossed the equator : heavy rain there in May is prejudicial to the rain brought by that current just as heavy rain at Zanzibar is prejudicial to the Arabian Sea current ; and the corr. coeff. between the May rain at Seychelles and the monsoon rainfall, J—S, of north east India (Upper Burma, Assam, Bengal, and Bihar and Orissa) if −·38.

In May the corr. coeff. of Mauritius press. with Seychelles rain is +·04.

38. In view of the strength of the controls exercised by and upon Java rain it seemed desirable to examine the rainfall of the southern equatorial region of the Pacific. The mean of the rainfall from Nov to March of Bua, Suva, Malden, Apia and Tahiti was tabulated from '84 to '13, and the following corr. coeffs. were worked out.

SOUTH PACIFIC RAINFALL (NOV TO MARCH).

—	Before.	Contemporary.	After.
Press.			
Honolulu, D—F,	...	—·15	...
N. W. India, D—F,	...	—·09	...
S. America, D—F,	...	—·09	...
S. America, J—A,	+·16	...	—·03
Rain.			
Peninsula, J—S,	+·14	...	—·17
Java, O—F,	...	+·27	...

These results did not seem to justify a further enquiry.

39. Some of the relationships with the snowfall accumulation at the end of May upon the Himalayas and the mountain region to their west are :—

SNOWFALL ACCUMULATION, MAY.

—	Before.	Contemporary.	After.
Port Darwin press., M—M,	+·44	...	...
S. America „ April + May,	—·35	...	...
N. W. India rain, J—S,	...	...	—·38
Zanzibar rain, May,	...	+·21	...
Seychelles rain, May,	...	+·34	...

With the Nile floods the corr. coeff. of Himalayan snowfall, based on data of '76—'08, is —·35, practically identical with the coeff. with N. W. India rain.

40. With the rainfall of Rhodesia, Oct—Mar ('00—'22), the corr. coeffs. prove to be:—

RHODESIA RAINFALL, OCT—MAR

Press.	2 qrs. before Rhod. J—A	Contemporary. D—F	2 qrs. after Rhod. J—A
Honolulu	...	—·21	...
N. W. India	...	—·06	...
Port Darwin	—·17	—·13	+·07
Mauritius	—·09	+·38	+·23
St. Helena	+·01	0	+·10
Samoa	+·07	+·08	+·15
S. E. Australia	—·04	—·17	—·12
Cape Town	—·15	—·43	+·18
S. America	—·01	—·05	+·01
S. Orkneys	...	...	...
Rain.			
Peninsula	+·38	...	—·55
Java	...	+·16	...

The reason for the investigation of Rhodesia rain was its large influence upon the subsequent rainfall of India, and its control by the previous rainfall of India. Apart from these relationships there is little of interest except the coeff. —·43 with Cape Town, which might be expected in view of its nearness to Cape Colony, and the coeff. +·38 with Mauritius, which suggests that increased strength in the damp winds from the Indian Ocean means more rain in southern Africa.

GENERAL REMARKS.

41. Perhaps the most striking feature of the press. correlations is the co-operation of the group Azores, Charleston, Honolulu (J—A), Samoa, S. America (J—A) and Peninsula rain on the one hand, and of the group Iceland, C. Siberia, N. W. India, P. Darwin, Mauritius and S. E. Australia on the other; members of the groups have positive contemporary corr. coeffs. with each other and negative with those of the other group. We can perhaps best sum up the situation by saying that there is a swaying of press. on a big scale backwards and forwards between the Pacific Ocean and the Indian Ocean; and there are swayings, on a much smaller scale, between the Azores and Iceland, and between the areas of high and low press. in the N. Pacific:

further, there is a marked tendency for the 'highs' of the last two swayings to be accentuated when press. in the Pacific is raised and that in the Indian Ocean lowered. As the influence of the Pacific Ocean—Indian Ocean swayings upon world weather seems to be much greater than that of either of the other two I have given considerably more weight to it in deciding the grouping of centres.

The adherence of Iceland to the second group holds in summer and winter; but it is not extremely consistent.

Alaska in winter, when its low press. is developed, is very strongly opposed to Honolulu (—·71); but, owing perhaps to the fragmentary character of the data, its relations with the other centres somewhat resemble those of the first group: on the whole it is neutral D—F, and belongs to the second group J—A.

Central Siberia is of interest in that as a centre of high press. in winter it might be expected then to be allied with the other high press. centres and opposed to the centres of low press.; but it has coeffs. +·34 with Iceland, —·29 with Charleston, and +·28 with Mauritius, all implying membership of the second group. In summer when it lies within, but far from the centre of, the Asian low it consistently belongs to the second group, with which it must therefore be classed.

Clearly Charleston, D—F and J—A, and Honolulu J—A belong to the first group, as also does the Azores, especially J—A when the high press. is more fully developed.

Northwest India lies in the second group in summer when it is the centre of the equatorial low: but in winter, when it has no special position as the centre of a region of high or low press., it also belongs definitely to the second group; it will be remembered that coeffs. with Honolulu and S. America for the period D—F may be ignored as these centres are then neutral.

Port Darwin, representing the equatorial low of the southern summer, D—F, is surprising in that it belongs as conspicuously to the second group in winter as it does in summer.

As to the classification of Mauritius there is little doubt, except J—A when it just goes into the second group.

St. Helena belongs feebly to the first group D—F and to neither group J—A.

Although the relations of S. E. Australia with places in the most northerly latitudes are indefinite, it is very clearly in the second group.

The same remark is applicable to Cape Town, D—F; but during the winter period, when it is in the high press. belt, its association with the low press. group is weakened, and it must be classed as neutral.

There is complete neutrality in the character of S. America in summer, when its coeffs. are small; but during J—A its coeffs. are moderately large and decisive of its place in the first group.

The number of years of data for the S. Orkneys, 14, means a probable error of about ·18 in the coeffs. and it would be unwise to classify it finally unless the indications were marked and consistent: unhappily this is not the case. I would class it provisionally as feebly in the first group D—F and feebly in the second group J—A.

As for the Peninsula rain there are excellent grounds for putting it in the first group.

For Java rain O—F the contemporary significant coeffs. exceeding ·30 are Port Darwin—·46, Samoa +·45, and Cape Town —·33; so Java rain must be treated as an adherent of the first group.

The arrangements of the centres in groups will be found in a tabular form in § 69 of chapter IV below.

42. This classification calls to mind at once that of the world's pressures by Bigelow* based on a visual comparison of greatly smoothed freehand curves of annual press. with a curve of solar prominences: he found two types, our first group corresponding with his 'inverse' and our second with his 'direct'; the main difference is that he did not distinguish winter and summer, and that he regarded Siberia as neutral, though N. China went with India, and Cape Town as 'direct'. Substantially the same scheme was made out by Sir Norman Lockyer from accurate graphs of annual press. in 1908 in the Solar Physics Committee report on 'Monthly mean values of barometric pressure' (pp. 1-7 and Plate I): he selected Bombay and Cordoba as the types of his groups, and he classed C. Siberia in the second group with a query. Another classification with which that here adopted proves to be very closely in agreement is that based on the relationships of sunspots and press. (Vol. XXI, Part 12 of these Memoirs†); regions of positive relationships with sunspots form the present first group and of negative relationships the second.

