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The Temperature Coefficients of the Edinburgh Transit Circle. By Professor R. A. Sampson and E. A. Baker, B.Sc. (Plates 5–7.)

The remarks made by Gill at the meeting of 1913 January regarding the use of fixed terrestrial azimuth marks with the Cape Transit Circle deserve attention.* A full description of the results has now been published in the *Cape Annals*, vol. xi. part iii. (1914). Azimuths determined from these marks have proved so reliable that by comparison with stellar observations even the variation of latitude, or rather the complementary lateral polar deviation, may be exhibited. The existence of these marks rendered possible Mr. Hough's scrutiny of the periodic errors in R.A. of the Catalogues of Newcomb and Boss (*M.N.*, lxxiii. 3, 1913 January).

Marks of this kind are not easy to set up. To sink the mark itself to such a depth in the rock that it should remain fixed secularly might give comparatively little difficulty, but provision of lenses of very long focus—those at the Cape are of 300 feet—would certainly involve cost, trouble, and delay. This lens is an essential part. It is apparent that it also must be adjusted over a deep fixed mark, as is done in the Cape equipment, since any lateral movement (x) of its mounting will shift the zero adopted for the azimuth measures by x/f where f is the focal length of the lens. The arrangement seemed to deserve further study. No one would use a 300-foot telescope with lens and focal marks entirely separate from one another if equivalent results could be otherwise obtained. It seemed possible that the ordinary collimating telescopes might give valuable results. Some recent work at Edinburgh has been connected with a scrutiny of the accuracy of time determinations, and in this naturally the study of instrumental error of the Transit Circle has played a large part. This is the subject of which the following paper gives an outline.

Some provision has been made in the design of the South Collimator of our Transit Circle for the use of an azimuth mark. The pier which carries it forms a granite table in which two iron supports ending in V's are embedded. These supports are made of sufficient height and are pierced with apertures which would permit the Transit Circle to be pointed so as to look straight through them in a line which strikes the ground about 150 feet away. The cell of an object-glass could have been attached to one of these apertures, and thus an azimuth mark upon Gill's plan could have been provided without any material disturbance of the existing arrangements. In view, however, of the difficulties mentioned above, it seemed best to begin at any rate by taking the collimators themselves as azimuth telescopes, for it appeared quite possible that their greater compactness, and all the control that went with it, might counterbalance a large part of the loss due to their small focal length of about $6\frac{1}{2}$ feet and less absolute fixture.

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* *Observatory*, No. 458; a description of the marks is given in *Observatory*, No. 459, and more fully in Gill's *History of the Cape Observatory*, p. 38.

The observations differ only in detail from those habitually made. The movable wire of the North Collimator was set in contact right and left five times with the image of the fixed vertical wire of the South Collimator, giving a mean reading [N/S] to which the North Collimator was then set; then similar settings of the Transit Circle on the North and South Collimators [TC/S and TC/N] were made, and for level the mercury trough with Bohnenberger eye-piece give a reading [L] for coincidence of images; then the quantities discussed below are

$c = constant - \frac{1}{2}[\mathrm{TC/S} + \mathrm{TC/N}] =$ collimation.
$l = \mathrm{L} - \frac{1}{2}[\mathrm{TC/S} + \mathrm{TC/N}] =$ level.
$\mathrm{A} = constant + \frac{1}{2}[\mathrm{TC/N} - \mathrm{TC/S}] =$ azimuth of Transit Circle east of South Collimator.
$[a] = constant - \mathrm{N/S} =$ azimuth of North Collimator east of South Collimator.

The factor for converting c, l, A into seconds of time is $1^{\mathrm{rev.}} = 1^{\mathrm{s}}{\cdot}313$; the corresponding factor for $[a]$ is $1^{\mathrm{rev.}} = 1^{\mathrm{s}}{\cdot}824$. Thus, without adding sensibly to the work, measures are obtained of the azimuth of the Transit Circle with respect to the collimators and of the collimators with respect to one another. The measures are, indeed, relative only, but so are all measures, and it is only by external comparisons and often by elaborate criticisms we can judge what absolute reliance may be placed upon any measure. In the present case the comparison takes the form of a collation with celestial azimuths, which are themselves relative to a number of things, in particular to the difficulties of observing polars, to Catalogue errors, and to movement of the earth's pole.

The observations—except those expressly for stellar azimuths—were begun on 1913 October 1 by Professor Sampson and continued by him until 1914 March 16, after which date they were taken by Mr. Baker. It was intended that they should furnish as far as practicable continuous data of the behaviour of the instrument as contrasted with the detached information available when similar observations are made only in order to reduce stellar transits; with this object they were made as often as practicable each day; the number made has seldom been less than three in the day, and since March, with few exceptions, it has been four, namely at 1, 7, 11, and 22 hours. Temperature has been read at the same time. At first several thermometers were read and considered—external, on the collimator piers and on the transit piers, but only the last is now retained and the temperatures given below refer to it. It soon became apparent that both level and azimuth thus derived followed the temperature of the piers in a general way, and often, more than this, in surprisingly close detail. Alongside this and often masking it there was visible a basic fluctuation of the standard from which these superficial temperature changes were reckoned. Thus the material presented itself chiefly as a study of the temperature coefficient, superficial and basic, of the different errors of the

