REPORT

OF

THE ASTRONOMER ROYAL

TO THE

BOARD OF VISITORS

OF THE

ROYAL OBSERVATORY, GREENWICH,

Read at the Annual Visitation of the Royal Observatory, 1889 *June* 1.

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The Report here presented refers to the year from 1888 May 11 to 1889 May 10, and exhibits the state of the Observatory on the last-named day.

I. Buildings and Grounds, Moveable Property, and Library :—

The new 18-foot dome, constructed by Sir Howard Grubb over the enlarged Computing Rooms, was completed shortly after the date of the last Report, and the north portion and corners of the room have been partitioned off to form photographic dark rooms and a staircase lobby, in preparation for work with the 13-inch Photographic Equatorial which is to be erected there in the course of this year.

The exterior of the Observatory buildings and the interior of the Astronomer Royal's Office, and of the Computing Rooms, have been painted in the course of the year.

Two copper Lux Calor gas stoves have been fixed at the east and west ends of the Magnet basement to raise the temperature of the horizontal and vertical force magnets in winter to equality with the summer temperature. A Lux Calor iron stove has also been fitted in the new portion of the Upper Computing Room.

The Admiralty have sanctioned the building of a suitable Lodge for the gate-porter in place of the small wooden hut which has been used for that purpose for many years.

Bradley's North Quadrant (removed from the Safe Room last year) has been mounted on the west wall of the Transit-Circle Room.

The principal moveable instruments are thus distributed :—

At Greenwich—

Transits B, C, and E, and the Transit with axis view.

Altazimuth D.

S.O. 10875.—270.—3/89. Wt. 23357. D. & S.

Equatorials (6-inch).—" Cooke No. 2," Simms No. 1," " Hodgson," and telescope tube of " Corbett " (mounted on Lassell Equatorial).

Photoheliographs.—One complete (mounted in South Ground), two tubes (with object glasses), and a driving clock (used for the Personal Equation Instrument).

Detached Telescopes (on tripod stands).—Two 4-inch (Simms Nos. 1 and 2), two 4-inch (R.O. Nos. 1 and 2), two $3\frac{1}{2}$-inch (R.O. Nos. 3 and 4), and one $2\frac{3}{4}$-inch (R.O. No. 5).

On loan—

Transits.—A, at the Cape Observatory ; D, at Bethnal Green Museum (Science and Art Department).

Altazimuths.—A, at Bethnal Green Museum ; B, at the Cape Observatory ; E, at the Royal Naval College, Greenwich.

Equatorials (6-inch).—" Lee " at Hong Kong Observatory, " Simms No. 2 " at Bethnal Green Museum, mounting of " Corbett " lent to Rev. S. J. Perry for observation of total solar eclipse in December next.

Photoheliographs.—One complete at the Cape Observatory, one complete and the mounting of another (without driving clock) lent to the Science and Art Department, and a photoheliograph mounting lent to the Mountain Observatory Committee of the Royal Society.

Clocks.—" Dent No. 1916," and " Dent No. 2013," at the Cape Observatory, and " Dent No. 2011 " at Kew Observatory.

The two Transits B and C returned from the Cape Observatory last summer were used in the redetermination of the Greenwich-Paris longitude, after their pivots had been re-ground by Mr. Simms. It is proposed to lend Transit B again to the Cape Observatory for use in longitude operations.

The Cooke 6-inch Equatorial has been dismounted, the transit hut under which it was temporarily mounted in the South Ground having been erected in the Front Court in the line of Bradley's meridian for the longitude operations, Greenwich-Paris-Dunkerque. Transit C has been mounted on a substantial pier under this hut, and a French transit instrument has also been mounted under another hut (belonging to the French " Service Géographique de l'Armée ") about 25 feet to the west of the English transit.

Owing to want of space in the Observatory buildings the moveable instruments, clocks, and other apparatus, which are not in actual use, are for the most part stowed away in their boxes in wooden sheds, where their periodical examination and renovation are attended with great difficulty. For the proper care of these instruments it would

be advisable that they should be housed in a brick building to serve as an Observatory museum for instruments and apparatus of scientific value or historical interest. A building of one storey, about 40 feet long and 30 feet broad, would be suitable for this purpose, and a convenient site could be found in the South Ground, the proposed building being connected with the circular Lassell building. In that situation it would not interfere with the use of any of the astronomical or magnetical instruments, a consideration of much importance.