It is surprising that our process of selecting two groups of which each shall be homogeneous and opposed to the other group should lead to so nearly the same results as Bigelow's selection for similarity to the prominence curve: and equally surprising that the same result is obtained from definite numerical relationships with sunspots in which Bombay and the Indian Ocean are found to vary inversely with solar activity not directly as estimated by Bigelow.‡ The agreement with the Lockyers is as good as is consistent with their selection merely for accordance with the Bombay-Cordoba seesaw, while ours include that of Iceland-Azores and of the North Pacific.

43. The question may be raised as to the relation between the scheme of centres adopted here and that worked out by Exner in the paper already referred to §. In that he deals with the winter months D—F, and his corr. coeffs. mainly concern the region to the north of latitude 40°; he discovers a very striking opposition between press. in the extreme north, as represented by Gjaesvaer and Markowo, and in an area central

* Washington M. W. R., 1903, p. 515.

† The chart there appended conveys the results of the analysis in a convenient form.

‡ The physical interpretation is discussed in Chapter IV below.

§ Sitz. d. K. Akad. d. Wiss. in Wien, CXXII, Abt IIa, June 1913.

near Malta,* of which he takes Lugano as representative. The contemporary relationships of a large number of stations with the polar region are given, and of 30 stations with Lugano some based on 10 yrs., and some on 20 yrs. But the cross coeffs. of these stations with each other are inevitably less complete: with Iceland there are 14, with Obdorsk 4, etc. If arranged in the form of our tables the relationships of his two main centres would be:—

—	Press, D—F			
	Extr. North.	Iceland.	Lugano.	Azores.
Extr. North	+1·00	(+·67)	— ·67	—·41
Iceland	+ ·67	+1·00	— ·61	(— ·54)
Alaska (or P. Simpson)	— ·36?	(— ·18)	+ ·26?	(+ ·24)
C. Siberia (or Barnaul)	+ ·46	(+ ·34)	— ·43	(— ·03)
Lugano	— ·67	...	+1·00	— ·03?
Azores	— ·41	(—·5 4)	— ·03?	+1·00
Charleston (or Nashville)	— ·24	(— ·33)	...	(+ ·35)
Honolulu	— ·17	(— ·19)	...	(+ ·15)
N. W. India (or Jaipur)	— ·27	(+ ·05)	+ ·20	(— ·02)

It will be seen that as far as this information goes the extreme north behaves very much like Iceland in which figures from my table have been inserted in brackets: Exner's —·03 between the Azores and Lugano is based on 10 years' data only and has therefore been marked with a query, but the sympathy between Lugano and the Azores is less marked than might be expected. I regard Exner's arrangement as admirably suited for examining the mechanism of northern relationships, and I have been tempted to introduce Gjaesvaer and Algiers (or Lugano) into my scheme: but it seemed to me that their addition would mean working out the northern regions in greater detail than the equatorial and southern; and as far greater attention has already been given to northern regions than to other parts of the globe, the addition seemed inadvisable. Readers interested in northern relationships must in any case read Exner's interesting and important paper.

CHAPTER III.

Temperature variations.

44. In addition to the ordinary changes of temp. that are produced by rainfall or by winds bringing warmer or cooler air there are changes of a more obscure type of which those of Batavia described by Braak† may be taken as typical. He smooths his data over six months before plotting them and in the graphs it appears that there

* See his Karte 2.

† 'Atmospheric variations of short and long duration in the Malay Archipelago'. Kon Mag. en Met. Obs. te Batavia, Verb. 5, 1919. See Figs 1, 2 and sections 12-14, 17—20.

is a time lag of about six months of Batavia temp. changes behind the similar ones of Batavia press.; also the changes in air temps. and sea temps. are 'practically equal and simultaneous'*, while the air temps. of Batavia, Seychelles and Mauritius are very closely related. Stated very briefly Braak's summary of our knowledge is that in the tropics temp. changes are due mainly to three causes:—

(*a*) fluctuations in the general air circulation (see his § 14), changes of press. setting up changes in winds; a fall of press. will in the tropics bring more air from colder regions, and cause more evaporation at sea, thereby also lowering sea (and therefore) air temp.

(*b*) a period of low press. is a period of increased rain and therefore decreased vertical temp. fall and of warmer upper air, which will tend to maintain the low press. (his § 15).

He points out further that

(*c*) in the southern winter, which is anti-cyclonic in north Australia, higher press. than usual there is associated with lower temp. since, owing to greater dryness of the air, there will be more loss of heat by radiation from the earth than gain by insolation. At such times the south-east monsoon winds will bring lower temps. from Australia to east Java and by causing increased evaporation will further lower the temp. there. (§ 16).

For his discussion of the special features of the changes during a complete press. cycle reference should be made to his §§ 18, 20.

45. In a previous paper† Braak sketches Indian conditions and says that between Kodaikanal (a hill station in S. India at 2340m) and the plains the average air temp. oscillates in harmony with that of the plains, the coeff. between them being ·69, and deduces that the temp. change extends to about 1000m. above the hill station.

46. In order to get definite facts I have examined unsmoothed data for Batavia and find the following coeffs. between its pressures and temps. during the four quarters: the figures −2, −1, etc. in the second line give the number of quarters that the quarter for the temp. comes *after* the press. quarter.

—	Batavia quarterly temp. ('66 —'15).						
	−2	−1	0	+1	+2	+3	+4
Batavia press.							
D—F	+·10	+·21	+·24	+·41	+·47	+·59	+·42
M—M	+·05	+·20	+·52	+·58	+·63	+·51	...
J—A	−·16	+·03	+·22	+·54	+·58	+·57	...
S—N	−·10	+·15	+·50	+·56	+·58	+·55	...

* See his footnote 2 p. 26.

† Kon. Akad. v. Wet. te Amsterdam. DLXXI, pp. 193—200, 29th June 1912.

It will be seen that the summer press. D—F has a coeff. of only +·24 with contemporary temp., but with those of succeeding quarters it is +·41, +·47, +·59, +·42, the maximum effect being shown 3 quarters after. For the other three seasons the maximum effect of press. appears 2 quarters after.

47. In order to throw light on this phenomenon I have drawn up similar tables for other places:—

—	India temp.		
	0	+1	+2
India press.			
D—F	—·15	—·29	+·34
M—M	—·26	+·53	+·42
J—A	—·15	—·07	+·14
S—N	—·03	+·13	·00

It is very surprising that the temp. of India during the monsoon should be largely controlled by the press. of India, March to May, and partly by that during the previous winter: and it might be inferred that press. M—M gave a useful indication as to the character of monsoon rainfall. Unluckily this is not so and the coeff. between India press. M—M, and Peninsula rainfall, J—S, is ·00. During the rains too we should have expected that low press. meant more rain and cooler weather: however parts of India get very little rain and may have a negative coeff. between press. and temp. If we take Allahabad as a typical inland station under monsoon influence we find:—

—	Allahabad temp.		
	0	+1	+2
Allahabad press.			
D—F	—·19	—·27	+·25
M—M	—·61	+·29	+·22
J—A	+·03	+·09	+·19
S—N	+·03	—·04	—·12

Even here we find that during the wet season the contemporary coeff. has not become appreciably positive; but in the dry hot weather there is a coeff. of —·61.