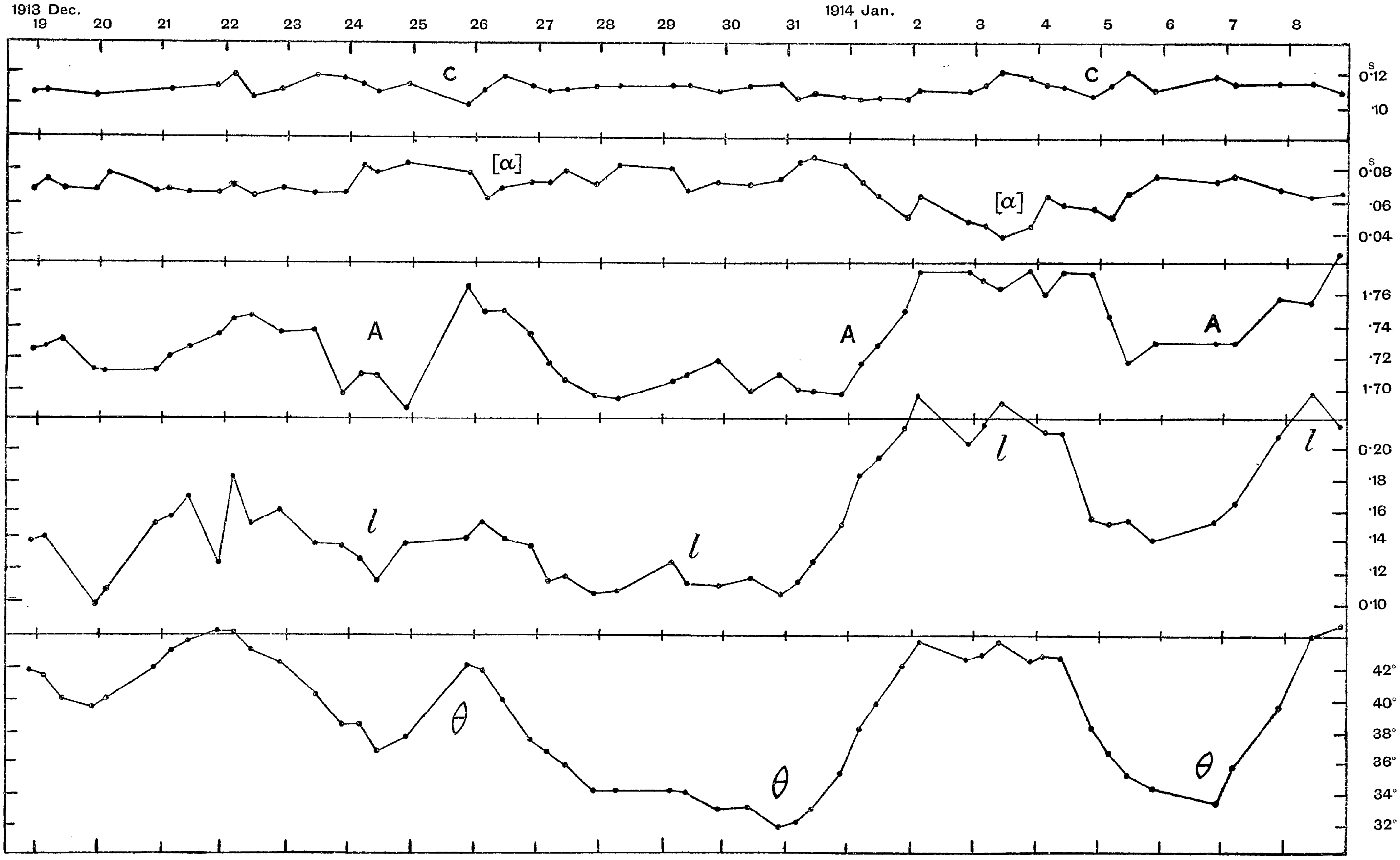

Fig. 1.—Superficial Temperature Changes.

Transit Circle, and from this point of view it is treated. Naturally it will not be expected that a complicated instrument should strictly and always follow a single thermometer placed in any one position. The results are regarded as preliminary. It is proposed to continue the inquiry to ascertain how far the features disclosed repeat themselves in another year, and if possible to assign more closely the laws which they follow.

The observations themselves are too numerous to give here except in extract. Fig. 1 shows the observations of three consecutive weeks, 1913 December 19–1914 January 9. Broadly speaking, the three lowest curves—showing azimuth, level, and temperature—are identical. One might in particular compare l and θ over the interval December 29^d 10^h–Jan. 5^d 4^h. The accordance of the azimuth curve is hardly less striking. It will not weaken this evidence that at other portions of the traces an agreement cannot be traced so readily. The failure never persists for long, and after it the parallelism is re-established. The conclusion from an examination of the whole is that there are superficial temperature coefficients in azimuth and level, declaring themselves without sensible lag, obscured at intervals by other changes which may be termed the basic changes. The systematic consideration of these is outlined below.

With respect to collimation, we cannot say that the section shown exhibits any definite evidence of a relation to the thermometer of the Transit Circle pier. There is, however, some indication of a daily period which is examined further below. It will be noticed that this period shows itself as on December 22 and January 5, where in the former case there is only a very slight indication of a corresponding wave in θ, and in the latter case none at all.

