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## Sir Gilbert Walker's formula for Ceara's droughts
## Suggestions for its physical explanation

By SAMPAIO FERRAZ
*Director of the Brazilian Meteorological Service*

It was a grateful surprise for Brazilian meteorologists when Sir Gilbert Walker published his study of the famines of Ceará (Brazil) in the light of the general air circulation, and his masterly effort to draw up a forecasting formula for them, based on the relations between that State's rainfall and the conditions at the "centres" of the "southern oscillation."* The retrospective verification of the formula from 1926 to 1876 is certainly encouraging and represents another well-won fight for the correlation workers under the intense leadership of the

*GILBERT T. WALKER. Ceará (Brazil) famines and the general air movement. *Beitr. Phys. frei Atmosph., Leipzig,* 14, 1928, pp. 88-93.

The regression formula developed by Sir Gilbert Walker takes the form

$$[\text{Ceará}] = \cdot 44\,[\text{Santiago}] + \cdot 20\,[\text{Honolulu}] - \cdot 10\,[\text{Cape}] - \cdot 42\,[\text{S. Rhodesia}] - \cdot 22\,[\text{St. Helena}]$$

where the sign [ ] indicates that the unit of measurement is the standard deviation.

Ceará rainfall for Jan.-June is compared with the following data for the preceding year:

| | | |
|---|---|---|
| Santiago | pressure | June-August. |
| Honolulu | pressure | June-November. |
| Cape Town | pressure | September-November. |
| S. Rhodesia | rainfall | July-November. |
| St. Helena | wind | September-November. |

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author. The predicting equation is based on positive coefficients with Santiago's and Honolulu's pressure, and negative coefficients with Cape Town's pressure. Southern Rhodesia's rainfall and St. Helena's wind.

I would like to offer a few suggestions for possible physical explanations of such relations. In 1925 (*Causas provaveis das sêccas do Nordeste Brasileiro*), I attempted to show that the north-east droughts were coincident with a very reduced frequency of the migratory anticyclones or with their abnormally southern tracks, and that excessive precipitation was always connected with northerly tracks and more active circulation of the general eastward currents of lower and upper air. In the drought years the large continental area of low pressure is very persistent, and often the highs that are able to get into the Argentine are kept violently back or dissipated by it. Naturally, as would be expected, drought years are also notable for stronger winds in the famine regions, but there are exceptions. As I had before explained the enigmatic winter rainfall of Pernambuco and contiguous States by the action of the anticyclones, and considering they are felt as "friagens"—cold and dull spells—as far north as the Jurua in the Amazon Valley, and certainly do affect energetically the weather of Fernando Noronha, I thought they could perhaps influence the famine region through the upper air, altering substantially its vertical lapse rate of temperature. The lower currents of cold air are not able to reach the north-east overland as they do the Jurua on account of large orographic systems, but the higher air should be able to arrive there when the massive westerly currents that carry the anticyclones are abnormally active and run in lower parallels, too much so for the season.

I am under the impression that too little attention has been paid by meteorologists to the powerful influence of abnormally cold upper currents between the tropics. And yet our daily charts exhibit frequently this influence as the biggest rainmaker. I go even further, admitting that the more intense and less obstructed South Atlantic anticyclones are responsible for the northward shifting of the doldrums, and would be led to explain Durst's assertion regarding rainfall of that region coinciding more often with cooler air, by the frequent northern rushes of those systems. From Fernando Noronha to the doldrums the distance is not prohibitive. We must remember that nowhere else in the southern hemisphere do the moving highs have such regular north-easterly tracks as in the Atlantic.

Cuyaba's pressure and Ceará's rainfall have a contemporary correlation coefficient of 0·54 (Jan.-June). Santiago and Ceará have a similar coefficient of 0·49. I should say Sir Gilbert Walker's Santiago coefficient for June-August could be explained by persistence, because the two periods June-August and

January-June are fairly well correlated (0·43). Highs which run to the Atlantic without appreciable land track will to some extent increase the south-east trades, and may contemporaneously help to reduce Ceará's rainfall. South African highs, such as are formed between the two continents, not necessarily connected with the South American highs, may possibly and indirectly affect Ceará's rainfall. They would increase Cape Town's pressure, St. Helena's wind and, according to our views, Southern Rhodesia's rainfall, acting through the upper air. As a matter of fact Bliss has given us negative low coefficients for such a relation, but Sir Gilbert Walker's cross coefficient of 0·50 for July-November and September-November, between Southern Rhodesia and Cape Town, comes to our support, noting that Southern Rhodesia's precipitation in July and August is insignificant.

The three last factors of the predicting equation will represent a diminution of the temperature of the oceanic current which five months later (from St. Helena and south of it) will run offshore the famine region of Brazil. All of them really stand for conditions which reduce that temperature, and the potential humidity of the trades.

In proposing these suggestions my objective is to interpret Sir Gilbert Walker's formula in the light of such factors as can be indicated as responsible for the droughts of north-eastern Brazil. Putting aside such factors as upper air inversions, and absence of forced ascensions of air brought about by under and over-running of currents, things that may occur above without our knowledge, but are not likely in those regions, we may consider the three others—(*a*) breaking up of convective activity by abnormally strong trades; (*b*) absence of cold upper currents from higher latitudes; (*c*) diminution of humidity in the trades. All these conditions are supposed to be frequent in drought years. Of the first two there are many eloquent indications; of the third there are no observations to support or oppose. As would be expected the second factor is only contrary to rainfall in the famine region; further north, in Maranhao, Para and in the Amazon it is a favourable factor, where the uprush of air is increased by accumulation.

In years of excessive rainfall in the north-eastern semi-arid regions, the maps do not show the usual orographic effect, which seems to favour my views.

These are mere suggestions. In the forecasting treatise which I am writing, and where the South Atlantic and South American air circulations are dealt with in detail, at least as far as the data available will allow, all these points are more clearly put down and an effort is made to base them on observations rather than on suppositions.

An attempt was also made to introduce a slight improvement in Sir Gilbert Walker's equation, considering the two big droughts of 1915 and 1919 are not predicted satisfactorily by it. I believed it would be bettered if increased by a factor which represented the activity of the continental depression. It must be remembered that Santiago gives us the frequency and intensity of incoming highs, but fails to represent the contrary effect of the equatorial currents upon them. Unfortunately, we have no long series of pressure or temperature observations in a strategic point of Brazil near the equator. Cuyaba is too far south, but is better than Santiago. I thought Samoa or Batavia would give us the factor needed, and a preliminary inspection of their temperature data in abnormal years of Ceará's rainfall, led us to introduce Samoa in the new equation, where also Punta Galera was placed instead of Santiago, on account of its higher coefficient. We were seriously handicapped, not having St. Helena's observations to work with. The new equation—[Ceará] = 0·67 [Punta Galera] − 0·39 [S. Rhodesia] − 0·16 [Cape] − 0·13 [Samoa], with a total correlation factor of 0·88, although it improved the forecasts for 1915 and 1919 a drought is indicated in 1914 which did not occur and rainfall deficiency appears to be exaggerated right through in the retrospective curve. New studies must be made, preserving St. Helena.

Punta Galera was handled only for the reason given. I do not believe it reliable, however, in longer series. Its high coefficient is surprising considering the position of that station, subject to the influence of the high-latitude lows. There is no persistence in the data as we note in Santiago. Cuyaba does not show it either. If a predicting formula should represent individual factors and not combinations of them, Santiago is a better station for picturing the incoming anticyclones. Another should be sought to represent the continental resistance (equatorial currents) with the indispensable persistence coefficient to make it available in a forecast equation. Or perhaps the "oscillation" principle to which I have not given any attention in this rapid study, may prove a bigger helper.

At any rate Sir Gilbert Walker's equation is a remarkable advance, and will certainly assist other workers in searching for improvements.

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## Sun Pillars, Crosses in the Sky, and Mock Suns

By F. J. W. Whipple, Sc.D., F.Inst.P.

The occurrence on a Good Friday of a beautiful cross in the western sky has appealed to the imagination of the public and has led to a good deal of discussion in the newspapers. The Editor of the *Meteorological Magazine* has asked me for an explanation of the phenomenon. I am sorry that I have no complete explanation to give, but I think it will be worth while to consider in some detail the questions raised by this rare appearance in the sky.

It is clear from the published descriptions that there were three distinct phenomena seen on the evening in question, the vertical column or sun pillar which attracted general attention, the cross arms which were seen by numerous observers and the bright patch or mock sun which was detected at the intersection by the practised observers, Messrs. Russell and Goodman. A sun pillar is by no means an unusual sight, though such a fine one as was seen on Good Friday must be rare. There is no doubt as to the explanation. It was given in vivid language in a letter written to *The Times* by Dr. Louis Cobbett.

"I once in Switzerland saw a sun pillar, similar to that which appeared here (in Cambridge) on Good Friday, but descending instead of ascending from the sun. The latter was high in the sky at the time, and the line of light stretched downwards across the dark background of the Weisshorn into the depth of the Rhone Valley below. So far as I remember it had no particular colour. The air was sparkling with crystals, and little feathery six-rayed plates of ice were falling sparsely out of a clear blue sky. These, being very thin, were unable to fall edgeways, but were kept gently wobbling about a mean horizontal position, and it was obvious that it was from their surfaces that the light which formed the sun pillar was being reflected in much the same way as moonlight forms a pathway of light on the sea."