48. For Seychelles we have :—

—	Seychelles temp.		
	0	+1	+2
Seychelles press.			
D—F	+·14	+·27	+·31
M—M	+·17	+·31	+·45
J—A	—·24	—·03	+·45
S—N	—·44	+·01	+·12

The contemporary coeff. is positive during the wet half year when Seychelles lies in the equatorial belt of calms and an increase of rain is associated with low press. and low temp. For J—A and S—N when the trade wind is blowing, we know that high press. there goes with high press. at Mauritius and with stronger winds from a cooler region : thus the — sign is explained. The driest quarter is J—A.

49. For Mauritius we find :—

—	Mauritius temp.		
	0	+1	+2
Mauritius press.			
D—F	—·13	+·25	+·12
M—M	+·29	+·43	+·65
J—A	+·04	+·36	+·60
S—N	—·08	·00	+·18

If we plot the successive quarterly values of press. and temp. there seems to be distinctly more opposition than the above figures indicate; and a glance at the temp. curve shows an appreciable secular change. If we make a rough allowance for this by applying corrections of $-0^{\circ}{\cdot}6$ from '75 to '86 and $+0^{\circ}{\cdot}8$ from '04 to '21, we then find that the contemporary coeff. M—M changes from +·29 to —·07. Such a process is however unsatisfactory, and the table need not detain us further.

50. For St. Helena we have :—

—	St. Helena temp.		
	0	+1	+2
St. Helena press.			
D—F	—·38	—·27	—·22
M—M	—·21	—·18	—·40
J—A	+·01	+·15	—·05
S—N	—·12	—·27	—·40

Here winds from the cool southeasterly direction prevail through the year, and the coeffs. of St. Helena press. with the strength of the trades during D—F is +·15, while during J—A it is —·26. The contrast in the above table between the contemporary coeffs. of — 38, D—F, and +·01, J—A, is thus explained, especially as J—A is the wet period.

51. The figures for Honolulu and P. Delgada may be put on record.

—	Honolulu temp.			P. Delgada temp.		
	0	+1	+2	0	+1	+2
Local press.						
D—F	—·22	—·18	—·34	—·04	+·07	—·31
M—M	+·02	—·39	—·17	—·15	—·35	—·08
J—A	—·36	—·19	—·14	+·27	—·03	—·05
S—N	+·02	—·27	—·13	+·07	—·09	—·34

52. Hitherto we have considered the explanations of only the contemporary coeffs. For subsequent ones we require a knowledge of the relationships of press. at one station with those of subsequent pressures at other centres.

At Batavia the coeff. between the pressures of D—F and the following M—M is +·76: this relationship alone would give a corr. coeff. of M—M temp. with D—F press. of +(·76) (·52) or +·39, the actual being +·41. With press. of the succeeding J—A the press. of D—F has a coeff. ·48 and as press. J—A has a coeff. of +·22 this particular chain of relationships provides a coeff. of only ·11 instead of ·47; so the effect of pressures at other places has to be introduced.

53. It is obvious that the effect of press. on temp. is partly direct and partly through associated rainfall, and the relative amounts of control are of interest. If we consider Java, and take Batavia as representing its press. and temp., we may write

$$\left\{\text{Java temp.}\right\} = a\left\{\text{Java press.}\right\} + b\left\{\text{Java rain.}\right\}$$

Then we have for D—F

$\cdot 24 = a - \cdot 40\, b,\ -\cdot 49 = -\cdot 40\, a + b$;
whence $a = +\cdot 05$, $b = -\cdot 47$. Thus for D—F all the effect of press. on temp. is exerted through the rainfall.

For India we can in a similar manner deduce for J—A in the rainy season :—

$$\left\{\text{India temp.}\right\} = -\cdot 44 \left\{\text{India press.}\right\} -\cdot 70 \left\{\text{India rain.}\right\}$$

Here though there is some of the normal continental negative relationship between temp. and press. the closer relationship is between temp. and rain.

54. Some examples of time lag in the relationships of temp. at neighbouring places may be a means of throwing light on the nature of these relationships. Thus for Mauritius and Seychelles an examination of the unsmoothed graphs of quarterly temps. indicates that while there is great resemblance the variations at Seychelles come before those at Mauritius. The following table gives some of the coeffs. :—

—	Seychelles temp.		
	−1	0	+1
Mauritius temp.			
D—F	+·29	+·54	+·46
J—A	+·17	+·43	+·35

[Here +1 indicates that the figures of the last column relate to quarters for Seychelles temp. one *after* those for Mauritius, *i.e.* +·46 is the coeff. between Seychelles M—M and Mauritius D—F.]

It will be seen that in both cases there is a much closer relationship when temp. at Seychelles is a quarter after Mauritius than when before, and not very much less than the contemporary relationship: thus the surges of variation travel from Mauritius to Seychelles. The interpretation in terms of the prevailing S. E. trades and northwestward sea currents is obvious: for Braak's data show a very close approximation between sea and air temps.

55. Between the temps. of India and Seychelles we have the following coeffs. .—

—	India temp.		
	−1	0	+1
Seychelles temp.			
D—F	+·41	+·21	+·04
J—A	−·04	+·12	+·12

The influence of J—A temp. in the Indian Ocean at Seychelles though presumably carried northward by sea currents and the monsoon winds counts for little in India against the control exercised by the local rainfall.

During the period D—F however Seychelles temp. has a higher coeff. with India S—N temp. (+·41), than D—F (+·21), *i.e.*, the influence travels southward. Thus, taking a time when the N. E. trades are active, temp. in India in December has a coeff. +·24 with Seychelles temp. of the same month, +·30 with Seychelles temp. in January, and +·14 with it in February.

56. The relationships between Batavia and Seychelles are as follows:—

—	Batavia temp.				
	−2	−1	0	+1	+2
Seychelles temp.					
D—F	+·07	+·30	+·50	+·41	+·32
M—M	+·34	+·42	+·51	+·50	+·19
J—A	+·30	+·33	+·41	+·49	+·27
S—N	+·33	+·28	+·54	+·38	+·34

Here there is slight evidence of control of Batavia by Seychelles J—A, but the outstanding feature is the similarity of the contemporary conditions.

57. As an example of such relations we may take the fact, obvious from a graph,* that temp. variations in India precede those at Batavia. We find that temp. J—A at Colombo has a coeff. of +·32 with temp. at Batavia two quarters later, but +·20 with temp. two earlier. For Allahabad these coeffs. with Batavia are +·26 and +·17, which are less significant. Here I regard the smaller coeffs. of ·20 and ·17 as due to mere persistence of the similarity of contemporary temps., and the time lag seems far more pronounced than is brought out by the coeff. of ·32. The explanation of this coeff. probably is, that low temp. in India in the monsoon means abundant rain, which has a coeff. of —·46 with press. at P. Darwin two quarters later, and this means low temp. at Batavia. It is true that we have not the explanation of the —·46, but the other links in the chain are provided.