The curve $[\alpha]$ of azimuth of the North Collimator east of the South Collimator shows signs of a diurnal period, and also of a temperature coefficient related to θ, the latter of sign opposite to that which affects A and l.

These are the features suggested for further inquiry by a preliminary examination of the curves.

Azimuth Curves.

The first problem to examine was the permanence and constancy of the superficial temperature changes visible above. This was taken in two steps, first graphically and then numerically. As it was clear that the observations could not all be collected in one group because of the basic changes, they were collected in 7-day groups, and each group was plotted with temperature and indicated azimuth as co-ordinates. Three of these groups are shown in fig. 2; these are examples of cases where one can read the apparent gradient with reasonable confidence; there were other cases, especially when the range of temperature was small, where no trustworthy deduction could be made. Nevertheless the whole of the observations up to the end of May were charted in this way and the gradients read as well as possible, with the following results:—

Gradients for Azimuth, Estimated Graphically.

1913.	Range of Temp.	Gradient per 1° F.		Range of Temp.	Gradient per 1° F.
Oct. 5–11	5·5	+·0108	Feb. 1–7	6·3	+·0072
12–18	6·5	100	8–14	6·1	50
19–25	18·1	84	15–21	9·7	64
26–32	6·6	+ 133	22–28	9·8	68
Nov. 2–8	9·1	− 10	Mar. 1–7	6·1	86
9–15	6·0	+ 118	8–14	9·8	67
16–22	9·1	113	15–21	7·3	+ 112
23–29	7·0	126	22–28	4·8	− 50
30–37	16·3	83	29–35	6·8	+ 106
...	...	...	Apr. 5–11	5·6	102
Dec. 14–20	8·9	86	12–18	10·5	73
21–27	10·3	63	20–25	14·0	81
28–32	10·4	68	26–32	11·5	90
Jan. 2–8	11·6	67	May 3–9	9·6	58
12–16	1·6	...	10–16	12·4	83
18–24	9·8	40	17–23	7·9	120
25–31	10·3	+·0044	24–30	11·5	+·0084

The mean of these is $+^{\mathrm{s}}{\cdot}0076$ per 1°. This was considered as fairly well established, and it seemed plausible to adopt it as a first approximation as constant throughout the set. It was then used to find the basic curve as follows:—Each observed azimuth was reduced to temperature 45° by applying a correction with coefficient ·0076 per 1°, and the results meaned in weekly groups. This gave a basic azimuth curve supposed clear from superficial temperature effect. This is the curve A_0 of fig. 3. Its regularity, and also its agreement with the basic level curve, l_0, which was similarly derived and is shown above it upon the same figure, are considered strong presumptions for its essential reality. Any permissible alteration in the adopted temperature gradient would not change it materially. This curve then was accepted, and was employed to make a second, purely numerical, estimate of the temperature gradient from each week's observations. This was done by interpolating the value of A_0 for the time of each observation, and attributing the difference $A - A_0$ between the observed and basic azimuths to the difference of temperature between 45° and that of the observation. The following table shows the results, and also the mean discrepancy or residue for each week between the observed azimuth at any time and the calculated azimuth, starting from the basic azimuth supposed known, and using the temperature gradient indicated for the week.