The annual comparison of the books and manuscripts with the catalogue has been made. The bound manuscript volume, the pamphlet, and two of the books missing last year have been found. There are now two books missing, one since 1886, and the other since 1888 April. Dr. Auwers has a copy of Maskelyne's printed observations on loan.

II.—Astronomical Observations :—

Transit-Circle.—The adjustment of the Y's mentioned in the last Report has been found quite satisfactory, the range of level error being from $-2''\cdot0$ to $+7''\cdot0$ in 1888, as compared with a range from $-10''\cdot2$ to $-1''\cdot2$ in 1887, and of azimuth error from $+3''\cdot3$ to $-8''\cdot2$ in 1888, as compared with a range from $+15''\cdot9$ to $+2''\cdot8$ in 1887. The mean level error is about $+2''\cdot5$ and the mean azimuth error about $-2''\cdot5$, both errors having been advisedly overcorrected, since in recent years the level error has been diminishing (algebraically) and the azimuth error increasing. The object-glass was cleaned and re-centred by Mr. Simms in July last, and its definition is now much improved. The instrument is in good working order.

Owing to pressure of work on the Greenwich-Paris longitude operations and other matters, the Personal Equation Instrument has not been used in the past year.

The regular subjects of observation with the transit-circle are the Sun, Moon, planets, and fundamental stars, with other stars from a working catalogue, which includes all the stars in Groombridge's Catalogue and in the Harvard Photometry not observed since 1867, and a selection from Piazzi's Catalogue. Ten close circumpolar stars taken from the *Connaissance des Temps* or from M. Lœwy's list of stars for longitude determinations have been observed regularly in addition to the four standard azimuth stars. The observation of these close circumpolars has been much facilitated by the adoption (since 1889 Jan. 1) of the method used by the officers of the French Service Géographique, which consists in making a number of bisections of the star with the R.A. micrometer during its transit, the exact time for each bisection being recorded on the chronograph. The Annual Catalogue of stars observed in 1888 contains about 1820 stars.

The following statement shows the number of observations made with the Transit-Circle in the year ending 1889 May 10 :—

Transits, the separate limbs being counted as separate observations	5360
Determinations of collimation error	306
Determinations of level error	356
Circle observations	5133
Determinations of nadir point (included in the number of circle observations)	335
Reflexion-observations of stars (similarly included)	544

About 140 transits (included in the above number) have been observed with the reversion-prism, to determine personality depending on the direction of motion.

Special attention has been given to the observation of the minor planet Iris and comparison stars in connection with the determination of its parallax at the late favourable opposition, 18 observations of the planet, and 113 of 28 comparison stars having been made last autumn.

The weather of the past year has been very unfavourable for astronomical observations, the months of June and July being exceptionally cloudy.

As regards the computations :—

The transits are completely reduced (so as to exhibit mean R.A. 1889 Jan. 1) to April 25, means of wires and limbs being taken to May 10. The copy for press is complete to January 22, except the notes, which have not yet been written for 1888.

The investigation of personal equations in eye and ear transits (two clock-stars on each night), as well as in chronographic, has been completed for the year 1888, the results for the regular observers showing little or no change as compared with previous years.

The circle observations are completely reduced (so as to exhibit Mean N.P.D. 1889 Jan. 1) to April 24, and the copy for press is complete to January 21, except the notes, which are written to the end of 1888.

The apparent correction for discordance between the nadir observation and the mean of results from reflexion observations of north and south stars is $-0''\cdot12$, with considerable fluctuations in the individual months, ranging from $-0''\cdot43$ in May to $+0''\cdot24$ in December. No correction on account of this discordance has been applied.

Two determinations of the astronomical flexure of the transit-circle telescope have been made since the last Report, the resulting values being $+0''\cdot08$, and $+0''\cdot52$. No correction for flexure as distinct from the R—D correction has been applied since 1879.

The correction for R—D, the error of assumed colatitude, and the position of the ecliptic have been investigated for 1888. The ledgers of mean R.A. and N.P.D. of stars for 1888, and the geocentric and heliocentric errors for the planetary results of 1888 are completed.