58. In the water of southern oceans there is in general a counter clockwise circulation, with a northward current and lower temps. against the eastern margin, St. Helena like the west coast of Africa south of the equator is cooled by the Benguela current, and it might be expected that the temp. at St. Helena would resemble that at Cape Town, probably with a time lag of a couple of months. The relationship is actually found, though it is not very close. Temp. at the Cape D—F has a coeff. of +·04 (17 yrs.) with St. Helena temp. of the same quarter, +·26 with that a quarter later, and +·18 with that two quarter later, J—A.

59. A region of great importance from the present standpoint is that of the S. Orkneys; and Mossman has pointed out in his contribution to this journal that there is a tendency to a press. 'see-saw' between Santiago and the region to the south, particularly in the winter: † the effect of this see-saw on the S. Orkneys is not great however, and in fact the coeff. J—A between pressures there and in S. America (B. Ayres, Cordoba and Santiago) is +·25. Mossman shows ‡ that excess rain in the extreme south of Chile (Evangelist's Island) falls with an excess of W. and N. W.

* A graph of annual and of smoothed monthly values is given in H. H. and F. N., p. 238; compare curves I and IV with III.

† Vol. XXIII, part 6, pp. 161, 2.

‡ Pp. 163, 4.

winds (as contrasted with S. E.) and tends to occur with deficient rain to the north of 30°S, where there will be an excess of S. as contrasted with N. winds. He also gives data of the amount of ice observed in the S. Orkneys, and after comparing these with the data of Indian monsoon rainfall concludes that "the results are not sufficiently conclusive to justify a statement that bad ice winters at the S. Orkneys are associated with deficient monsoon and *vice versâ*."

Mossman's data show that while ice generally occurs all the year round it is only in winter that it has been classed as 'very close'; and as this is the active period of S. American press. it is desirable to consider it further: the data that I have are from '03 to '16.

I find that for the period J—A the coeff. of temp. at S. Orkneys with contemporary press. at Santiago (33°S) is + ·2, at Pt. Galera (40°S), '03—'13, is +·45, and at S. Orkneys (61°S) is —·35 : with temp. at Santiago it is —·4 : and with rain, May to August, at Concepcion (37°S) —·35, while with Evangelist's Island (52°S) it is +·65. The probable errors are about ·2. That the temp. at the S. Orkneys is very largely controlled by the amount of ice follows from the fact that the temps. of the three open winters are much the highest temps. of the 13 years, with a mean departure of +2°·8 while that of the four very close winters is —1°·1. Now more ice will drift north to the S. Orkneys with a stronger southerly wind; and thus high temp. will be associated with northerly winds. This explains the association of high temp. at S. Orkneys with high press. at Santiago and Pt. Galera, and low press. at S. Orkneys. With high press. at Santiago is associated deficient rain at Concepcion, and with the steeper gradients come more westerly winds with more rain at Evangelist's I. The above coeff. of +·45 with press. at Pt. Galera contrasted with +·2 at Santiago, which lies to the north of it on the belt of high press., seems to support the view that in years of scanty rain at Concepcion and excess rain at Evangelist's I the belt is shifted to the south, as stated by Mossman*; but if we use the same period '03 to '13 for Santiago as for Pt. Galera its coeff. becomes ·4 and on the difference of ·05 no conclusion can be based. A mere accentuation of the belt would strengthen the normal southerly winds at Concepcion and Santiago, and explain the decreased rain and the negative relationship between temps. at S. Orkneys and Santiago.

60. In order to trace in more detail the effect of Santiago press. the following table has been worked out :—

—		Santiago press.			
		May	June	July	Aug
S. Orkneys temp.	May	+ ·2(+ ·4)	—·25(—·05)	—·25(·0)	—·3(·0)
	June	+·25(+·25)	—·05(·0)	—·1(—·05)	+·05(+·1)
	July	+·65(+·65)	+·4 (+·55)	+·45(+·55)	+·25(+·25)
	August	— ·1(—·25)	—·05(·0)	—·05(·0)	+·4(+·5)

* Page 163 of Vol. XXIII, pt. 6 of these Memoirs.

The data available cover the years '03—'16, and the figures in brackets are the coeffs. worked out when the years available were '03—'14; they have fewer negative values. It may be inferred that temp. at the S. Orkneys has little or no influence on subsequent press. at Santiago; for coeffs. ranging between + ·25 and —·3 establish nothing when the probable error is ·2. On the other hand it is clear that the S. Orkneys temp. of June and July is controlled by previous press. at Santiago and there is thus a presumption that the contemporary coeffs. of July and August must be interpreted as controls from Santiago.

61. It obviously cannot be maintained that because press. in S. America exercises a certain amount of control over the ice-conditions at the S. Orkneys, there is no control over them from the antarctic; on the other hand as the coeff. between S. America press. J—A and S. Orkneys temp. J—A is +·23* other factors must control the S. Orkneys to an extent $\left\{1-(\cdot 23)^2\right\}^{\frac{1}{2}}$ or ·97. It seems inevitable that the antarctic conditions of press., temp. and snowfall must have considerable influence; I have constructed a table of coeffs. with the Peninsula monsoon rainfall, J—S of previous and contemporary conditions:—

	—2 D—F	—1 M—M	0 J—A
S. Orkneys temp.	+·31	+·38	+·22
S. America press.	—·09	+·38	+·44

The upper line is based on data of '03—'16 and the lower on '75—'20; but if the upper line is maintained by future data it will be clear from the D—F coeff. that there is an independent element at the S. Orkneys; and the rough equality of the coeffs. of M—M and J—A suggests the interpretation that the system (1) antarctic, (2) S. Orkneys (3) S. America forms an interrelated whole as does the Atlantic system of the arctic region, Iceland, the Azores and the Gulf Stream.

The same suggestion may be derived from the coeffs. with C. Town press. D—F of conditions two quarters earlier; with S. Orkneys temp. J—A the coeff. is —·31 and with S. America press. J—A—·48.

62. We have seen that temp. at the S. Orkneys is probably controlled by the quantity of antarctic ice in the neighbourhood, and as the ocean current flows in a northeasterly and then easterly direction it might be supposed that there would be a control exercised by S. Orkneys temp. over that at C. Town. The coeffs. are however disappointing:—

———	C. Town temp. Contemporary.	C. Town temp. 2 quarters after S. Ork.
S. Orkneys temp. D—F	—·35	+·01
„ „ M—M	+·04	+·12
„ „ J—A	—·02	+·18
„ „ S—N	—·08	+·16

* For D—F this coeff. is +·15.

In the same way a control is suggested of temp. on the coast of S. W. Australia by temp. at the Cape: but the coeffs. of temp. D—F at the Cape with that 0 and 2 qrs. later at Perth are only +·07 and +·04.

63. With the possible exception of the S. Orkneys we have not hit upon any temperatures in the equatorial regions or southern hemisphere which are prime factors in controlling the general weather distribution. Where the coeffs. with temperature are high, as for Batavia, it is pressure which controls temperature. Similarly Exner found that when he had obtained a specification of the relations of pressure and temperature in northern regions with those of the extreme north, he could infer the temperature relations from those of pressure. We shall therefore in the succeeding chapter, when attempting to get a preliminary idea of the mechanism involved, in general ignore the effects of temperature as a prime cause, and in the first place consider variations of pressure and rain.