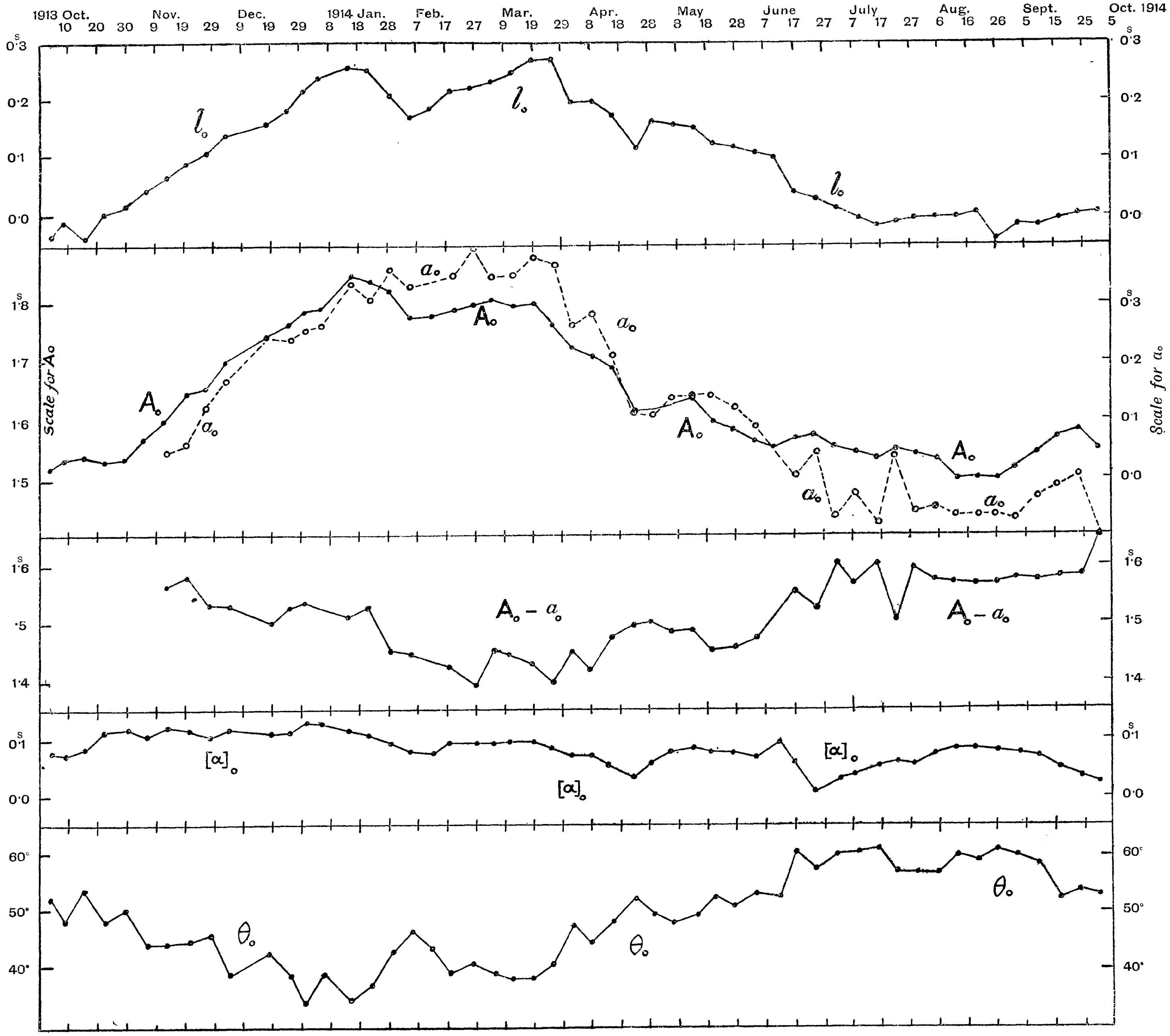

Fig. 3.—Basic Changes.

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Azimuth Gradient, Estimated Numerically, and Mean Residues.

Date.	Gradient.	Residue. s	Date.	Gradient.	Residue. s
Oct. 5–11	+ ·0056	± ·008	Apr. 5–11	+ ·0068	± ·012
12–18	94	·008	12–18	48	·018
19–25	79	·013	20–25	49	·020
26–32	146	·016	26–32	83	·020
Nov. 2–8	19	·009	May 3–9	58	·006
9–15	98	·012	10–16	79	·013
16–22	141	·010	17–23	86	·010
23–29	99	·010	24–30	82	·014
30–37	50	·014	31–37	55	·014
...	...	...	June 7–13	44	·014
Dec. 14–20	63	·009	14–20	16	·014
21–27	61	·011	21–27	3	·010
28–32	36	·008	28–34	80	·012
Jan. 2–8	+ 45	·011	July 5–11	54	·011
12–16	– 13	·008	12–18	100	·011
18–24	+ 37	·008	19–25	80	·013
25–31	50	·009	26–32	60	·009
Feb. 1–7	23	·006	Aug. 2–8	122	·008
8–14	38	·004	9–15	44	·010
15–21	73	·009	16–22	70	·012
22–28	47	·007	23–29	72	·015
Mar. 1–7	61	·013	30–36	49	·016
8–14	52	·008	Sept. 6–12	56	·011
15–21	+ 69	·010	13–19	32	·008
22–28	– 7	·012	20–26	68	·005
29–35	+ ·0068	± ·013	27–33	+ ·0083	± ·013

The mean gradient shown is +^{s}·0062 per 1° F.; this may be taken as more reliable than +^{s}·0076 per 1° derived by graphical estimation. Returning now to the basic azimuth curve A_0, we see that it shows a maximum in the second week in January, another early in March, and a minimum in the middle of August. It is much smoother than the mean temperature curve (θ_0) which is shown for the same dates on the same figures, but all the main fluctuations of the one are shown in the other, without lag. It seems probable that it would agree with the temperature a little way below the ground or within the pier. This must be reserved for further examination. If so we should have to attribute changes in A to two curves, one which followed the temperature of the metal work of the V's, and a second which followed the temperature within the granite pier or the rock. It will be noticed that the coefficient for the latter change is of opposite sign to that for the former and of about twice its magnitude.

Relation to Celestial Azimuth.