The value of the correction for discordance between reflexion and direct observations of stars, as found by the simple method hitherto used for solving the equations of condition, is + 0″·011 + 0″·699 sin Z.D., the term depending on zenith distance being sensibly the same as the mean of the five previous years, + 0″·693 sin Z.D. But as this solution gave residuals which did not appear to be quite satisfactory for large zenith distances, the equations were solved by the method of least squares with the result + 0″·010 + 0″·746 sin Z.D., for the R—D correction. The difference between the two solutions is small, but it would seem that with the extended range for reflexion observations introduced in 1882, it is advisable to use the rigorous method of least squares.

Since the date of the last Report, it has been found that the R—D correction for 1887 had been erroneously applied, the corrections for reflexion and direct observations having been inadvertently transposed. The results for colatitude and for position of the ecliptic as given in the last Report are consequently erroneous, and the correct values are here given with those recently found for 1888. The values found for the colatitude from the observations of 1887 and 1888 respectively are, 38°. 31′. 21″·99 and 38°. 31′. 22″·08 ; the respective corrections to tabular obliquity of ecliptic are + 0″·14 and − 0″·28 ; and the discordances between the results from the summer and winter solstices are + 0″·29 for 1887, and + 0″·24 for 1888, indicating that the means of the observed distances from the pole to the ecliptic are too small by + 0″·15 and + 0″·12 respectively. In both these years the freely exposed thermometer in the front court has been used for the observations of the Sun in place of the ordinary exterior thermometer near the north wall of the transit-circle room. The mean excess of the reading of the front court thermometer over that of the exterior thermometer at the time of observation of the Sun ranged from + 0°·4 in December to + 3°·7 in May, and the consequent increase in the correction for refraction from + 0″·07 in July to + 0″·42 in October.

The mean error of the Moon's tabular place (computed from Hansen's lunar tables with Newcomb's corrections) is + 0ˢ·090 in R.A. and + 1″·21 in longitude as deduced from 74 meridian observations in 1888. The mean error in tabular N.P.D. is − 1″·19, indicating that the mean of the observed N.P.D.'s is too great.

The computations for the Ten-Year Catalogue are practically complete, and the whole of the copy for press has been prepared, except the Introduction, which is in hand. Several laborious subsidiary discussions, to be given in the Introduction, have been completed. The ecliptic investigations for the several years 1877 to 1886 have been thoroughly revised to reduce the results to the same system of flexure, R.–D.

correction, refraction, and colatitude, some errors in the original computations having been corrected in the course of the work, and they have been further corrected for the effect of using the ordinary exterior thermometer instead of the front court thermometer, now adopted for observations of the Sun. The resulting correction for epoch for the Ten-Year Catalogue is $0^{s}\cdot000$. Fundamental mean R.A.'s of clock stars have been formed from 342 groups of at least twelve hours' duration, and these have been compared with the Ten-Year Catalogue places (which depend on all groups of more than six hours) to deduce the systematic corrections to the R.A.'s of the Catalogue. These are almost insensible, the largest being $+ 0^{s}\cdot007$ in the neighbourhood of 23^{h} R.A. The R.A.'s and N.P.D.'s of all circumpolar stars above and below pole have been compared, and the results tabulated in order of R.A. and in order of N.P.D., to give information on systematic errors and on co-latitude and refraction. This discussion is based on observations of about 700 circumpolar stars. A comparison has also been made of the places of southern stars in the Ten-Year Catalogue with those of the same stars in Mr. Stone's Cape Catalogue for 1880.

The examination of discordances and correction of errors of observation or computation has necessarily occupied much time, and in the course of this work a list was prepared of cases where the thermometer had not been read sufficiently near the time of observation of the star, and where a correction to the adopted reading could be advantageously inferred from the photographic registers of the meteorological branch. The resulting corrections to N.P.D. are in general small.

The computations in connection with the Ten-Year Catalogue have pressed very heavily on the Observatory staff during the past two years, as this catalogue contains about 40,000 observations of 4,059 stars, and these required to be corrected for reduction to the same system of proper motions, flexure, R—D correction, and thermometer readings, besides which subsidiary discussions have involved much labour.

The three thermometers mounted in the horizontal shutter opening of the transit-circle room have been read about 220 times during the past year simultaneously with the interior, exterior, and front court thermometers, and the readings have been tabulated to give information on the distribution of temperature in the neighbourhood of the instrument.