CHAPTER IV.

Physical interpretation of the relationships.

64. We shall now attempt to interpret some of the facts empirically found, and of these the most important is the general swaying of press. over the earth and its classification in two groups.

Although the Lockyers in their 1902 paper* had regarded the maxima and minima of the Bombay press. curve as coinciding in time with the subsidiary maxima and minima of short period in the curve of solar prominences, they recognised that the solar relationship required confirmation † and did not employ it in their classification of 1908.

On the other hand Bigelow in 1903, as already stated in § 42, divided the earth's surface into regions according as the press or temp. varied directly or inversely with the prominence curve. Unluckily his method of free-hand smoothing led him to assign a closer correspondence than really existed; so that although the correspondence is in reality close from 1875 to 1891, but is feeble from 1872 to 1874 and 1892 to 1900, he did not realise this and stated his conclusions without the caution that was necessary. Thus two years later ‡ in reviewing his work Bigelow said "The changes of temp. from year to year are such that in the tropical zones, where the sun shines fully on the earth's surface, temps. rise and fall directly with the solar prominence frequency; but in the middle latitudes of the earth the opposite or reverse conditions of temp. prevail. Hence, when solar activity increases and more spots or prominences can be seen, there is an increase of heat in the earth's Tropics, and this produces an increase in the circulation of the entire atmosphere. The warm air of the Tropics rises more rapidly than usual, the cold air of the upper strata over the temperate zones pours down vigorously upon the United States, Europe and Asia, and these countries are covered with a rapid succession of pronounced cold waves, such as

* Proc. Roy. Soc., LXX, June 14, 1902, pp. 500-4.

† "Should the solar origin ...... be subsequently confirmed" (pp. 502, 3).

‡ M. W. R., Washington, July, 1905, p. 295.

have marked the years 1904 and 1905." Several examples of graphical handling of the actual figures are to be found in the book of Helland-Hansen and F. Nansen, who recognise that in the tropical and subtropical regions temps. vary inversely with the prominence curve: see their pp. 137, 186, 191, 238, 252. The first of these diagrams shows clearly the great similarity between the temp. over a very large part of the earth, which includes the tropics and most of Bigelow's 'direct' region, with the *reversed* prominence curve of Palermo and Catania.

65. The question can be handled numerically. In Boletin No. 1 of the Ofic. Meteor. Argentina (1911) Bigelow explains (p. 7) that he works not with actuals but with 'residuals' obtained by subtracting from the actual value for any year the mean of the five consecutive annual values of which that is the central one. If we take the data of the Osservatorio del Collegio Romano, '71—'00, in H. H. and F. N., p. 336, calculate the residuals and correlate them with the 'residuals' of Bombay * annual press., we find a corr. coeff. of +·37; while with India temp. treated similarly the coeff. is +·05, the probable error being ·12.

In order to elucidate the point at issue I have obtained from Mr. Evershed of the Kodaikanal Observatory, which maintains a very complete record, the appended table of the average daily areas of prominences from 1890 to 1921.†

AVERAGE AREAS OF PROMINENCE.

—	0	1	2	3	4	5	6	7	8	9
189 . . .	1·76	2·89	9·36	9·27	5·23	3·75	2·61	3·53	3·61	2·87
190 . . .	3·17	2·07	2·15	2·65	4·72	4·64	3·98	4·37	5·57	4·18
191 . . .	4·12	2·91	2·46	2·20	3·10	5·12	3·71	5·17	4·21	3·67
192 . . .	4·32	4·14	...	...	...	...	...	...	...	...

On determining the residuals in Bigelow's manner the coeff. between those of Bombay press. and of the prominence areas is −·24, and between those of India temp. and of the prominence areas is −·18: thus the relationship of the residuals over the past 32 years has been inverse, not direct.

66. Having realised that press. in India as a representative of our second or negative group tends on the whole to vary inversely with the curve of sunspots or prominences the question arises how far relations with solar conditions lead to a classification resembling ours; and the answer, briefly given in § 42 above, is surprising. The corr. coeffs. of annual press. with sunspots given in Table I (pp. 94-97), as well as in its accompanying chart, of Vol. XXI, Part 12 of these memoirs, shows a pronounced negative region over Australia, southern Asia (reaching north to Irkutsk but not Eniseisk), Mauritius, and east and south Africa, with a pronounced positive region over the Argentine and Chili, Hawaii, the S. E. of the United States and the

* I have selected Bombay and India merely for convenience.

† Of this the portion from 1890 to 1904 is based on Mr. Evershed's measurements at Kenley.

Azores: Iceland is very feebly negative; and it may be claimed that the chart of sunspots-press. coeffs. agrees with that of our press. oscillations to the extent involved in the known probable errors.* The similarity is not confined to the annual values: the coeffs. with sunspots of the D—F and J—A pressures given in § 8 above are in perfect agreement in indicating that while S. America and Honolulu are positive centres J—A they are neutral D—F; probably the chief discrepancies are that Stykkisholm D—F has +·10 instead of a small negative coeff., P. Delgada has ·00 and —·01 instead of small positive coeffs. and India J—A has —·02 instead of about —·20.

67. The meaning of this similarity must be either that the variations of sunspots dominate the world-weather to such an extent that world-press. oscillates directly under its control; or else that variations of world-weather tend to occur in a definite manner, *i.e.*, to be associated with definite swayings or surges of press., and that changes in solar conditions tend to favour or check these weather changes; such oscillations if they had been strictly periodic might have been regarded as forced oscillations of a type corresponding to the natural weather oscillations of the atmosphere. Now we have already, in § 16, seen reasons for thinking that world-weather is not directly dominated by solar conditions; but we may state the question now at issue in an analytical form. Let us take Peninsula rainfall as an example and express its departure by the equation:—

$$\left\{\begin{matrix}\text{Peninsula}\\ \text{rain}\end{matrix}\right\} = a\left\{\begin{matrix}\text{press.}\\ \text{distribution,}\\ \text{J—A}\end{matrix}\right\} + b\left\{\begin{matrix}\text{sunspot}\\ \text{number}\end{matrix}\right\},$$

where as a rough approximation we may take as a measure of the press. distribution of J—A the press. departures, (Honolulu + S. America) — (Australia + Mauritius). If the pressures are dependent on the contemporary† spot number we shall obtain a small a and a large b, and *vice versâ*: in fact we obtain the decisive result, $a = \cdot 48$, $b = \cdot 09$.

The same conclusion may be drawn at once from the decidedly greater coeffs. between the seasonal pressures at different places than between them and the sunspot numbers.