The azimuths read from the azimuth marks of the Cape Transit Circle appear to be of so absolute a character that their smoothed values are more fixed than stellar azimuths themselves determined from polars, since the latter must be cleared of the small fluctuation due to motion of the earth's pole before an even comparison between the two can be made. With this fact in remembrance, special pains have been taken with the stellar azimuth determination for comparison with the curve A. More will be said upon this point below. At the moment attention is drawn to the result of the comparison, which is shown in the second curve of fig. 3. In this A_0, as explained above, denotes azimuth read with respect to the South Collimator, reduced to temperature 45° by an adopted common coefficient $+{}^{s}\cdot0076$ per 1° F., and meaned for each week. Superposed to A_0, the stellar azimuth, a_0, is shown connected by a dotted line; this is also meaned for the week and reduced to the same temperature with the same coefficient. The coefficient may be somewhat at fault, but if no reduction at all had been made the comparison of the two curves would have been very much the same. It shows a well-marked wave exhibited below as $A_0 - a_0$. If the determinations of A_0 were absolute and those of a_0 completely reliable, we should expect a level straight line, modified only by the barely sensible movement due to the motion of the pole itself. The fluctuation actually shown is fully $0^{s}\cdot15$ between its greatest and least values, following to some degree the mean temperature curve. This calls for explanation. Since A_0 is taken with respect to the South Collimator, we might suppose that the optic axis of the South Collimator was liable to movement to this amount. We can only test this by another reference. The fourth curve on the same figure $[a_0]$ shows the mean azimuth of the North Collimator east of the South, reduced to 45° with a coefficient $-{}^{s}\cdot0036$ per 1° F. This does not seem to offer any promise of explaining the curve $A_0 - a_0$. If we attribute the latter to the South Collimator, we should be obliged to attribute to the North Collimator, roughly speaking, an equal and simultaneous movement. This appears improbable, as none of these movements show the lag with respect to surface temperature that one would expect from deep-seated movements. There is so little resemblance between the curves $[a_0]$ and $A_0 - a_0$ that one is disposed to conclude that the South Collimator is almost completely steady, and that most of the movement shown in $[a_0]$ is due to the North Collimator. One must then examine the stellar azimuths a_0. We may record as a specimen the details for the interval between March 9 and April 25. In this interval A_0 on the whole falls by $0^{s}\cdot17$; but a_0' besides erratic movements, falls much more rapidly, *i.e.* by $0^{s}\cdot22$ at least. The following table shows the observer, the individual stars observed, with the azimuth as deduced from each entered below it, the mean azimuth for the night, (a) the mean for the week, $((a))$ and the same reduced to temperature 45°, a_0 for the purposes of the chart. It shows also A, for each night as read from the collimators.

Observed Azimuths, 1914 *March* 9–*April* 25.

Date.	Observer.	Temperature.	δ Urs. Min. S.	Cephei 51.	λ Urs. Min. S.	Groomb. 1119.	Groomb. 3548 S.	Brad. 3147 S.	Brad. 1672.	(*a*).	((*a*)).	a_0.	A.
		°	s	s	s	s	s	s	s	s	s	s	s
ar. 9	J.S.	34·8	·266	·313	·302					·294			1·723
10	W.	35·4	·330	·285	·344	·289	·364			·322			·727
11	J.S.	36·3	·184	·259	·175	·263				·220			·730
12	W.	40·3		·309	·382	·296				·329			·744
14	W.	43·5				·332	·427			·380	·301	·351	·775
16	W.	40·0	·352	·328	·364	·268	·362			·335			·762
17	J.S.					·289	·200			·245			
18	W.	38·5		·302	·377	·348	·382			·352			·752
19	J.S.	38·3		·275	·255	·319				·283			·726
21	J.S.	39·6		·382	·414	·364				·387	·330	·383	·754
24	W.	42·6		·318	·407	·370	·386			·370			·749
27	J.S.	42·4	·295	·286		·339				·307	·343	·370	·741
29	W.	45·0		·291	·357					·324			·745
31	J.S.	50·0				·305	·310			·308			·776
pr. 1	W.	51·3		·236		·329	·354			·306			·768
2	J.S.	48·9		·310						·310			·742
3	W.	49·5				·212	·289			·251			·733
4	J.S.	48·0					·184			·184	·289	·268	·718
7	W.	42·7				·171	·219			·195			·686
8	B.	44·0					·264	·262	·292	·273			·709
9	J.S., B.	45·2				·284		·366		·325			·699
10	J.S., B.	47·0					·369	·307		·338			·736
11	B.	46·9				·288	·333			·311	·287	·289	·733
13	J.S., B.	46·2					·269	·192	·287	·249			·733
14	J.S., B.	45·6					·204	·186		·195			·707
15	B.	49·1					·234	·366	·335	·312			·688
16	B.	52·8					·233	·150	·244	·209			·704
17	B.	52·6					·186	·145	·272	·201			·725
18	B.	52·9					·303			·303	·240	·213	1·735
20	B.	55·0						·105	·203	·154			...
21	B.	60·8						·207	·281	·244			1·687
23	B.	49·6							·158	·158			·656
25	B.	51·5						·100	·164	·132	·177	·116	1·641

Stellar azimuths must be considered at present the ultimate appeal; yet it is difficult to draw any definite conclusion from the material here before us as to the source and reality of a relative change of a_0 with respect to A_0 of amount $0^{\rm s}\cdot05$ or thereabouts. We may compare the transits of the three stars *Cephei* 51, λ *Urs. Min.*, and *Groomb.* 1119 on March 11 and 12, and there are many other anomalous instances. Some of this may be due to personality in the observers; this is reserved for fuller subsequent examinations. The transits are taken by shifting the wire and tapping the moment of transit on the chronograph. But personality would not generally affect very much the means for the weeks, which are irregular by amounts of the same order as that under discussion. One would be disposed to attribute a considerable part of the separate differences between A_0 and a_0 to uncertainty as to the true value of the latter, but this is an insufficient explanation, since the curve $A_0 - a_0$ does not consist merely in irregularities; there is also a systematic dip in it to the total amount of fully $0^{\rm s}\cdot15$, and this seems very difficult to account for.