Another interesting description is given by Prof. E. W. MacBride, who made his observation in the Windsor Terminus of the Canadian Pacific Railway in Montreal. The air was full of minute crystals condensed from the steam produced by one or two large locomotives just outside the station and the part of the sun was played by a powerful electric light. He writes to me: "I can not clearly recollect whether I saw any halo round the electric light or trace of horizontal arcs. What remains clearly and ineffaceably imprinted on my memory is the image of the strongly marked vertical pillar. The air in the station must have been in a state of comparative quiet."

Dr. Cobbett's description justifies the assumption that sun pillars are produced by the reflection of light from flat crystals. Prof. MacBride's evidence indicates that such crystals can be produced artificially.

A marvellous feature of sun pillars such as that of Good Friday is the large area over which they are seen. On this occasion the pillar could be seen by anyone who looked at the western sky from anywhere in the eastern counties from Lincoln to Kent. It was also seen in Surrey, Berkshire, Hampshire and

Wiltshire. There were still more widely spread observations on March 13th, 1924, when the area covered included the half of England east of a line from Scarborough to Paignton. On Good Friday there was little visible cloud to catch the eye of a meteorological observer. The presence of the crystals was revealed only by the light which they reflected towards the spectators far to the east of them. How and why this enormous swarm of crystals was produced we cannot tell. The fact that the pillar was still visible half an hour after sunset is evidence for the great height of the swarm. It was too diffuse to be noticed as cloud however and it may have been at a lower level than the cirrus which was visible to some of the observers.

We have now to consider the horizontal arms of the cross. The crosses in the sky which have been recorded before nearly all occurred with the sun above the horizon and in most cases the sun or moon was at the intersection of the arms. That sort of cross can be regarded as the simultaneous appearance of a sun pillar and a part of the mock sun ring. The mock sun ring is believed to be produced by the reflection of light from the surfaces of little prisms floating in the air with their axes vertical. Why prisms do float sometimes in the upright position is still uncertain. It may be that each prism has a flat cap which acts as a parachute, it may be that each contains an air bubble near one end or it may be that needle-like prisms point up and down in a strong electric field, just as iron filings all point the same way in a strong magnetic field.

The Good Friday cross was not in this category. There is however a famous parallel. We quote from a letter written to *The Times* by Miss Barbara Carter: "A flaming cross such as that seen on Good Friday is described by Digno Compagni, the Florentine chronicler, as having appeared in the November of 1301. 'That evening,' he writes, 'there appeared in the sky a marvellous sign, to wit, a vermilion cross, over the palace of the Priors. Its stem was a palm and a half in width; its upright appeared to be 20 braccia long, the cross-piece a little less. It lasted for the time it would take a horse to run twice round the lists. Hence the people who saw it, and I who saw it clearly, understood that God was greatly angered with our city.' Dante, for whom the date marked the beginning of his 20 years' exile, refers to the same phenomenon in his *Convivio*; in Florence, at the outset of her destruction, a great quantity of those vapours that are of the following of Mars, were seen in the air in the shape of a cross."

The short duration of the cross-piece "the time it would take a horse to run twice round the lists," may be compared with the seven minutes recorded by Spencer Russell on Good Friday.

In Russell's observation there was a mock sun at the intersection of the cross-piece with the sun pillar. This intersection was at an elevation of 10°. Goodman, who saw no cross-piece, though he records streaks of cirrus crossing the pillar, also records a mock sun at the same elevation, 10°. The distance of the mock sun from the true sun which was a little below the horizon, must have been about 11°, much less than the angle of 22°, which is the radius of the common halo. The hypothesis that the mock sun was the intersection of a halo with the sun pillar is ruled out. That hypothesis is in any case very improbable, for there was no halo reported that afternoon.

A very remarkable instance of a mock sun seen with the sun well below the horizon is to be found in Vol. I of the *Proceedings of the British Meteorological Society*. The phenomenon was seen at Wrotham in Kent by the Rev. Charles Lane on January 27th, 1862.

"The sun appeared to have already risen, and to be about 3° above the horizon, showing a sickly face through a bank of fog; and from the northern limb of the sun there streamed upwards a broad ray of creamy light. . . . . . Mr. Lane noticed the time, which was 7.15 a.m.—too soon by 33 minutes . . . . for the sunrise of the almanac. . . . . The ball of the mock sun was well defined (its form distinctly globular) for fully fifteen minutes; it then began gradually to disappear; and it entirely vanished in the first beams of the real luminary of day."

At the time of Lane's first observation the sun was 5° below the horizon, so that the mock sun was initially 8° from the true sun. Just before sunrise, if we can trust the sketch in the *Proceedings*, the interval was reduced to about 2°. With the sun 5° below the horizon clouds about 11km. above ground and 170km. away would have had the right elevation, 3°, and would have been lit by the sun. As to how the round image of the sun was formed I have no suggestion to make. This early observation must be placed in the same class as those made by Applegate on March 9th and by Russell and Goodman on Good Friday. The explanation of the occasional occurrence of mock suns in association with sun pillars must be left as a problem for the devotees of Meteorological Optics.

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## Royal Meteorological Society

The monthly meeting of this Society was held on Wednesday, April 17th, at 49, Cromwell Road, South Kensington, Sir Richard Gregory, D.Sc., President, in the Chair.

*W. H. Dines and L. H. G. Dines.—Monthly mean values of radiation from various parts of the sky at Benson, Oxfordshire. (Memoirs Vol.* 2, *No.* 11, *May*, 1927.)

This paper summarises and discusses the observations of radiation from the sky made at Benson from 1922 to 1926. The luminous rays and long-wave radiation are each tabulated separately for clear and overcast skies for different zones, and several interesting conclusions are drawn.

*L. H. G. Dines.—An analysis of the changes of temperature with height in the stratosphere over the British Isles.* (*Memoirs Vol.* 2, *No.* 18, *April*, 1928.)

The Dines meteorograph, when employed with balloons giving a velocity of ascent of 200 to 250 metres per minute, is not sufficiently well ventilated to give accurate readings of the temperature of the upper part of the stratosphere during the hours of daylight. Using Hc for the height of the base of the stratosphere, the results appear to be about 3°C. too high at (Hc + 6)km., and the error increases upwards. The corresponding error in the descent is believed to be insignificant. The average temperature in the stratosphere over the British Isles is accordingly found from night observations, and consists of a pronounced inversion of 3°C. at the bottom, followed by a gradual upward decrease at the rate of about 0.5°C. per km. from (Hc + 3) to (Hc + 8) km. As the height increases there is a definite tendency for the temperature to become independent of that at the base of the stratosphere, and at (Hc + 17) km. the temperature may be independent of that at Hc. The available evidence is against the existence of a diurnal variation of temperature in the stratosphere.

In the discussion the method of tabulation was questioned, but was justified by the statement that the great majority of ascents which reach the stratosphere do show a sharp inversion.

*H. A. Hunt, Commonwealth Meteorologist.—A basis for seasonal forecasting in Australia.*

The author's investigations into the sequence of wet and dry seasons in Australia indicate a fairly definite four-year cycle. This period usually consists of two dry years followed by two wet years, requiring two years to be allotted to the drying and heating phase and two to the wetting and cooling. In the tables given the years are shown coupled in pairs, of which the aggregates for the 24 months make alternate wet and dry periods, although the single years do not always display higher or lower totals than each of the years in the opposing pair. The four-year period in the rainfall is also fairly well marked in the percentage of the continental area over which the rainfall is above the average each year.

A good discussion followed, in which it was pointed out that in Ceylon there are two periods of about 3·7 and 4·5 years respectively which combine to give a four-year cycle similar to that found in Australia. Analysis of the Australian cycle shows it to consist of a similar periodicity of 3·7 years with indications of a longer periodicity of between four and five years.

# Correspondence

To the Editor, *The Meteorological Magazine*

## Exceptional Dryness

With regard to the comments in your magazine on the exceptional dryness and extremes of temperature experienced in February and March, I might say that here on two days in March, early in the afternoon, the humidity in the screen was down to 30 per cent. The weather was very fine and warm. Also about 2 p.m. one afternoon in February, the weather being very fine and cold with east wind, the dry bulb temperature was 29° while the wet was 25° [humidity 52 per cent].

G. WESTON.

*Munsted Heath, Godalming, April 28th*, 1929.

## Shortage of Snow on Ben Nevis

I have been informed by members of the Scottish Mountaineering Club that the amount of snow this spring on Ben Nevis and other mountains is the smallest that can be remembered. This is of course what one would expect in view of the drought which has prevailed all this year.

C. K. M. DOUGLAS.

*April 25th*, 1929.

## Snow Falling through Drizzle

In the *Meteorological Magazine* for September, 1927, results concerning the investigation of rain falling through drizzle are given, but no mention is made as to the occurrence of snow falling through drizzle, and I wonder, therefore, whether it is comparatively rare. The following account of this phenomenon at Dover preceded by glazed frost may prove of interest.