68. We have now therefore to attempt to form an idea of the processes that determine the regions over which press. rises or falls simultaneously. One of the more plausible theories of world-weather was urged by Col. H. E. Rawson in 1908,‡ who interpreted the changes as due to northward and southward oscillation of the belts of high press. in the periods of 19 years advocated by Mr. Hutchins. His ideas were mainly based on S. Africa where he showed that there were decidedly numerous N. W. winds at the Cape in the winter months from '96 to '00, as compared with '42—'55 and '62—'65. But at Cape Town the wind that brings most rain is N. N. W.‖ and generally in S. Africa N. W. winds are associated with rain-bearing depressions; so that it is unsafe to argue that their greater frequency necessarily implies a long-lasting northerly displacement of the anticyclonic belt. Rawson's second source of

* It must be remembered that as shown in Vol. XXI, Part II, of these Memoirs the probable value of the greatest of 16 of these errors is three times the probable value of a single one.

† Even if the pressures depend on the spot number of the previous year the argument will in great measure hold as the spot numbers change fairly continuously from year to year while the press. changes are often abrupt.

‡ Q. J. R. Metl. Soc., XXXIV, pp. 165—185.

‖ Hann's Klimatologie, III, p. 462, 1911.

information with regard to the belt appears also of doubtful reliability: he infers (p. 176) that because the annual pressures for '87 and '99 at Durban were the highest and second highest on record, the belt must have had the same position in both years, very close to Durban: he seems to forget that press. may rise and fall over a region without any change in the position of the highest press. Colonel Rawson regards the influence of the oscillations of the belt as extending to Australia (p. 183), and if so years of good S. African and Indian rains and abundant Niles, which are in his view associated with a northward displacement, would be years of high press. at Mauritius, which lies well to the north of the belt: as a matter of fact the opposite is the case.

69. The obvious tendency for centres of high press. to be in the first group and of low press. in the second suggests a closer examination. Let us make a table of our centres, indicating those in the first group by + 1, + 2, + 3 according as the adherence is slight, moderate or strong, and those in the second group by — 1, — 2, — 3.

These numbers are inserted under the heading 'Group' for D—F and J—A. Under the heading 'Departure' I have inserted the departure from 760 mm. of the press. at the place in January and July respectively, as indicated on Kassner's globes (Berlin, 1907).

—	D—F		J—A	
	Group.	Departure.	Group.	Departure.
Iceland	−1	−10	−2	− 4
Alaska	0	− 4	−1	+ 1
C. Siberia	−1	+17	−2	− 5
Azores	+1	+ 4	+2	+ 9
Charleston	+2	+ 6	+1	+ 3
Honolulu	0	+ 3	+3	+ 2
N. W. India	−2	+ 4	−2	−12
P. Darwin	−3	− 8	−3	0
Mauritius	−2	− 1	−1	+ 5
St. Helena	−1	+ 1	0	+ 5
Samoa	+2	− 4	+3	0
S. E. Australia	−2	− 3	−2	+ 4
C. Town	−2	+ 1	0	+ 6
S. America	0	− 2	+3	+ 3
S. Orkneys	−1	−18	+1	−20
Peninsula rain	...	...	+3	...
Java rain	+2	...	...	...

There must be an element of uncertainty in assigning the group number, especially as the Iceland-Azores oscillation is not very closely related with that between the Pacific and Indian Oceans, which affects a far larger portion of the earth's surface, and is therefore much more important: but of three cases where there is a marked difference between the group numbers D—F and J—A at the same place, *i.e.*, Honolulu, C. Town and S. America, the differences in the last two cases accord with the seasonal differences of press.; at Honolulu the difference of press. is insignificant.

There are in the above Table 9 examples of differences of sign between the group number and the departure out of 30 cases, the group number being about a third of the departure number with the modification that in C. Siberia, N. W. India, P. Darwin, Mauritius, St. Helena and S. E. Australia we have to subtract something from the group number so calculated during one or both seasons; while for Honolulu, Samoa, S. America and especially the S. Orkneys we have to add to it.

70. The obvious remark is that a general increase of circulation would send up those pressures which are normally above the general level and down those which are normally below it: and with this we should expect to find the raising of press. over the biggest sea area (the Pacific) and the lowering of it over the biggest land area (eastern Europe, Asia and much of Africa); an increase of circulation will produce rain over the continents much more than over the oceans, and hence press. will fall over the continents and rise over the oceans. The weak points in this theory are Australia, Mauritius and S. Africa during their dry periods when the ocean influence might be expected to predominate; and the matter must be postponed to § 79.

71. At this stage it seems desirable to leave speculations of a general character and learn what we can of the connections which maintain the groups. It was Hildebrandsson's view that tropical climates are very regular and that there is no phenomenon in the temperate regions of sufficient importance to be the cause of the considerable differences between successive seasons: in the northern hemisphere therefore the principal cause must be sought in the polar seas.* In the southern hemisphere however Hildebrandsson considered that while the ultimate control lay in the extreme south,† in the varying amounts of drifting antarctic ice, the types of season were propagated from west to east like waves. For the latter view he relied upon the extent to which Java rain (O—M) was controlled by C. Town press. a year before, or Mauritius press., Ap—S, before: in Australia the Java association was with press. contemporary with the Java rain, and in S. America with press. of the succeeding Ap—S. We have however already seen that subsequent data have not confirmed Hildebrandsson's ideas of the relations between the Cape and Java, or Java and S. America (See § 31 and § 35 above); and we shall therefore consider the propagation across the oceans separately.

72. For the S. Atlantic if we take C. Town press. D—F, the time when it is significant, and correlate it with S. America press. three quarters before we find a coeff. of −·38, for 2 qrs. before −·48, for 1 qr. before −·29, contemporary +·12, 1 qr. after −·42 and 2 qrs. after −·16: the probable error being ·1 it is doubtful whether

* H 5, p. 5.

† See H 4, p. 20, the lower portion.

the isolated —·42 expresses a physical reality; but the coeff. —·48, with —·38 and —·29 next to it, affords good evidence of an eastward propagation of a reversed wave in about six months.

73. Now a reversal of this kind is hard to conceive, and it is fortunate that there are sufficient data from the region to the south of C. Horn to transform Hildebrandsson's guess that antarctic ice was of vital importance into a working theory. We have seen in § 59 that temp. at S. Orkneys J—A has a coeff. of +·45 with press. at Pt. Galera (11 yrs. only), of —·35 with press. at S. Orkneys (13 yrs.), and of —·4 with temp. at Santiago: and its coeff. —·3 with Cape Town press. D—F of the succeeding summer supports the view that when press. in S. America is high and temp. near S. Orkneys is high the eastward current from the region of the S. Orkneys will be less cold than usual and will bring lower press. with it. It is true that press. J—A at S. Orkneys has a coeff. +·25 with the contemporary press. of S. America; but there is ground for believing that at Snow Hill (64° 22′ S, 57° 00′ W) the coeff. with S. America is negative. From the 20 monthly values of press. available Dr. G. C. Simpson deduced a coeff. +·38 between press. at Snow Hill and at Mc Murdo Sound; while the coeff. between the latter and Santiago, Cordoba and B. Ayres were —·40, —·54 and —·48 respectively, the data being 48 monthly values in each case. For S. Orkneys the coeff. was +·12 (34 months) and for Samoa —·44 (48 months).* For a determination of the coeff. between Snow Hill and Santiago there are available here only the twelve monthly press. values for Snow Hill given by Dr. Simpson on his p. 199; and these give a coeff. of —·53 with contemporary press. at Santiago. It appears that for a complete explanation we must await more data from the antarctic: but it is, I think in the region south of C. Horn that the key to the problem of the reversal of S. American press. will be found.