Since an error—Δa—in the value adopted for a would reproduce itself in the adopted clock error to amount of the mean value for the whole set of clock stars of Δa $(\sin\phi - \cos\phi \tan\delta)$, which may be about four-fifths of the full value of Δa, some light may be thrown upon the reliability of a by collecting the adopted clock errors for the same period. These are given below for the clock Riefler. Over the same period a nightly comparison was made by wireless with the Paris clock; the result of this is shown alongside the other as *P. − Ed.*

Date.	Riefler's Error.	*P. − Ed.*	Date.	Riefler's Error.	*P. − Ed.*	Date.	Riefler's Error.	*P. − Ed.*
	s	s		s	s		s	s
Mar. 9	+ ·20	+ ·16	Mar. 27	+ ·31	+ ·05	Apr. 11	+ ·07	+ ·16
10	·24	·13	29	·17	...	13	·12	·14
11	·32	·11	31	·06	·08	14	·15	...
12	·24	·07	Apr. 1	+ ·04	·15	15	·05	·25
14	·25	·13	2	− ·01	·21	16	·10	·10
16	·31	·09	3	+ ·07	·13	17	·08	·06
17	·26	·12	4	·08	·19	18	+ ·03	·11
18	·28	·13	7	·04	·14	20	− ·02	...
19	·28	·12	8	·00	·19	21	·05	·07
21	·35	·10	9	·02	·17	23	·15	·05
24	+ ·38	+ ·08	10	+ ·07	+ ·16	25	− ·11	+ ·02

March 24. Riefler's pressure reduced.
April 1. ,, ,, increased.
14. ,, ,, reduced.
15. ,, temperature found low.
21. ,, ,, ,, high.

Each of these columns supplies material for forming a judgment, but each again is relative to something else, the column of Riefler's errors being relative to the regular going of that clock, which was interrupted several times by changes in the barometer and temperature, and the Paris references introducing the Paris clock. Up to March 31 these references include a revision of the times originally sent out from Paris, which was kindly communicated by M. Baillaud. If now we take, say, the dates March 10–18, where the azimuths run $^{s}\cdot 322$ (W.), $^{s}\cdot 220$ (J.S.), $^{s}\cdot 329$ (W.), $^{s}\cdot 380$ (W.), $^{s}\cdot 335$ (W.), $^{s}\cdot 245$ (J.S.), $^{s}352$ (W.), and so naturally evoke some suspicion of personality, we are quite unable to trace any corresponding fluctuation in the table last given. Indeed the conclusion from this table would be that the clock errors, and therefore the individual azimuths, were remarkably reliable and did not admit of variation of amount much greater than $\pm 0^{s}\cdot 02$. The true nature of the discrepancy between instrumental and stellar azimuths must be reserved for further examination.

Azimuth of North Collimator with respect to South Collimator.

The interest of this is the collateral evidence which it brings to bear upon the degree of fixity of the axis of the South Collimator. A specimen of the curve is shown in [α] in fig. 1. An examination of the fluctuations of this curve, and they are considerable, shows that they follow pretty closely the superficial temperature θ, the coefficient being negative—that is to say, the axis of the North Collimator moving west with respect to that of the South as the temperature rises. There is also some evidence of a daily period apart from this movement. Such a period might perhaps be ascribed to a form of personality, the habit of the observer differing slightly at different hours of the day, or to more rapid temperature fluctuations than are shown in θ, the temperature of the Transit Circle pier. The determination of the temperature coefficient was effected graphically by a method slightly modified from that employed for A and illustrated in fig. 2. A whole or a portion of a month was treated together and one dot registered for the mean of each day. By this means the following coefficients were concluded:—

Temperature Gradient for [α].

Date.	Gradient per 1° F.	Date.	Gradient per 1° F.
	s		s
Oct. 1–16	– ·0040	Mar. 1–31	– ·0027
17–31	38	Apr. 1–10	40
Nov. 1–30	36	11–18	42
Dec. 1–31	36	18–28	35
Jan. 1–31	27	May 1–31	33
Feb. 1–28	– ·0027	June 1–18	– ·0035

The adopted mean coefficient is $-^{s}\cdot 0036$ per 1° F. When the weekly means are cleared of superficial changes by the help of this coefficient and reduced to 45°, the basic curve which results is

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shown as $[a_0]$ on fig. 3. This curve has already been remarked upon. It has a small and generally steady movement, which shows little trace of following the waves in the temperature θ_0.

Collimation.