The weather of February 26th was dull and frosty with a strong easterly wind (Force 6 at 9h.). The screen temperature remained unusually steady throughout the day, varying from 29.8°F. at 8h. to 30.2°F. at 20h. Heavy drizzle commenced at 9h. 50m. and fell continuously until 11h. 15m. covering most objects with a coating of smooth transparent ice which rendered many roads and pavements dangerous to traffic and pedestrians. At 11h. 10m. large well-frozen snow flakes began to fall through the drizzle and these conditions continued for several minutes, ending with the gradual cessation of the drizzle but a rapid increase in the snowfall. I hasten to emphasise the fact that the snow flakes were very large and well frozen because under the circumstances one might easily be led to think the occurrence was that of drizzle turning to fine snow. Conditions became somewhat similar again at 17h. 15m., but in this case the drizzle was very slight, and the soft hail and snow which followed fell through the drizzle for a very short period only, and, indeed, might easily have passed unnoticed but for careful observation.

Close examination of my barogram reveals a slight rise of pressure just before 10h. followed by a gradual fall until after 11h. when a further slight rise is discernible. Careful study of the thermogram fails to show any change of temperature during the phenomenon.

CYRIL G. W. LEWIS.

69, *Barton Road, Dover. March 9th,* 1929.

## Brilliant Parhelia

Between 9h. and 9h. 30m. this morning the parhelia of the halo of 22° were observed in a cirrus cloud. The halo was not visible. Both parhelia showed prismatic colours, especially the left-hand one, which for a few minutes was very brilliant and had a white "tail" pointing away from the sun estimated at 1° long.

CICELY M. BOTLEY.

17, *Holmesdale Gardens, Hastings. March 3rd,* 1929.

## Wet Bulb Temperatures as "Thaw Temperatures"

*A propos* of Col. Gold's letter on the above subject in your issue of February, 1929, the following set of readings of the wet and dry bulb thermometers, which I took at Wengen in Switzerland in January last, confirms his observation that the ground will not thaw when the wet bulb is below 32°F. The following readings were taken by means of a whirling psychrometer in the shade :—

| Day January | Hour (C.E.T.) | Dry Bulb | Wet Bulb | Relative Humidity | Temperature in sun against a cream coloured wall facing SSE. |
|---|---|---|---|---|---|
| | h. m. | °F | °F | % | °F |
| 10th | 14 15 | 34·8 | 29·0 | 48 | 62 |
| 13th | 14 00 | 32·4 | 27·2 | 40 | 62 |
| 19th | 14 15 | 34·2 | 28·2 | 46 | 64 |
| 20th | 14 00 | 35·8 | 30·4 | 52 | 72 |
| 21st | 14 00 | 38·2 | 30·2 | 35 | — (overcast) |

Except on the 21st the sun shone brightly at the time of observation. There was no thaw in the shade even on much frequented paths, the snow being dry to the touch. Only in direct sunshine was there any thaw, and this was least in open spaces. Thus the ice on the skating rink was damp to the touch, but there was no water. In more sheltered corners the thaw was much more pronounced. There can be no doubt, therefore, as Col. Gold points out, that the continued frost on the surface of the ground (or snow) is to a large extent due to evaporation

—in the table above the humidities are very low—and to a less extent to radiation or to the low temperature of the snow or ground immediately underneath the surface.

Nevertheless the following figures are puzzling. The temperature of the air is below 32°F.; yet even after whirling the psychrometer for more than 15 minutes it was found impossible to get ice on the wet bulb. In the last two examples it seems

| Day January | Hour (C.E.T.) | Dry Bulb | Wet Bulb | Humidity | Weather and cloud |
|---|---|---|---|---|---|
| | h. m. | °F | °F | % | |
| 11th | 14 10 | 31·5 | 26·4 | 48 | c (high cloud) |
| 12th | 14 10 | 31·2 | 26·2 | 48 | $b_0v$ |
| 22nd | 23 50 | 31·9 | 31·1 | 91 | ov after ors. |
| 23rd | 10 20 | 30·4 | 29·2 | 87 | $b_0$ |

possible to give some explanation. The non-freezing of the water may, in part, be due to the high humidity. Some confirmation of this is offered from the following observations at South Kensington on February 19th at 17h. (G.M.T.). The roads were in a damp condition and the snow in Hyde Park was decidedly wet to the touch though the temperature of the air was 30·8°F. The humidity was, however, 90 per cent. Here, then, in spite of the air temperature being well below 32°F. no freezing occurred. The wind at the time was E. force 3. The above examples are clear cases of super-cooling.

Again, in no instance, except one, was I able to get the wet bulb to freeze when the air temperature was slightly above 32°, and that of the wet bulb well below this figure. Here are some examples from Wengen:—

| Day January | Hour (C.E.T.) | Dry Bulb | Wet Bulb | Humidity | Weather and cloud |
|---|---|---|---|---|---|
| | h. m. | °F | °F | % | |
| 7th | 14 00 | 33·0 | 27·5 | 46 | o |
| 13th | 14 00 | 32·4 | 27·2 | 40 | b, ci 2 |
| 19th | 14 15 | 34·2 | 28·2 | 46 | bv, ci 1 |
| 21st | 18 00 | 34·0 | 29·0 | 53 | o, st. cu. 10 |
| 21st | 23 30 | 32·9 | 27·9 | 52 | o, st. cu. 9 |
| The exception was | | | | | |
| 22nd | 08 25 | 32·2 | 29·4 | 72 | $os_0s_0+$ |

Perhaps in this case a flake of snow may have touched the wet muslin and have started the freezing. It seems, therefore, that while it is possible to preserve freezing, at any rate in open spaces, when the air temperature is above the 32°F. if the wet bulb is below that figure and the humidity low, it is not possible to freeze water when the temperature of the air is at or a little above or below 32°F. be the humidity high or low, at any rate over a small surface such as a thermometer bulb.

As regards a snow layer being an effective agent in reducing the temperature of the air of the surface layers of air, I found, from several observations, that in clear weather the mean difference of temperature of the air at 2in. and 4ft. above the snow to be 5.5°F., while in overcast weather the difference was only 1.7°F., the temperature at the lower level being the lower of the two. J. E. BELASCO.

21, *Gunter Grove, Chelsea, S.W.*10. *February* 20*th*, 1929.

Mr. Belasco's observations on the super-cooling of water on the wet bulb are very instructive. This super-cooling occurs, not only when the dry bulb is above 32° but also on occasions when the dry bulb is below 32°. It would be interesting to have records of other occasions than the single one mentioned by Mr. Belasco, when ice was formed on the wet bulb with the dry bulb above 32°. Mr. Belasco's suggestion that on the occasion he mentions, January 22nd, formation of ice was due to contact with a snowflake appears probable. It is supported by the facts which Aitken mentioned some years ago in connexion with the super-cooling of water.* E. GOLD.

Further to my letter of February 20th arising out of Col. Gold's remarks, it occurred to me that super-cooling of water on the wet bulb thermometer might be arrested or, if not arrested completely, at any rate much reduced by artificial means. Messrs. Harrods were kind enough to allow me to carry out some experiments on this point by permitting me the use of their cold storage chambers. For this work I used an Assmann Psychrometer, the muslin of the wet bulb being moistened with distilled water. In one chamber the temperature of the air was 31·0°F., while the wet bulb, when steady state had been reached, gave 29·9°F., but the water on it had not frozen. I then endeavoured to promote freezing by applying a little sawdust to the muslin by means of a long thin piece of wood, thus hoping to provide the necessary nucleus at which the change of state could begin. The result was not successful, and the temperature of the wet bulb rose to 30·3°F. I repeated the experiment but was still unable to promote freezing. There being some ice on a nearby window, I procured a little of this on my stick and applied it to the muslin. The temperature of the wet bulb immediately rose to 32·0°F., freezing having begun. At the end of the experiment, when the steady state had been reached, the dry bulb was 30·0°F., the ice bulb 28·9°F. I then repeated this experiment in a much colder chamber, the dry bulb being 24·0°F. The chamber was

*Collected Scientific Papers of John Aitken, LL.D., F.R.S. By C. G. Knott, 1923, No. 37, Ground Ice.

small, one-half of it being fitted with pipes which were thickly coated (an inch or more) with hoar frost, though the floor was damp. As water the wet bulb fell to 23·7°F. Immediately on reaching this figure the mercury of the wet bulb thermometer rapidly rose to 32·0°F., where it remained for about two minutes after which it fell to 23·6°F. Still remaining in the same chamber and after completely thawing the ice bulb to well above 40°F., I allowed it to cool to 30·0°F. I then, as before, applied the sawdust. The cooling of the wet bulb immediately ceased and the temperature rose slowly to 32·0°F. It remained at that figure for quite a considerable time and then fell to 23·6°F. Once more I thawed the ice bulb and when later the wet bulb had cooled to 30·0°F. I applied a little ice to the muslin. This time the temperature rose rapidly to 32·0°F. and then later fell to 23·7°F. where it remained steady. (In all cases—both at Harrods and in Switzerland—I have noticed that the descent from 32°F., after freezing has occurred, is at first extremely slow to about 30·5°F. after which the descent is quite rapid. In Switzerland I never observed super-cooling when the temperature of the air was below 20°F., the descent of the mercury of the wet bulb, say, from 50°F. being stopped at 32°F. while freezing was taking place.) From the above experiments it would appear that when the temperature of the air is well below the freezing point, super-cooling can be arrested and a nucleus at which to begin freezing can be provided for in the form of ice or wood being applied to the bulb. This is a great saving of time. On the other hand when the air temperature is only a little below the freezing point super-cooling can only be arrested by the application of ice.