74. For the southwest of the Indian Ocean the coeffs. between press. D—F at the Cape and press. of —2, —1, 0, +1, +2 quarters later at Mauritius are +·29, —·02, —·03, ·00, ·00, which give little idea of movement: the only big coeff. in the Mauritius table with press. two quarters earlier is —·49 with S. America, J—A, and this recalls —·48 the coeff. between C. Town and S. America, J—A, two quarters earlier. It seems that the antarctic influence arrives directly at Mauritius, not across C. Town.

75. For Mauritius to Australia the coeffs. of press. S. E. Australia, J—A, with press. at Mauritius 2 qrs. earlier is —·02, 1 qr. earlier +·30, contemporary +·43, 1 qr. after +·04 and 2 qrs. after +·17: the movement here also appears to occur eastwards and to take one or two months.

76. For the western Pacific region we have coeffs. between S. E. Australia press. J—A and Samoa press. 2 qrs. before —·07, 1 qr. before —·19, contemporary —·37, 1 qr. after —·01, 2 qrs. after —·13. Taking S. E. Australia D—F the coeffs. with Samoa +2, 0 and —2 qrs. earlier are —·41, —·54 and —·30. If instead of S. E. Australia (Alice Springs, Brisbane, Adelaide) we take P. Darwin, D—F, then with

* British Antarctic Expedition, 1910-13, Vol. I, pp. 201-3, 1919.

Samoa 2, 0, −2 qrs. earlier we have −·62, −·57, −·28; and for P. Darwin, J—A, −·23, −·55, −·29. There is evidence that P. Darwin and S. E. Australia D−F are affected by Samoa about 3 months earlier, but there is not much evidence of this kind for P. Darwin or S. E. Australia, J—A.

77. Across the Pacific between Samoa and S. America a time-lag seems fairly definite. If we consider annual pressures first as a rough indication we find that with Samoa press. that at Honolulu has coeffs. +·16, +·33 and +·04 one year before, the same year and the year after; but for S. America with Samoa these coeffs. are +·50, +·58 and +·17, so that the effect of S. America on Samoa is shown as much a year afterwards as at the time. This may be studied more in detail in the table of corr. coeffs. with S. America press. For D—F, when the influence of S. America press. is insignificant, its coeff. with press. at Samoa −2, 0 and +2 qrs. afterwards are −·35, +·24 and +·11; so that there is no westward propagation, but perhaps some reversed movement eastwards for a time. For J−A, on the other hand, the three coeffs. are −·01, +·49 and +·48; and with press. at Samoa 4 qrs. afterwards the coeff. is +·46: we therefore have a strong positive influence exerted for a considerable period by S. America at this time.

78. In the west Pacific the contemporary opposition between Samoa and Australia requires little elucidation. If a rise of press. occurs in S. America a wave of low press. travels eastward from the southern regions and reaches Australia in a few months. In this way we have between S. America J—A and Australia a contemporary coeff. of −·33, and a coeff. of −·57 with press. in Australia in the D−F following. On the other hand, as we have seen in § 77, S. America press. J—A has with contemporary Samoa press. a coeff. +·49, and with Samoa press. in the D—F following a coeff. +·48.

79. We are now in a position to take up the question of the contrast between the Pacific and the Indian Oceans to which attention was drawn in §§ 69, 70. It is mainly due to the propagation of waves of opposite signs eastward and westward from the system situated in S. America and the region to the south of it. Also the explanation of the fact that the waves of low press. which travel eastwards are not damped out before reaching Australia may perhaps lie partly in further influences from the antarctic of which nothing is known; but it probably lies mainly in the existence of monsoons in India and Australia which reinforce the waves because an increase of monsoon rainfall diminishes press. and so amplifies the decrease of press. to which it is due.

It may be that there is no real propagation westward from Chile, but that the influence of the process which creates the opposition between Chile and the antarctic extends westwards to Samoa along the belt of high press.

80. One of the most surprising features in the table of § 69 is the neutrality of S. America during the quarter D—F, in spite of its being very strongly in the first group of centres J—A; while on the other hand S. E. Australia is −2 during both seasons. This supports our interpretation that the source of the variations of weather lies mainly in the S. America-antarctic system. For if the control of general weather

lies in the variations of an ice-bearing current it must have an annual period; and in the classification of S. America the annual period is strongly marked. In order to test whether there is a change of character in the system between D—F and J—A as far as the available data allow I have taken the twelve monthly departures of Snow Hill (corrected for annual variation) and the corresponding departures of Santiago press. from March '02 to Feb. '03 referred to in § 73:—

	M	A	M	J	J	A	S	O	N	D	J	F
Snow Hill	−15	+61	−65	+216	+140	−109	+45	−84	+76	−50	−1	−201
Santiago	−90	−66	−30	−125	−11	+69	−08	+19	−45	−25	+17	−30

(In the upper line the unit is a thousandth of an inch: in the lower a hundredth of a mm.)

It will be observed that during the months D—F the variations are mainly of the same sign: while during the eight months April—Nov there is strong opposition, the corr. coeff. being −·8.

The lack of an annual period in Samoa may be due to the persistence of the S. American influence J—A through a year (§ 77); and we might perhaps explain the reappearance of neutrality D—F at Honolulu as due to its separation from Samoa by the equatorial low press. which prevails at that time.

81. In our present ignorance regarding the mechanism of press. changes all facts are worth putting down; it appears that (*a*) there is a time lag of India press. (mean of Calcutta, Bombay, Madras) behind that of Adelaide: the coeffs. of Adelaide, D—F, press. with that of India 0, 1, 2 qrs. afterwards are +·34, +·45, −·05; with that of Adelaide J—A, press. the coeffs. are +·31, +·62, +·33: (*b*) there is some evidence of a lag between Adelaide in winter and P. Darwin: the coeffs. with Adelaide press. J—A and that at P. Darwin −1, 0, 1, 2 quarters later are +·04, +·70, +·55, +·47, while with D—F press. the coeffs. are +·44, +·47, +·34 and −·16. This lag is however probably due entirely to the persistence of winter press. at P. Darwin, the coeff. between press. J—A there and press. two quarters later being +·83.