There is little indication of the presence of a superficial temperature coefficient in the collimation. Owing to some trouble with the micrometer of the telescope the line of collimation was changed several times during the year, so that it is not possible to draw clear conclusion as to basic changes. The results of collecting the means for periods of about one week are as below:—

Period.		(*c*).
Oct.	1– 4	+·376
	5–11	·379
	12–16	·388
	17–19	·221
	20–25	·230
	26–32	·229
Nov.	2– 4	+·224
	5– 8	−·171
	9–15	·162
	16–18	·164
	19–22	·087
	23–29	·079
	30–36	−·076
Dec.	14–19	+·105
	21–27	·112
	28–32	·108
Jan.	2– 8	·114
	12–16	·119
	18–24	·117
	25–31	·115
Feb.	1– 7	·120
	8–10	·120
	15–21	·315
	22–28	·317
Mar.	1– 7	·315
	8–16	·317
	18–21	+·306
Mar.	22–28	+·298
	29–30	·295
	31–35	·189
Apr.	5–11	·193
	12–18	·193
	20–23	·201
	23–25	·312
	26–32	·309
May	3–10	·313
	10–16	·310
	17–23	·302
	24–30	·303
	31–37	·296
June	7–13	·295
	14–16	·286
	17–20	·272
	21–26	·261
	27–34	·252
July	5–11	·253
	12–18	·250
	19–25	·242
	26–32	·242
Aug.	2– 8	·233
	9–15	·223
	16–22	·211
	23–29	·196
	31–36	·253
Sept.	6–12	·248

The slow steady change between April 23 and August 29 is remarkable.

Perhaps a more interesting feature in *c* is the well-marked daily coefficient, which is distinct though small, and, like that shown by $[\alpha]$, appears even when there is no corresponding movement apparent in θ. To exhibit it, we collect the observations under the hours 1^{h}, 7^{h}, 11^{h}, and 22^{h} for prolonged periods; thus we have the means—

1914.	1^{h}.	7^{h}.	11^{h}.	22^{h}.
	s	s	s	s
Mar. 19–May 21	·306	·304	·300	·300
May 22–July 13	·280	·281	·276	·274

Similarly for nearly the same hours, but with less weight—

1913.				
Oct. 5–Nov. 8	·071	·069	·068	·067

which shows an indication in the same direction. Presumably this is merely a temperature phenomenon, though following changes which are not exhibited by the thermometer of the Transit Circle pier.

Curves of Level.

These were approached in the same way as the curves of azimuth; they were collected first in the same weekly groups and charted, in order to estimate the superficial temperature coefficient graphically. The results are shown in the following table:—

Gradients for Level, Estimated Graphically.

Date.	Range of Temp.	Gradient for 1° F.	Date.	Range of Temp.	Gradient for 1° F.
	°			°	
Oct. 1–5	6·0	+·0126	Feb. 22–28	9·8	+·0076
5–11	5·5	94	Mar. 1–7	6·1	120
12–18	6·5	94	8–14	9·8	93
19–25	18·1	53	15–21	7·3	110
26–32	6·6	60	22–28	4·8	100
Nov. 2–8	9·1	40	29–35	6·8	88
9–15	6·0	102	Apr. 5–11	5·6	92
16–22	9·1	88	12–18	10·5	97
23–29	7·0	93	20–25	14·0	75
30–37	16·3	72	26–32	11·5	61
Dec. 14–20	8·9	88	May 3–9	9·6	95
21–27	10·3	70	10–16	12·4	85
28–32	10·4	104	17–23	7·9	84
Jan. 2–8	11·6	90	24–30	11·5	73
12–16	1·6	...	31–37	10·3	94
18–24	9·8	37	June 7–13	9·3	90
25–31	10·3	68	14–20	7·6	135
Feb. 1–7	6·3	82	21–27	5·1	138
8–14	6·1	98	28–34	10·7	99
15–21	9·7	+·0093	July 5–11	6·7	+·0116

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The mean is $+^{s}{\cdot}0085$ per 1° F. Adopting this as determined, each observation of level was reduced to temperature 45° and the results meaned for each weekly period. The outcome, which is supposed to be free from superficial temperature effects and is called l_0 or the basic level-curve, is shown as the first curve of fig. 3. If the adopted temperature coefficient is in error, the effect would be that of adding to the ordinate of l_0 as shown the due fraction of the corresponding ordinate of θ_0. Its character could not then be changed much, since it already follows θ_0 quite closely in general feature, with reversed sign, though it is decidedly smoother. But its resemblance to A_0 is more remarkable and more interesting. Remembering that the two curves are completely independent, their agreement is as near to identity as one could look for. There is no difficulty in admitting an identity if we suppose that both are due to the same movement of the one V relative to the other, and show merely the vertical and horizontal projections of the same motion. This would imply that the curve A_0 belonged to the Transit Circle alone, and contained no admixture arising from a movement of the South Collimator. If we attribute a portion of A_0 to the latter, it becomes much more difficult to explain the agreement with l_0. The agreement of l_0 with a_0 is much inferior. It seems that we cannot reject A_0 from its claim to represent the true basic azimuth of the instrument unless we are prepared to argue away as without significance the agreement of A_0 with l_0.

In order to determine the temperature coefficient by a method free from possible bias, the weekly groups were treated numerically in the manner that has already been explained in the case of A_0.

Level Gradient, Estimated Numerically, with Mean Residues.