J. E. Belasco.

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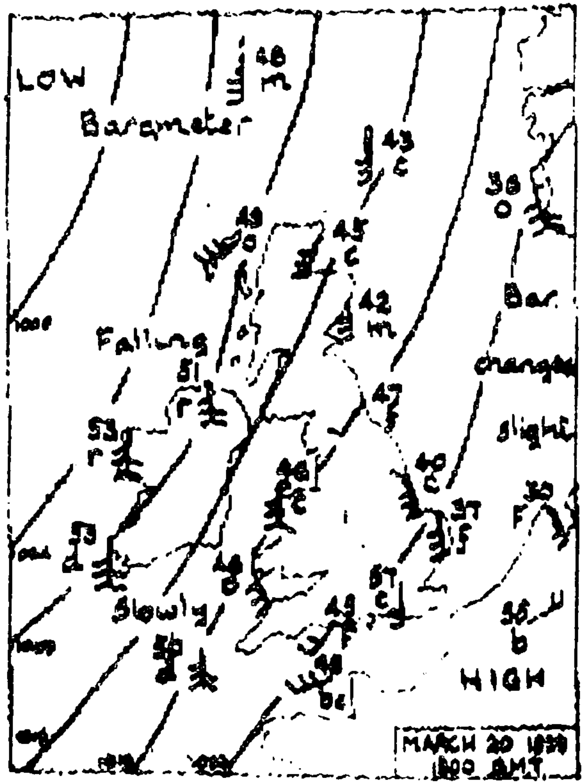
## NOTES AND QUERIES

### Underground Water Level in the Thames Valley

Owing to the prolonged drought the flow of the Thames has been reduced much below normal, and the level of the underground water in the riverside gravel-beds is exceptionally low.

The level of underground water is recorded at Kew Observatory where there is a small well provided for the purpose. No water is drawn from this well, so that the changes in level are due entirely to natural causes. Normally during the months January to March the water is at its highest level, about 300cm. above sea level and 250cm. lower than the Observatory lawn. From March onwards the water falls more or less steadily to September in which month the level is on the average about 200cm. above sea level. This winter the highest level, 263cm., was attained on January 4th. By the end of the month the water had fallen to 220cm. On March 8th the measurement was




GENERAL INFERENCE FROM OBSERVA-
TIONS AT 1800 GMT., MARCH 20 1929.

THE CONTINENTAL ANTICYCLONE
IS PASSING AWAY SOUTHEASTWARD
AND A LARGE DEPRESSION IS
SPREADING IN FROM THE ATLANTIC.
SOME RAIN OR DRIZZLE WILL
OCCUR IN WESTERN AND NORTHERN
DISTRICTS BUT IN THE SOUTHEAST
THERE WILL BE LITTLE OR NONE
FOR ANOTHER 24 HOURS.

FORECAST FOR SE ENGLAND
TOMORROW.

WIND SOUTH TO SOUTHWEST,
LIGHT OR MODERATE. CLOUDY,
LOCAL COASTAL FOG AND DRIZZLE.
VERY MILD.

WEATHER CHART AND FORECAST TRANSMITTED BY THE FULTOGRAPH SYSTEM.

200cm., and the fall has continued almost without intermission. For May 5th the minimum reading is 178cm. The only periods during which the water has been so low as 178cm. above M.S.L. since the systematic record began in January, 1916, were:— from the middle of 1921 to February, 1922, the greater part of December, 1922, and four weeks in the autumn of 1923. The lowest level of all was recorded on four days in January, 1922, viz., 157cm. above M.S.L.

As has been mentioned the water level is controlled by the state of the river rather than by local rainfall. It may be noted, however, that the rainfall for the first four months of 1929 is the lowest ever recorded at Kew Observatory for this period of the year, only 59·4mm. having fallen. The difference from the minimum for any four consecutive months, 59·0mm. in May to August, 1921, is insignificant.

F. J. W. WHIPPLE.

## The Wireless Transmission of Weather Maps

By the courtesy of Messrs. Travers Cleaver Ltd., we are enabled to reproduce on the opposite page the specimen weather chart for 6 p.m. on March 20th, and the accompanying forecast, transmitted by the Fultograph system at the lecture on "Weather and Wireless" given by Mr. R. A. Watson Watt at the Royal Meteorological Society on that date. A full summary of the lecture appeared on p. 64 of the *Meteorological Magazine* for April.

## A Destructive Thunderstorm in December

On December 30th, 1928, a thunderstorm passed over the Falmouth district about 8 a.m.

Mr. George Knowles, of Penmorva, Budock, Falmouth, reported that the lightning was extraordinarily vivid and was accompanied by a very heavy squall of wind and hail. Some damage was done to property about ¾ mile from his house. "There was only one flash of lightning and that struck a large fir tree which it completely wrecked, scattering the pieces for a distance (it was said, though I wonder if it was accurate) of about 200 yards. At the same time it struck the telephone." Later, Mr. Knowles interviewed the owner of the damaged property and he now sends the following report: "The owner said that her telephone was struck and there was a brilliant flash; the receiver, which was by her bed, was thrown violently against her chest, inflicting a severe bruise, which had to be treated by her doctor. The flash left a smell of sulphur in her room. The tree was about ½ mile from the house and the telephone wires were about 80 or 100 yards from the tree, which was a very tall fir over 100 feet high. The gardener who saw the lightning flash told me that it seemed to fall like a large ball of fire which burst just above the tree with a tremendous report. The tree was smashed and the pieces scattered over a wide area. He said that there was a man in a shed about 100 yards from the tree and he was knocked down by the shock. The house, called "The Cragg," is situated on a high rock about 200 yards from Maen Porth, an inlet of the sea about 2½ miles southwest from Falmouth. Unfortunately, I did not see the tree till all the debris was cleared away and cut up, but the gardener said that some of the pieces were very large."

On the morning of the 30th a depression over southeast England, an offshoot of a depression south of Iceland, was moving southwards and deepening. In the rear of this depression showers of rain or hail fell locally in the southern parts of England, while a few stations recorded thunder and lightning. According to the *Daily Weather Report* heavy rain and hail showers and lightning were observed at Falmouth (Pendennis) between 7h. and 13h. on the 30th.

In this connexion it is of interest to note that the inquiry into winter thunderstorms over the British Isles, conducted in recent years by Mr. S. Morris Bower, under the auspices of the Royal Meteorological Society, has shown that there is a tendency towards a secondary maximum of frequency of winter thunderstorms over parts of Devon and Cornwall. Winter thunderstorms are most frequent on the west coasts of Scotland and Ireland.

## The Effect of Exposure on Climate

In the summer of 1926 the Bavarian Forest Research Department carried out an investigation of very great interest, which is described by Dr. R. Geiger.*

On a plateau in the Swabian Jura, in eastern Wurttemberg, rests an isolated hill of a regular conical shape, known as the "Hohenkarpfen," rising at an average slope of about 20° from a general level of some 800 metres to 912 metres at its highest point. Symmetrically disposed on its slopes and on the summit, a number of meteorological stations were erected, the principal ring, at a height of 860 metres, averaging only 45 metres apart. The observations included temperature and humidity, rainfall, wind-velocity (with electric self-recording cup anemometers) and intensity of light.

The phenomena are naturally distributed in relation to the direction of the wind at the time, and the feature of most interest is the rainfall. The heaviest falls, averaging 4 to 7 per cent. above the average for the whole hill, were found on the flanks, with a slight minimum on the leeside and a pronounced

*Messung des Expositionsklimas. *Forstwiss. Centralbl. Berlin.* 49, 1927, pp. 665-675, 853-859, 914-923; 50, 1928, pp. 73-85, 437-448, 633-644; 51, 1929, pp. 37-51.

minimum to windward; the gauge in the centre of the summit received nearly the average fall for the whole area. This is not the whole story however, for the rain-gauges were exposed with their apertures horizontal, while it is obvious that a slope facing towards the wind must receive more rain than a horizontal surface. At one point on the south-west slope two gauges were accordingly exposed, one upright, and the other with its aperture parallel with the ground surface; the latter received altogether 2 per cent. more rain than the former, but with winds from south-west exceeding 5 m./s. in velocity the excess rose to 27 per cent. On such steep slopes the orthodox exposure of rain-gauges with their apertures horizontal gives rise to a curious paradox. On a windward slope the rain falls obliquely into the gauge, but meets the ground almost at right angles and the gauge receives less rain than an equal area of ground. To leeward, where the rain falls almost vertically, it meets the gauge at right angles but is inclined to the ground, and the gauge receives more rain than an equal area of ground. Hence, as Dr. Geiger points out, although the gauges on the leeward slopes of the Hohenkarpfen caught about 4 per cent. more rain than those on the windward slopes, the actual fall per unit area of ground was very nearly the same both to windward and leeward. It seems desirable to add, moreover, that on such exposed sites the "catch" of the rain-gauge is not always a measure of the true fall, and that the deficit recorded on the windward side may be more apparent than real. Some experiments in this connexion are being made by Mr. Hudleston at Hutton John, near Penrith; preliminary accounts are published in *British Rainfall* for 1926 and 1927.