82. When selecting a relationship in a region where ample data are available for more detailed examination of the processes involved, it is advisable to choose one in which the results produced by the relationship follow the cause after as long an interval as possible: we may hope to get intermediate factors and to use the time element to decide which is cause and which is effect in a case of doubt. If departures *a*, *b*, *c*, *d*, tend to occur in monthly means of the same month it is often hard to arrange them in logical sequence, but if they occur in the monthly means of four consecutive months, we may not be certain that *b* is the cause of *c*, but we do know that *c* is not the direct cause of *b*. I have therefore chosen for further examination the prejudicial effect of excessive Java rain, Oct—Feb, on the subsequent monsoon rain of India, June to Sept, the coeff. being −·38. First let us look at the press. conditions. The effect of Java rain on Batavia press. is −·40 from D—F, −·02 in the succeeding

M—M, and +·12 during J—A after that. The effect of Batavia press. on India press. is given in the table :—

Batavia.	India (mean of Calcutta Bombay and Madras).		
	Same quarter.	One qr. after Batavia.	Two qrs. after Batavia.
D—F	+·93	+·69	—·16
M—M	+·82	—·09	+·06
J—A	—·06	+·63	+·39
S—N	+·85	+·53	+·58

The marked negative effect of —·40 on Batavia D—F will not explain the marked positive effect on India press. which starts in June. The intermediate factor not being Batavia press. let us consider India press.; the corr. coeff. of Java rain with Bombay press. of the successive months, Jan to June, are —·28, —·09, — 21, + 10, —·11 and —·02 : for June to Aug with press. over India as a whole it is +·31. So India press. does not yield the solution.

With Zanzibar rainfall during the months Jan to May the coeffs. of Java rain are —·03, ·00, —·18, +·35, +·17 ;* and with the corresponding Seychelles rain the coeffs. are +·02, —·27, —·64, —·25, —·40. It is worthy of note that it is rainfall in the Peninsula that is seriously affected by Java rain, and it is this which is seriously affected by excessive rainfall at Zanzibar,† chiefly in May but partly in April. The large negative coeffs. with Seychelles are interesting in that a deficiency of rain there in May is good for the monsoon in northeast India, and it is here alone in India that an excess of Java rain is beneficial.

83. For the other centres we have :—

Press.	Coeffs. of Java rain, O—F, with		
	D—F Contemporary.	M—M One qr. after.	J—A Two qrs. after.
Iceland	+·26 (—·10)	+·14 (—·08)	+·19 (+·03)
Alaska	+·33 (—·38)	......	+·05 (—·11)
C. Siberia	—·15 (+·24)	—·03 (+·14)	+·35 (—·33)
Azores	—·15 (+·21)	—·17 (—·03)	—·18 (+·10)
Honolulu	—·32 (+·23)	—·07 (+·29)	—·14 (+·46)
P. Darwin	—·46 (—·03)	+·08 (—·33)	+·17 (—·40)
Mauritius	—·05 (+·08)	—·16 (—·17)	+·03 (—·52)
C. Town	—·33 (+·01)	—·04 (—·11)	—·13 (+·10)
S. America	+·28 (—·09)	+·19 (+·38)	—·18 (+·44)
S. Orkneys	—·13 (+·34)	......	+·33 (+·03)

* The data refer to the rainfall of Zanzibar alone, not to the Zanzibar district: the May coeff. of the district is +·04.

† Reference to Table II, Vol. XXIII, part 2 of these memoirs will show the close correspondence between the areas affected by rainfall at Zanzibar, Seychelles and Java.

The figures in brackets are the coeffs. of the factor in question with Peninsula rainfall: thus Java rain has a coeff. of $-\cdot15$ with C. Siberia press. D—F, and this has a coeff. of $+\cdot24$ with Peninsula rain; also Java rain is related $+\cdot35$ with C. Siberia press. J—A, and this is related $-\cdot33$ with Peninsula rain: both these contributions from the variations of Siberia towards variations of the Peninsula rain are negative; and out of the twentyeight contributions obtained in this way only seven are positive, of which most are small. It would seem therefore that part of the effect of Java rain on the Indian monsoon is produced through Zanzibar and Seychelles rain, and the rest through general unfavourableness of the conditions.

84. Now the effect of excess rain is to make the lapse rate of temp. smaller than usual; thus temp. at a height of say ·6 km. will be higher than usual, and as more air than usual has, in view of its relative lightness, risen above the level of condensation and must be spreading out horizontally, press. in the upper air will be relatively higher than in regions where rainfall is in defect. The result of this outflow must be a slight rise of press. over the neighbouring regions; and the result of the decreased lapse rate is greater stability of the air and so less facility for the production of rain in the region affected. In the table of the previous paragraph the centres nearest to Java are P. Darwin, Mauritius, and C. Siberia, to which we may add N. W. India from the original Java table (§35): the coeffs. of Java rain with the contemporary pressures D—F at these centres are $-\cdot46$, $-\cdot05$, $-\cdot15$ and $-\cdot32$ all negative; and the coeffs. with the pressures two quarters later are $+\cdot17$, $+\cdot03$, $+\cdot35$ and $+\cdot10$. It is an attractive hypothesis that we have here an illustration of excess pressures caused by excess rain; just as Rhodesia rain, O—M, has a coeff. of $-\cdot43$ with C. Town D—F, but $+\cdot18$ for the J—A after. On the other hand the coeff. of Peninsula rain with press. 2 qrs. later at P. Darwin is negative and with C. Siberia press. is negligible: so judgment in the matter must be postponed. The marked diminution of rain at Seychelles, between which and Java an upper east wind prevails during much of the time, may be due partly to increased press. and also to decreased lapse rate: Zanzibar is farther away from Java, but probably not at a sufficiently greater distance to explain the reversal of effect.

85. As other examples of a negative effect of rainfall on subsequent rain in its neighbourhood we may quote the May rainfall of Aminidivi (Laccadive Islands) with a coeff. of $-\cdot32$ with Peninsula rainfall, J—S (based on 27 yrs.), and the May rainfall of S. Ceylon, with a coeff. of $-\cdot29$ with N. W. India rainfall, J—S.

86. Using the ordinary formula which gives the temperature departure of the column of air between a hill-station and a neighbouring station in the plains in terms of the press. departures of the two stations, we may find that for Simla (height 2·1 km.) and Ambala in the plains the coeff. between N. W. India rainfall (J—S) and the mean temp. of the column J—A is $-\cdot49$; conditions are here continental and the altitude is not nearly high enough for the coeff. to change sign. On the other hand for the mean temp. between Kodaikanal (height 2·34 km.) and Madura, in the extreme south of the Peninsula, J—A, we find with the Peninsula rainfall J—S, $+\cdot08$ and with the rainfall of Madras Southeast $+\cdot10$.

87. Another marked relationship is that between N. W. India rainfall, J—S, and the press. at C. Town, D—F, two quarters later of which the coeff. is —·59. This effect of the Indian rain is not exerted through the ground level air pressure, for the coeff. between N. W. India press. and C. Town press. two quarters later is only +·27. On the other hand we find that for Leh (height 3·5 km.) press. J—A the coeff. with C. Town two quarters later is +·03: for this purpose the neutral height is about 3·9 km. or ·4 km. above Leh, and if there is in the upper air a considerable press. relationship with C. Town its seat must be much above Leh.

88. It was pointed out (§ 84 above) that conditions would be the more favourable for rainfall the steeper the lapse rate and therefore the lower the temp. at a height of a few km: it is interesting therefore to note that the coeff. of the max. temp. in May at Leh with N. W. India rainfall, J—S, is —·22 ('75—'20) and with Peninsula rainfall —·15: with the N. W. India rainfall of the following July the coeff. is —·43*.

* I owe the knowledge of the influence of Leh temp. to Dr. G. C. Simpson: for the interpretation put upon it here he is in no way responsible.

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