Date.	Gradient per 1° F.	Residue.	Date.	Gradient per 1° F.	Residue.
		s			s
Oct. 5–11	+ ·0029	± ·011	Feb. 1–7	+ ·0004	± ·011
12–18	− 25	·014	8–14	− 20	·012
19–25	+ 40	·012	15–21	+ 27	·013
26–32	29	·009	22–28	+ 11	·011
Nov. 2–8	67	·007	Mar. 1–7	70	·019
9–15	48	·007	8–14	34	·014
16–22	81	·007	15–21	55	·018
23–29	79	·006	22–28	108	·010
30–37	62	·022	29–35	59	·014
Dec. 8–13	...	...	Apr. 5–11	75	·007
14–20	73	·011	12–18	62	·019
21–27	71	·010	20–25	55	·015
28–32	97	·004	26–32	34	·014
Jan. 2–8	+ 85	·009	May 3–9	85	·005
12–16	...	...	10–16	91	·009
18–24	+ 25	·009	17–23	66	·006
25–31	+ ·0061	± ·021	24–30	+ ·0047	± ·013

Level Gradient, Estimated Numerically, with Mean Residues—continued.

Date.	Gradient per 1° F.	Residue.	Date.	Gradient per 1° F.	Residue.
		s			s
May 31–37	+·0064	±·015	Aug. 2–8	+·0062	±·010
June 7–13	97	·011	9–15	63	·012
14–20	37	·016	16–22	72	·012
21–27	147	·009	23–29	56	·013
28–34	53	·012	31–36	47	·010
July 5–11	99	·014	Sept. 6–12	55	·014
12–18	59	·010	13–19	83	·007
19–25	77	·015	20–26	68	·012
26–32	+·0047	±·010	27–33	+·0093	±·013

The general mean gradient is +^{s}·0057 per 1° F. This differs from the graphical estimate +^{s}·0085 by more than perhaps might have been expected. As a determination it is to be preferred. But none of the conclusions drawn above would be altered by replacing the one by the other.

It is worth mentioning in connection with the above that a basic change of level in the course of the year is observed with the Milne seismograph, which is mounted with its boom North and South. It had been noticed that in the spring the boom required repeated adjustment owing to a tendency to move to the East, with a compensating movement to the West in the autumn, and a hair was attached to it so that the amounts might be measured. The measures, so far as they go, run as follows:—

1913 Sept. 29	0″·0	1914 Jan. 22	5″·6 West.
Oct. 11	0·5 West.	Mar. 29	2·4 West.
29	1·5	June 22	1·2 East.
Nov. 6	2·1	Aug. 6	2·9
12	2·1	17	2·5
17	2·1	Sept. 26	2·1
20	2·3	Oct. 24	1·2
22	2·5	26	1·1
Dec. 8	3·4	29	1·0
1914 Jan. 16	5·5 West.	1914 Nov. 2	0·8 East.

That is to say, there is an indicated oscillation of level of amplitude 8″·5 in the course of the season, with maxima about the same season as shown by the Transit Circle, but with phase opposite. The matter is worth sifting further; *prima facie* it may be attributed to a temperature coefficient of the seismograph. For the present the discussion may be closed here. The questions opened possess a good deal of interest and some importance. It is proposed to accumulate further material so that definite and reliable conclusions may be drawn with regard to them.

On Professor Turner's Theory of a Sun-spot Swarm of Meteors, associated with the Leonids. By Professor R. A. Sampson.

Professor Turner's theory of the production of sun-spots by a swarm of meteorites, circulating in an elongated orbit, and refreshed periodically by encounters of Saturn with the Leonid swarm, was published in *Monthly Notices*, lxxiv. 2 (1913 December). In a short work recently issued * I made the following note upon it:—

"More than one attempt has been made to connect the periodicity of the Sun with the planets. That of Professor H. H. Turner is the latest and boldest. He supposes that the sun-spots are produced by meteors detached by encounters of Saturn with the Leonid swarm and projected to the Sun. Certain numerical relations would fit very well with this idea. But it does not appear that Saturn could ever approach the meteors closely enough to produce such an effect—indeed not within a distance about one-half that which separates the Earth from the Sun. Moreover, the perturbations of the planets upon the Leonids are already known. Adams calculated them in 1867, and found that Jupiter produces a regression † of the node of 20′ in 33¼ years, Saturn 7′, and Uranus 1′. These small amounts are known to tally well with observation; and it seems quite certain that nothing so striking as Professor Turner's theory requires can remain to be discovered."

It has been objected to me that it is illegitimate to be quite certain of a negative upon evidence which, as is further objected, is irrelevant. I am not concerned to defend the precise form of a compressed note, inserted upon the proof-sheets of a work which is itself a mere summary, beyond saying that the statements of fact in it are correct, and are clearly distinct from statements of my own judgment upon them. But from another point of view the issue has some general importance. It is undesirable that so novel, attractive, and far-reaching a theory as that of Professor Turner should find a place in astronomical literature without receiving careful examination. Too many instances are known of theories, never really established, which are copied from one work into another upon the credit of a name. I will mention one instance which I shall make good later—Leverrier's theory that the Leonids were captured by Uranus and launched in their present orbit in A.D. 126. I shall show that this often-repeated statement rests upon a very dubious foundation.

Professor Turner's account of his theory is avowedly a rapid sketch. In a note added at the end of his paper he writes, "Several points in the above rapid sketch of a new theory and its possibilities would now be modified; but it is clear that each separate point must be examined with great care before anything like precision could be given to it, and such an examination will

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* *The Sun*, Cambridge University Press, 1914.

† *Sic.* It should be "progression."