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## Engineering and Industrial Instruments (List E.5) Negretti & Zambra, London

It might, perhaps, be thought that a catalogue possessing the above title would contain little of interest to the meteorologist. A very brief perusal of its beautifully printed pages is sufficient to correct this impression, for we find that the book is devoted almost entirely to instruments for the measurement of air speed, pressure and temperature. It is true that the compilers have had in mind the requirements of industry, first and foremost, and that the needs of the ordinary meteorologist are dealt with more adequately in other lists issued by the same firm. Nevertheless, space has been found for a good deal of matter which concerns ourselves as much as anybody. Apart from descriptions and illustrations of airmeters, anemobiagraphs, thermometers, thermographs, barometers, barographs, hydrometers and hygrographs, we cannot but be interested in the notes on pitot tubes (pp. 10-11), recording pens (p. 274), glass thermometers (pp. 288-291) and other explanatory matter. The book is much more than a mere price list and no one interested in instruments could fail to profit from a perusal of it.

The expansion of meteorology into fresh channels involves an ever-increasing demand for new types of instruments and it is interesting to find that such needs can frequently be met by instruments developed for industrial purposes. We may take, for example, Negretti & Zambra's mercury-in-steel thermometers and thermographs. In these instruments the thermometer bulb, made of steel and filled with mercury, is connected by fine capillary tubing, also of steel, to the dial or recorder which may be up to 150ft. from the bulb. Many pages of the catalogue are devoted to various patterns of this instrument, and it is certain, therefore, that it has found a wide market in the industrial world. At the same time, the meteorologist finds it useful for such purposes as recording earth temperature, indicating air temperature on aeroplanes, &c. On the other hand, it is of interest to note that industrial applications have been found for so typical a meteorological instrument as the Symons earth thermometer.

In designing instruments for industrial purposes, manufacturers have been compelled to give special attention to such features as robustness, clear and permanent figuring, protection of working parts from dirt and corrosion and reliability (in the sense of freedom from liability to breakdown). These desiderata are equally important to the meteorologist, who is likely to profit, therefore, from the experience gained by the manufacturer in the industrial sphere. An accurate instrument need not necessarily be a "delicate" instrument. Under modern conditions, costly instruments of elaborate construction must often be designed in such a way that expert attention is only necessary at rare intervals. Messrs. Negretti & Zambra are to be congratulated on the success with which they have endeavoured to meet this need and also on their enterprise in producing so helpful and elegant a list of their products.

## News in Brief

We are informed that Commandant Alvaro de Freitas Morna has been appointed Director of the Marine Meteorological Service of Portugal, in succession to Commandant Joao Batista de Barros.

According to *The Times* "work has begun on the building of an observatory for meteorological and scientific research on the Jungfraujoch (11,340ft.). The promoter of the scheme is the Swiss meteorologist Prof. A. de Quervain, and the £20,000 needed for the carrying out of the enterprise has been raised.

The Adams Prize for 1927-8 (value about £246) has been awarded to Prof. Sydney Chapman, F.R.S., of Trinity College, Cambridge. The subject was "The variations in the earth's magnetic field in relation to electric phenomena in the upper atmosphere and on the earth.''

*Staff News.*—The final round of the Air Ministry Interdepartmental Association Football Cup Competition was played at Waddon on Thursday, April 18th, against a team representing the Aeronautical Inspection Department. The Meteorological Office team after a very keen game won by 5 goals to 1. At the close of the match the cup was presented to the Office team by Lieut.-Col. H. W. S. Outram, C.B.E., Director of Aeronautical Inspection. This is the first time the Meteorological Office has held the cup since 1923.

## Errata

The review of Müller-Pouillet's *Lehrbuch der Physik* on p. 50 of the *Meteorological Magazine* for March contains a reference to the death of Prof. Dr. B. Gutenberg. Happily that reference was an error; Prof. Dr. Gutenberg is in fact the principal author of the section on "Thermodynamics of the Earth."

March, 1929, p. 30, Table I, *for* "Newcastle" *read* "Tynemouth", *for* "Oxford, 10° on the 15th, 0° on the 16th" *read* Leafield 10° on the 14th, 0° on the 15th," and *for* "Manchester" *read* "Winchester."

# The Weather of April, 1929

The weather of April was generally dry and in Great Britain cold with a preponderance of northerly winds. During the opening days pressure was high to the westward of the British Isles, while shallow depressions moved southwards across the North Sea. Snow and sleet showers occurred in Scotland and sleet and hail showers in the Midlands from the 1st-4th and snow as far south as Norfolk on the 3rd; further south and west the rainfall was slight. Considerable periods of bright sunshine occurred during this time. On the 5th an anticyclone coming from the west covered the British Isles, and the 6th was a sunny day over the whole kingdom with between 11 and 12½hrs. bright sunshine at numerous places, *e.g.*, 12·2hrs. at Hastings, and 11·8hrs. at Edinburgh. This fair weather continued in England on the 7th and 8th, while overcast skies and slight rain occurred in Ireland and Scotland during the passage of a shallow depression. On the 9th there was a general change, an anticyclone to the north of the British Isles brought fine weather to Ireland from the 9th-13th and to Scotland from the 9th-16th, an average of 8-10hrs. bright sunshine daily being recorded at several places. Meanwhile cold cloudy unsettled weather with easterly winds prevailed in England generally; snow and sleet fell at many places from the 10th-12th, and on the 12th temperature did not rise above 38°F. at Harrogate, Birmingham and

Huddersfield. On the 16th and 17th the weather became unsettled with westerly winds in the west and north, but anticyclonic in the south. It was at this time that the one really warm spell in the month was enjoyed, especially in southern England where temperature rose above 70°F. generally on the 19th from Devonshire to Norfolk and 74°F. was reached at Greenwich. A cold northerly wind, however, in the rear of a depression over Norway was spreading southward over Scotland on the 19th and reached southern England on the 20th. The weather continued sunny though cold on the 21st and 22nd. From then until the end of the month it was generally cold and unsettled except in the north with showers in most places but many bright intervals. Moderate rain occurred on the 27th-29th, among the heaviest falls being 0·84in. at Killybegs (Donegal) on the 27th and 0·86in. at Guernsey on the 29th. Snow fell in many parts of Scotland and north England from the 24th-28th, but from the 28th-30th the weather was fine and sunny in north and west Scotland; Tiree had 14·7hrs. bright sunshine on the 30th and 13·0hrs. on the 28th. Temperature was low during the greater part of the month; the lowest minimum in the screen being 22°F. at Marlborough on the 6th and at Durham and Marlborough on the 22nd and the lowest on the grass, 10°F. at Marlborough on the 22nd and 11°F. at Rhayader on the 4th. Rainfall totals for the month were again below normal except for a small area in southeast Scotland. The distribution of sunshine for the month was as follows :—

| | Total (hrs.) | Diff. from normal (hrs.) | | Total (hrs.) | Diff. from normal (hrs.) |
|---|---|---|---|---|---|
| Stornoway | 197 | +43 | Valentia | 177 | +17 |
| Aberdeen | 154 | — 4 | Liverpool | 192 | +34 |
| Dublin | 145 | —20 | Falmouth | 190 | + 6 |
| Birr Castle | 130 | —24 | Kew | 146 | —11 |

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Pressure was above normal from Spitsbergen to northern France, over the northern North Atlantic and at Bermuda, the greatest excess being 11·1mb. at Isafjord, and below normal over Scandinavia, central and southern Europe, the Azores and Newfoundland, the greatest deficits being 3·9mb. at Bornholm and 3·6mb. at Horta. Temperature was generally below normal except in the extreme south, and rainfall was below normal in most parts of northern and western Europe but above normal in central Europe. In western Svealand and northwestern Gothaland however it was 150 per cent. of the normal.

The warm sunny weather experienced generally at the end of March broke in Switzerland and France on the 2nd and 3rd respectively, when there was a sudden drop in temperature accompanied by heavy falls of snow. Heavy snow and cold weather were also experienced in Germany, Austria, northern Italy, and the Balkan Peninsula from about the 1st-8th. A severe storm, said to be the most violent for fifty years, occurred along the

Spanish coast between Cadiz and Gibraltar from the 17th to 19th, causing much damage. Intense cold weather set in again in Turkey on the 19th when snow fell generally, and snowstorms were experienced in Germany as late as the 25th. On the 30th a strong Föhn wind blowing over Switzerland caused the snow up to a height of 6,000ft. to melt rapidly.

In Kenya the spring rains, which were about a month late, began definitely in most districts during the week ending the 27th. The drought had caused injury to the crops.

Owing to floods and gales a portion of the bridge of boats at Mosul broke from its moorings on the 14th.