Altazimuth.—The total number of observations made in the year ending 1889 May 10 is as follows :—

Azimuths of the Moon and stars	358
Azimuths of Mark I.	83
Azimuths of Mark III.	72
Zenith distances of the Moon and stars	212
Zenith distances of Mark I.	84
Zenith distances of Mark III.	68

With the reversion prism eye-piece 20 chronographic and 8 eye-and-ear double transits of the Moon's second limb have been observed on one night.

After the erection of the new building, the errors of collimation and azimuth and the zenith points were determined entirely by observations of high and low stars until November 26, when the cornice of the Altazimuth building was cut through to allow of the observation of marks on three church spires (Marks I., II., and III.) distant about 6600, 1060 and 6930 feet respectively. A long focus lens has been made by Messrs. Troughton and Simms for observation of the nearest church spire (Mark II.), and is now being mounted, the more distant marks being frequently invisible in the hazy weather of the winter months.

The altazimuth observations are completely reduced to April 8, so as to exhibit errors of Moon's tabular R.A., N.P.D., longitude and E.N.P.D., and the copy for press has been prepared to the same date.

The following table shows the number of days on which complete observations of the Moon were obtained with the transit-circle and altazimuth respectively :—

Moon's Time of Meridian Passage.	Transit-circle.	Altazimuth.
1^h to 2^h mean solar time . . .	0	3
2^h to 3^h ,, . . .	0	5
3^h to 4^h ,, . . .	3	10
4^h to 5^h ,, . . .	2	9
5^h to 6^h ,, . . .	8	8
6^h to 9^h ,, . . .	18	7
9^h to 12^h ,, . . .	13	3
12^h to 15^h ,, . . .	22	1
15^h to 18^h ,, . . .	13	4
18^h to 19^h ,, . . .	4	8
19^h to 20^h ,, . . .	2	3
20^h to 21^h ,, . . .	2	6
21^h to 22^h ,, . . .	0	1
22^h to 23^h ,, . . .	0	2

The whole number of places of the Moon observed with the transit-circle is 87 or 7·0 per lunation, and with the altazimuth 70 or 5·6 per lunation.

The Moon's diameter has been measured with the transit-circle 3 times in R.A. and 6 times in N.P.D., and with the altazimuth 6 times in Z.D.

Clocks and Chronographs.—These are all in good order, except the Mean Solar clock, which requires cleaning after the disturbance caused by the renewal of the telegraph wires and batteries. The clock "Hardy," which had not been going well, was cleaned and repaired by Messrs. E. Dent & Co. in January.

Reflex Zenith Tube.—Since the date of the last Report 24 double observations of γ Draconis have been made and completely reduced to the end of 1888.

A new copper amalgamated mercury trough, similar to those used successfully with the portable transits in the longitude operations, was mounted in February for use with the reflex zenith tube, but no opportunity has since occurred for testing its efficiency with this instrument.

Equatorials.—The Lassell, South-east, Sheepshanks, and Shuckburgh equatorials are in good working order.

A pair of very satisfactory glass disks for the new 28-inch refractor was supplied by Messrs. Chance last October, and Sir Howard Grubb is now engaged in working the object glass, and in making the special tube required for it. As the object glass is to be of a special form adapted to photography as well as eye-observation, on the plan proposed by Prof. Stokes (in a letter to me dated 1886 August 16), of reversing the crown to correct for the spherical aberration, which is introduced by the separation of the lenses necessary for photographic correction, Sir H. Grubb has made an experimental 4-inch object glass, which has just been received and is being mounted on the Sheepshanks equatorial for trial.

The provision of a photographic refractor of 13 inches aperture with a 10-inch guiding telescope, equatorially mounted, to enable this Observatory to take part in the Photographic Map of the Heavens, was sanctioned by the Treasury at the end of August, and the construction of the instrument has been entrusted to Sir H. Grubb, who has made a trial 6-inch photographic object glass, as a preliminary to the construction of the 13-inch. A number of photographs of stars were taken last summer with this experimental object glass, mounted on the Sheepshanks equatorial, but the results are inconclusive, as it was found that one of the pieces of tinfoil between the lenses was missing, and that consequently the object glass was not properly adjusted. It was therefore returned to Sir H. Grubb, from whom it has again been received after being re-worked, and it is now being mounted on the Sheepshanks equatorial.