Torrential rains occurred in the northern part of Tasmania on the 3rd and 4th with subsequent severe floods during which 27 people were drowned, and roads, bridges and property were destroyed to the value of £1,000,000. The floods were abating on the 8th.

Storms of snow, sleet and cold winds swept across the central provinces of Canada on the 1st, and across Ontario on the 5th followed by thunderstorms on the 6th-8th. The prairie provinces also experienced wintry conditions early in the month. Temperature was considerably above normal in the United States, except for the Pacific States, during the first part of the month, 90°F was recorded in parts of the Atlantic States and 94°F. at Washington, D.C., and Richmond, Va., on the 7th. Later the temperature fell considerably. The rainfall was above normal in most districts. Storms were experienced on the Atlantic Coast on the 16th, torrential rain in the Mississippi Valley about the 21st and 22nd followed by floods, a tornado in Texas and the Rocky Mountain States on the 22nd, and a tornado in Georgia and South Carolina on the 25th. A hurricane which struck the banana region of Santa Marta (Colombia) on the 4th destroyed about a million banana plants.

Icebergs and vast icefields in the North Atlantic were much more southerly than usual.

The special message from Brazil states that the distribution of rainfall in the northern and central regions was irregular with 0·35in. and ·04in. below normal respectively, and that the rainfall was scarce in the southern regions with 2·60in. below normal. Eight anticyclones passed across the country. The crops were generally in good condition despite the rainfall deficit. At Rio de Janeiro pressure was 1·4mb. above normal and temperature 2·2°F. below normal.

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## Rainfall, April, 1929.—General Distribution

| | | |
|---|---|---|
| England and Wales ... ... | 57 | per cent. of the average 1811-1915 |
| Scotland ... ... ... ... | 76 | |
| Ireland ... ... ... ... | 51 | |
| British Isles ... ... ... | 61 | |

## Rainfall: April, 1929: England and Wales

| Co. | Station | In. | Per-cent of Av. | Co. | Station | In. | Per-cent. of Av. |
|---|---|---|---|---|---|---|---|
| *Lond* . | Camden. Square......... | 1·33 | 86 | *Leics* . | Belvoir Castle............ | 1·09 | 71 |
| *Sur* . | Reigate, The Knowle... | ·96 | 62 | *Rut* . | Ridlington ....................... | 1·26 | ... |
| *Kent* . | Tenterden, Ashenden... | ·99 | 61 | *Linc* . | Boston, Skirbeck ...... | ·61 | 45 |
| ,, . | Folkestone, Boro. San. | 1·14 | ... | ,, . | Lincoln .................. | ·70 | 50 |
| ,, . | Margate, Cliftonville... | ·63 | 47 | ,, . | Skegness, Marine Gdns | ·41 | 31 |
| ,, . | Sevenoaks, Speldhurst | 1·06 | ... | ,, . | Louth, Westgate ...... | ·65 | 39 |
| *Sus* . | Patching Farm ......... | ·77 | 44 | ,, . | Brigg, Wrawby St. ... | ·65 | ... |
| ,, . | Brighton, Old Steyne | ·70 | 43 | *Notts* . | Worksop, Hodsock ... | ·88 | 60 |
| ,, . | Heathfield, Barklye* | 1·00 | 59 | *Derby*. | Derby, L. M. & S. Rly. | ·94 | 58 |
| *Hants*. | Ventnor, Roy. Nat. Hos. | 1·28 | 76 | ,, . | Buxton, Devon Hos.... | 1·53 | 52 |
| ,, . | Fordingbridge, Oaklnds | ·85 | 46 | *Ches* . | Runcorn, Weston Pt. | ·88 | 51 |
| ,, . | Ovington Rectory ...... | ... | ... | ,, . | Nantwich, Dorfold Hall | ·96 | ... |
| ,, . | Sherborne St. John ... | ·96 | 54 | *Lancs* . | Manchester, Whit. Pk. | 1·07 | 56 |
| *Berks* . | Wellington College ... | ·70 | 43 | ,, . | Stonyhurst College ... | 1·28 | 66 |
| ,, . | Newbury, Greenham... | ·93 | 51 | ,, . | Southport, Hesketh Pk | ·88 | 48 |
| *Herts* . | Benington House ...... | ... | ... | ,, . | Lancaster, Strathspey | 1·59 | ... |
| *Bucks* . | High Wycombe ......... | 1·25 | 80 | *Yorks*. | Wath-upon-Dearne ... | ·81 | 51 |
| *Oxf* . . | Oxford, Mag. College | 1·39 | 90 | ,, . | Bradford, Lister Pk.... | ·96 | 48 |
| *Nor* . | Pitsford, Sedgebrook... | 1·64 | 107 | ,, . | Oughtershaw Hall...... | 2·74 | ... |
| ,, . | Oundle ................. | ·82 | ... | ,, . | Wetherby, Ribston H. | ·96 | 55 |
| *Beds* . | Woburn, Crawley Mill | 1·85 | 123 | ,, . | Hull, Pearson Park ... | 1·06 | 68 |
| *Cam* . | Cambridge, Bot. Gdns. | ... | ... | ,, . | Holme-on-Spalding ... | ·91 | ... |
| *Essex* . | Chelmsford, County Lab | ... | ... | ,, . | West Witton, Ivy Ho. | 1·28 | ... |
| ,, . | Lexden Hill House ... | 1·77 | ... | ,, . | Felixkirk, Mt. St. John | 1·30 | 78 |
| *Suff* . | Hawkedon Rectory ... | 1·70 | 110 | ,, . | Pickering, Hungate ... | 1·26 | ... |
| ,, . | Haughley House ...... | 1·06 | ... | ,, . | Scarborough ........... | 1·13 | 72 |
| *Norf* . | Norwich Eaton ..... ... | 1·18 | 69 | ,, . | Middlesbrough ......... | ·99 | 72 |
| ,, . | Wells, Holkham Hall | ·86 | 61 | ,, . | Baldersdale, Hury Res. | 1·28 | ... |
| ,, . | Little Dunham ......... | ·99 | 61 | *Durh* . | Ushaw College ......... | 1·39 | 74 |
| *Wilts*. | Devizes, Highclere...... | ·58 | 31 | *Nor* . | Newcastle, Town Moor | 1·42 | 87 |
| ,, . | Bishops Cannings ...... | ·91 | 45 | ,, . | Bellingham, Highgreen | 1·68 | ... |
| *Dor* . | Evershot, Melbury Ho. | 1·23 | 52 | ,, . | Lilburn Tower Gdns.... | 1·19 | ... |
| ,, . | Creech Grange ......... | 1·03 | ... | *Cumb* . | Geltsdale................. | 1·99 | ... |
| ,, . | Shaftesbury, Abbey Ho. | ·74 | 35 | ,, . | Carlisle, Scaleby Hall | 1·31 | 67 |
| *Devon*. | Plymouth The Hoe ... | ·87 | 38 | ,, . | Borrowdale, Seathwaite | 5·90 | 80 |
| ,, . | Polapit Tamar ......... | 1·28 | 55 | ,, . | Borrowdale, Rosthwaite | 2·65 | ... |
| ,, . | Ashburton, Druid Ho. | ... | ... | ,, . | Keswick, High Hill ... | 1·55 | ... |
| ,, . | Cullompton...... ....... | 1·03 | 45 | *Glam* . | Cardiff, Ely P. Stn. ... | ·65 | 26 |
| ,, . | Sidmouth, Sidmount... | ·48 | 23 | ,, . | Treherbert, Tynywaun | 1·00 | ... |
| ,, . | Filleigh, Castle Hill ... | ·60 | ... | *Carm* . | Carmarthen Friary ... | 1·03 | 38 |
| ,, . | Barnstaple. N. Dev. Ath. | ·81 | 38 | ,, . | Llanwrda ............... | 1·47 | 45 |
| *Corn* . | Redruth, Trewirgie ... | 1·33 | 46 | *Pemb* . | Haverfordwest, School | ·93 | ... |
| ,, . | Penzance, Morrab Gdn. | 1·38 | 57 | *Card* . | Aberystwyth ........... | ·90 | ... |
| ,, . | St. Austell, Trevarna... | 1·48 | 52 | ,, . | Cardigan, County Sch. | ·80 | ... |
| *Soms* . | Chewton Mendip ...... | ·99 | 33 | *Brec* . | Crickhowell, Talymaes | 1·20 | ... |
| ,, . | Long Ashton ........... | ·90 | ... | *Rad* . | Birm W. W. Tyrmynydd | 1·36 | 37 |
| ,, . | Street, Millfield ... | ·72 | ... | *Mont* . | Lake Vyrnwy........... | 1·78 | 59 |
| *Glos.* . | Cirencester, Gwynfa ... | ·97 | 52 | *Denb* . | Llangynhafal ........... | 1·01 | ... |
| *Here* . | Ross, Birchlea........... | ·88 | 46 | *Mer* . | Dolgelly, Bryntirion... | 1·60 | 44 |
| ,, . | Ledbury, Underdown | ·75 | 41 | *Carn* . | Llandudno ............... | 1·45 | 80 |
| *Salop* . | Church Stretton......... | ·81 | 38 | ,, . | Snowdon, L. Llydaw 9 | 4·39 | ... |
| ,, . | Shifnal, Hatton Grange | ·72 | 43 | *Ang* . | Holyhead, Salt Island | ·98 | 47 |
| *Worc* . | Ombersley, Holt Lock | ·63 | 41 | ,, . | Lligwy..................... | 1·04 | ... |
| ,, . | Blockley ................. | 1·48 | ... | *Isle of Man* | | | |
| *War* . | Farnborough ........... | 1·59 | 81 | | Douglas, Boro' Cem.... | 1·39 | 57 |
| ,, . | Birminghm, Edgbaston | ·78 | 45 | *Guernsey* | | | |
| *Leics* . | Thornton Reservoir ... | 1·14 | 67 | | St. PeterP't. GrangeRd. | 2·41 | 120 |

* Gauge formerly at Tottingworth Park.

## Rainfall: April, 1929: Scotland and Ireland

| Co. | Station | In. | Per-cent of Av. | Co. | Station | In. | Per-cent of Av. |
|---|---|---|---|---|---|---|---|
| *Wigt* . | Stoneykirk, Ardwell Ho | ... | ... | *Suth* . | Loch More, Achfary ... | 4·54 | 94 |
| ,, . | Pt. William, Monreith | ·91 | ... | *Caith* . | Wick .................... | 1·69 | 85 |
| *Kirk* . | Carsphairn, Shiel. ...... | 2·06 | ... | *Ork* . | Pomona, Deerness ...... | 1·49 | 72 |
| ,, . | Dumfries, Cargen ...... | .. | ... | *Shet* . | Lerwick ................. | 1·48 | 65 |
| *Dumf*. | Eskdalemuir Obs. ...... | 1·81 | 53 | *Cork* . | Caheragh Rectory ...... | 1·83 | ... |
| *Roxb* .. | Branxholm ............... | 1·51 | 80 | ,, . | Dunmanway Rectory... | 2·10 | 51 |
| *Selk* . | Ettrick Manse ......... | ... | ... | ,, . | Ballinacurra ........... | ·93 | 36 |
| *Peeb* . | West Linton ............ | 1·21 | ... | ,, . | Glanmire, Lota Lo. ... | 1·38 | 49 |
| *Berk* . | Marchmont House...... | 1·54 | 76 | *Kerry*. | Valentia Obsy. ......... | 1·70 | 46 |
| *Hadd*. | North Berwick Res. ... | 1·91 | 136 | ,, . | Gearahameen ............ | 3·90 | ... |
| *Midl* . | Edinburgh, Roy. Obs. | 1·59 | 115 | ,, . | Killarney Asylum ...... | 1·61 | 49 |
| *Ayr* . | Kilmarnock, Agric. C. | 1·25 | 61 | ,, . | Darrynane Abbey ...... | 1·62 | 47 |
| ,, . | Girvan, Pinmore ..... | 1·33 | 45 | *Wat* . | Waterford, Brook Lo... | 1·59 | 63 |
| *Renf* . | Glasgow, Queen's Pk. . | 1·44 | 73 | *Tip* . | Nenagh, Cas. Lough... | 1·31 | 52 |
| ,, . | Greenock, Prospect H. | 1·26 | 35 | ,, . | Roscrea, Timoney Park | ·66 | ... |
| *Bute* . | Rothesay, Ardencraig. | 1·46 | 49 | ,, . | Cashel, Ballinamona... | 2·18 | 87 |
| ,, . | Dougarie Lodge ......... | 1·81 | ... | *Lim* . | Foynes, Coolnanes...... | 1·18 | 48 |
| *Arg* . | Ardgour House ......... | 3·73 | ... | ,, . | Castleconnel Rec. ...... | ·88 | ... |
| ,, . | Manse of Glenorchy ... | 3·31 | ... | *Clare* . | Inagh, Mount Callan... | 1·23 | ... |
| ,, . | Oban ..................... | 2·74 | ... | ,, . | Broadford, Hurdlest'n. | 1·37 | ... |
| ,, . | Poltalloch .............. | 2·17 | 72 | *Wexf*. | Newtownbarry ......... | .. | ... |
| ,, . | Inveraray Castle... ..... | 3·68 | 80 | ,, . | Gorey, Courtown Ho .. | ·79 | 36 |
| ,, . | Islay, Eallabus ... ..... | 2·43 | 85 | *Kilk* . | Kilkenny Castle......... | 1·40 | 64 |
| ,, . | Mull Benmore ......... | 5·30 | ... | *Wic* . | Rathnew, Clonmannon | ·87 | ... |
| ,, . | Tiree ................... | 1·96 | ... | *Carl* . | Hacketstown Rectory.. | ·86 | 32 |
| *Kinr* . | Loch Leven Sluice...... | 1·39 | 72 | *QCo* . | Blandsfort House ...... | 1·40 | 54 |
| *Perth* . | Loch Dhu .............. | 1·95 | 41 | ,, . | Mountmellick........... | ... | ... |
| ,, . | Balquhidder, Stronvar | 1·40 | ... | *KCo* . | Birr Castle .............. | ·91 | 42 |
| ,, . | Crieff, Strathearn Hyd. | ·99 | 45 | *Dubl* . | Dublin, FitzWm. Sq... | 1·44 | 76 |
| ,, . | Blair Castle Gardens ... | 1·41 | 67 | ,, . | Balbriggan, Ardgillan. | 1·32 | 67 |
| ,, . | Dalnaspidal Lodge ... | 1·25 | 34 | *Me'th* . | Beauparc, St. Cloud... | 1·19 | ... |
| *Forf* . | Kettins School ........ | ·70 | 42 | ,, . | Kells, Headfort ......... | 1·16 | 46 |
| ,, . | Dundee, E. Necropolis | 1·15 | 68 | *W.M*. | Moate, Coolatore ...... | ·92 | ... |
| ,, . | Pearsie House........... | 1·43 | ... | ,, . | Mullingar, Belvedere.. | ·68 | 29 |
| ,, . | Montrose, Sunnyside... | 1·33 | 73 | *Long* . | Castle Forbes Gdns...... | 1·11 | 46 |
| *Aber* . | Braemar, Bank ... ..... | 1·65 | 70 | *Gal* . | Ballynahinch Castle ... | 1·57 | 44 |
| ,, . | Logie Coldstone Sch.... | 2·32 | 115 | ,, . | Galway, Grammar Sch. | ·92 | ... |
| ,, . | Aberdeen, King's Coll. | 1·75 | 94 | *Mayo* . | Mallaranny.............. | 1·45 | ... |
| ,, . | Fyvie Castle ........... | 2·09 | ... | ,, . | Westport House......... | ·87 | 32 |
| *Mor* . | Gordon Castle ......... | 1·82 | 104 | ,, . | Delphi Lodge ........... | 2·65 | ... |
| ,, . | Grantown-on-Spey ... | 2·58 | 131 | *Sligo* . | Markree Obsy........... | 1·32 | 50 |
| *Na* . | Nairn, Delnies ......... | 1·48 | 99 | *Cav'n* . | Belturbet, Cloverhill... | ·79 | 35 |
| *Inv* . | Kingussie, The Birches | 1·66 | ... | *Ferm* . | Enniskillen, Portora... | 1·01 | ... |
| ,, . | Loch Quoich, Loan ... | 4·10 | ... | *Arm* . | Armagh Obsy........... | ·85 | 40 |
| ,, . | Glenquoich.............. | 6·08 | 94 | *Down* . | Fofanny Reservoir...... | 1·56 | ... |
| ,, . | Inverness, Culduthel R. | 1·08 | ... | ,, . | Seaforde ................ | 1·41 | 54 |
| ,, . | Arisaig, Faire-na-Squir | 2·89 | ... | ,, . | Donaghadee, C. Stn ... | 1·21 | 60 |
| ,, . | Fort William ........... | 3·52 | ... | ,, . | Banbridge, Milltown... | 1·15 | ... |
| ,, . | Skye, Dunvegan ...... | 1·36 | ... | *Antr* . | Belfast, Cavehill Rd ... | 1·58 | ... |
| *R & C*. | Alness, Ardross Cas. ... | 1·89 | 78 | ,, . | Glenarm Castle ......... | 1·29 | ... |
| ,, . | Ullapool ................ | 3·31 | ... | ,, . | Ballymena, Harryville | 1·68 | 64 |
| ,, . | Torridon, Bendamph... | 3·90 | 75 | *Lon* . | Londonderry, Creggan | 1·96 | 76 |
| ,, . | Achnashellach ......... | 5·10 | ... | *Tyr* . | Donaghmore ........... | 1·66 | ... |
| ,, . | Stornoway ............. | 1·59 | 52 | ,, . | Omagh, Edenfel......... | 1·42 | 54 |
| *Suth* . | Lairg ................... | 2·16 | ... | *Don* . | Malin Head.............. | 1·21 | ... |
| ,, . | Tongue ................. | 2·14 | 82 | ,, . | Dunfanaghy ........... | ... | ... |
| ,, . | Melvich ................ | 2·55 | 110 | ,, . | Killybegs, Rockmount. | 1·80 | 50 |

# Climatological Table for the British Empire, November, 1928.

| STATIONS | Mean of Day M.S.L. | Diff. from Normal | Absolute | | Mean Values | | | | Mean | Relative Humidity. | Mean Cloud Am'nt | | | | SUNSHINE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Max. | Min. | Max. | Min. | ½ max. and min. | Diff. from Normal | Wet Bulb | | | Am'nt | Diff. from Normal | Days | Hours per day | Per-centage of possible |
| | mb. | mb. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | % | 0—10 | | | | | |
| London, Kew Obsy. .. | 1009·3 | — 5·3 | 59 | 28 | 52·3 | 42·1 | 47·2 | + 3·2 | 43·7 | 89 | 7·8 | 1·81 | — 0·41 | 15 | 1·9 | 21 |
| Gibraltar.......... | 1020·4 | + 2·4 | 73 | 48 | 65·5 | 53·0 | 59·3 | — 1·2 | 52·5 | 81 | 4·4 | 7·06 | + 0·67 | 6 | .. | .. |
| Malta .......... | 1014·4 | — 2·1 | 78 | 45 | 66·9 | 58·0 | 62·5 | — 1·4 | 57·3 | 72 | 6·2 | 7·28 | + 3·71 | 16 | 5·9 | 58 |
| St. Helena .......... | 1013·5 | + 2·1 | 67 | 53 | 62·7 | 55·0 | 58·9 | — 1·2 | 56·0 | 96 | 9·9 | 0·35 | — 1·33 | 7 | .. | .. |
| Sierra Leone .......... | 1012·9 | + 2·0 | 90 | 68 | 86·9 | 72·7 | 79·8 | — 1·4 | 75·6 | 81 | 2·7 | 3·62 | — 1·50 | 7 | .. | .. |
| Lagos, Nigeria ...... | 1008·6 | — 2·2 | 90 | 73 | 87·9 | 77·3 | 82·6 | + 1·2 | 77·7 | 82 | 5·1 | 0·54 | — 2·04 | 4 | .. | .. |
| Kaduna, Nigeria .... | 1014·7 | + 3·4 | 96 | .. | 90·5 | .. | .. | .. | .. | .. | .. | 0·00 | — 0·12 | 0 | .. | .. |
| Zomba, Nyasaland .. | 1009·3 | + 0·4 | 95 | 58 | 87·8 | 66·8 | 77·3 | + 1·7 | .. | 57 | 4·5 | 1·01 | — 4·07 | 8 | .. | .. |
| Salisbury, Rhodesia .. | 1008·3 | + 0·1 | 92 | 52 | 83·6 | 60·4 | 72·0 | + 1·3 | 61·1 | 47 | 4·4 | 3·06 | — 0·64 | 9 | 7·7 | 60 |
| Cape Town .......... | 1018·0 | + 2·2 | 85 | 43 | 73·1 | 55·2 | 64·1 | — 0·3 | 57·9 | 71 | 5·4 | 0·89 | — 0·19 | 8 | .. | .. |
| Johannesburg.......... | 1012·0 | + 0·5 | 88 | 45 | 76·1 | 54·8 | 65·5 | + 2·0 | 57·7 | 68 | 3·7 | 5·79 | + 0·83 | 13 | 7·8 | 58 |
| Mauritius .......... | 1018·6 | + 2·5 | 88 | 63 | 80·4 | 67·3 | 73·9 | — 1·6 | 67·8 | 60 | 6·3 | 1·05 | — 0·53 | 23 | 9·0 | 69 |
| Bloemfontein .......... | .. | .. | 95 | 44 | 80·6 | 55·3 | 67·9 | — 0·5 | 56·5 | 50 | 3·7 | 2·79 | + 0·52 | 7 | .. | .. |
| Calcutta, Alipore Obsy. | 1014·2 | + 0·9 | 90 | 59 | 85·0 | 66·5 | 75·7 | + 2·6 | 67·5 | 87 | 1·6 | 0·00 | — 0·66 | 0* | .. | .. |
| Bombay .......... | 1012·0 | 0·0 | 95 | 71 | 90·9 | 73·8 | 82·3 | + 1·8 | 71·9 | 76 | 1·4 | 0·09 | — 0·36 | 0* | .. | .. |
| Madras .......... | 1012·0 | + 0·7 | 89 | 69 | 86·0 | 74·0 | 80·0 | + 1·1 | 74·7 | 79 | 5·7 | 6·64 | — 7·61 | 6* | .. | .. |
| Colombo, Ceylon .... | 1011·1 | + 1·0 | 88 | 71 | 85·7 | 74·0 | 79·9 | + 0·2 | 76·3 | 79 | 7·1 | 17·59 | + 5·80 | 25 | 6·7 | 57 |
| Hongkong .......... | 1017·4 | — 0·2 | 82 | 57 | 74·0 | 65·7 | 69·9 | + 0·3 | 62·3 | 63 | 5·9 | 0·81 | — 0·86 | 4 | 5·9 | 54 |
| Sandakan .......... | .. | .. | 89 | 72 | 86·7 | 74·8 | 80·7 | — 0·1 | 77·5 | 81 | .. | 13·41 | — 1·25 | 18 | .. | .. |
| Sydney .......... | 1015·0 | + 1·3 | 100 | 50 | 75·3 | 58·6 | 66·9 | — 0·2 | 60·0 | 53 | 5·7 | 0·26 | — 2·55 | 3 | 8·4 | 60 |
| Melbourne .......... | 1015·1 | + 0·9 | 94 | 44 | 72·4 | 51·3 | 61·9 | + 0·6 | 54·7 | 58 | 5·9 | 1·20 | — 1·02 | 12 | 7·7 | 54 |
| Adelaide .......... | 1016·6 | + 1·5 | 100 | 45 | 79·9 | 55·6 | 67·7 | + 0·8 | 56·0 | 36 | 4·4 | 0·49 | — 0·67 | 3 | 10·8 | 78 |
| Perth, W. Australia .. | 1017·0 | + 1·7 | 99 | 49 | 76·5 | 56·8 | 66·7 | + 0·7 | 59·4 | 52 | 3·3 | 0·41 | — 0·38 | 5 | 10·8 | 79 |
| Coolgardie .......... | 1014·3 | + 1·2 | 102 | 48 | 88·1 | 55·3 | 71·7 | + 0·9 | 57·3 | 36 | 2·4 | 0·01 | — 0·67 | 1 | .. | .. |
| Brisbane .......... | 1016·0 | + 1·5 | 103 | 59 | 83·1 | 64·7 | 73·9 | + 0·3 | 66·3 | 55 | 5·1 | 2·90 | — 0·76 | 9 | 9·0 | 67 |
| Hobart, Tasmania.... | 1010·2 | + 0·8 | 86 | 41 | 64·8 | 48·0 | 56·4 | — 0·8 | 50·7 | 59 | 6·6 | 1·59 | — 0·93 | 19 | 7·2 | 50 |
| Wellington, N.Z. .... | 1014·0 | + 1·9 | 67 | 40 | 60·5 | 48·7 | 54·6 | — 2.3 | 52·5 | 77 | 7·0 | 5·16 | + 1·64 | 9 | 7·7 | 53 |
| Suva, Fiji .......... | 1012·1 | + 1·0 | 85 | 65 | 81·3 | 71·2 | 76·3 | — 0·9 | 71·2 | 72 | 7·0 | 6·14 | — 3·37 | 16 | 5·8 | 45 |
| Apia, Samoa .......... | 1010·0 | + 0·5 | 90 | 71 | 84·7 | 74·5 | 79·6 | + 0·9 | 77·6 | 79 | 6·0 | 14·31 | + 5·02 | 22 | 5·4 | 43 |
| Kingston, Jamaica.... | 1012·5 | + 0·1 | 89 | 70 | 86·5 | 71·9 | 79·2 | — 0·1 | 72·1 | 95 | 4·4 | 2·83 | — 0·20 | 12 | 7·2 | 64 |
| Grenada, W.I. ...... | 1008·0 | — 2·3 | 90 | 69 | 85·6 | 73·5 | 79·5 | + 0·2 | 76·7 | 83 | 5·2 | 9·78 | + 1·39 | 19 | .. | .. |
| Toronto .......... | 1015·6 | — 1·2 | 65 | 16 | 45·2 | 34·2 | 39·7 | + 3·4 | 35·6 | 82 | 7·6 | 4·22 | + 1·27 | 15 | 2·3 | 24 |
| Winnipeg .......... | 1017·2 | + 0·5 | 55 | 8 | 36·9 | 23·8 | 30·3 | + 9·5 | .. | .. | 5·7 | 1·66 | + 0·70 | 3 | 3·0 | 33 |
| St. John, N.B. ...... | 1012·9 | — 1·0 | 55 | 13 | 40·9 | 28·7 | 34·8 | — 1·9 | 30·4 | 73 | 7·0 | 3·02 | — 1·39 | 14 | 3·6 | 37 |
| Victoria, B.C. ...... | 1018·1 | + 2·6 | 59 | 38 | 49·9 | 43·0 | 46·5 | + 2·1 | 44·0 | 86 | 7·5 | 1·91 | — 4·55 | 16 | 2·4 | 26 |

* For Indian stations a rain day is a day on which 0.1 in. or more rain has fallen.