Twenty photographs were taken in June and July to demonstrate the practicability of transferring stellar images from the curved plates, of which mention was made in the last report, to flat plates, where they can be more readily measured with a micrometer. For this purpose, the Dallmeyer lens, with which the plates were originally taken, was mounted about the middle of a wooden tube 20 feet long (four times the focal length), and the aperture was reduced to two inches to diminish aberration. The curved original and the flat plate to receive the copy were placed at the ends of the tube, diffused daylight being used in these operations. The results appear to be satisfactory, and indicate that the curved plate gives a flat field at the conjugate focus, as was expected.

Further micrometric measurements of the flat plates obtained with the Dallmeyer objective have confirmed the conclusion that star places can be obtained with sufficient accuracy over a field 4° square, for which the images are nearly round, and even outside this limit where the images become crosses or ellipses. In one case the places of 47 stars on the plate as photographed at three positions for focus, differing by 0·16 inch, or about one four hundredth of the focal length, were measured, to determine the effect of a change of focal length, when the exposure remains the same. In another instance two exposures (of 20^m and 5^m) were taken at the standard focal reading, and a similar pair at a reading differing by 0·10 inch ; and the places of each of 30 stars compared in the four cases. The results indicate that the places obtained are independent of a considerable change in focal adjustment (allowance being made for change of scale), and of a considerable difference in exposure.

Since the date of the last report 7 occultations of stars by the Moon (6 disappearances and 1 re-appearance) and 9 phenomena of Jupiter's satellites have been observed with one or more of the equatorials or with the altazimuth. The occultations and phenomena of Jupiter's satellites are completely reduced to the end of 1888, for all stars for which we have places. The past year has been exceptionally unfavourable for observations of occultations and phenomena.

Comets have been observed with the Sheepshanks equatorial on 21 nights, the observations being thus distributed :—Comet *a* 1888 on 14 nights, Comet *e* 1888 on 6 nights, Comet *f* 1888 on 1 night.

III.—Spectroscopic and Photographic Observations :—

For determination of motions of approach or recession of stars 236 measures have been made of the displacement of the F line in the spectra of 38 stars, and 18 of the *b* line in the spectra of 8 stars, besides 5 of the *b* line in the spectrum of Saturn's ring, and comparisons with the spectra of the Moon, Venus, the Sun, or the sky, as a check on the general accuracy of the results. Observations of Algol on three nights during the past year confirm the previous results indicating orbital motion, but further evidence is required to establish the fact. The spectra of γ Cassiopeiæ, ο Ceti, β Lyræ, P Cygni, R Cygni, and β Pegasi, have been examined on several occasions, and Comet *e* 1888 has been spectroscopically observed on one night, the spectrum being chiefly continuous. The spectroscopic observations of all kinds are completely reduced.

In the year ending 1889 May 10, photographs of the Sun have been taken at Greenwich on 182 days, and of these 358 have been selected for preservation, besides 12 photographs with double images of the Sun for determination of zero of position.

For the year 1888 Greenwich photographs have been used on 177 days, and photographs from India and Mauritius filling up the gaps in the series on 182 days,

making a total of 359 days out of 366 on which photographs have been measured in this year.

The Sun has been free from spots on 155 days in the year 1888, the longest spotless periods being February 4 to 17, May 24 to June 8, and October 4 to 25. The mean spotted area in 1888 was half that of the preceding year, and corresponded closely to that for 1877, so that the minimum may be expected to occur during the present year. The mean distance of spots from the equator has also diminished to 7°·38 in 1888, being very little larger than it was in 1878, just before the last minimum, and this is a further indication that the Sun-spot minimum is close at hand. The faculæ in 1888 show a diminution in correspondence with that of Sun-spots, their area for 1888 being intermediate between those for 1876 and 1877.

The photographic reductions for 1888 are completed and the copy for press is prepared.

The photographs from India and Mauritius have been received from the Solar Physics Committee as far as 1888 Dec. 31 and Dec. 9 respectively.

As regards the further discussion of the results of former years :—

The projected areas of spots and faculæ (uncorrected for foreshortening) have been computed from the beginning of 1882 to the end of 1885, and the daily spotted area for each 10° of heliographic longitude has been taken out from the beginning of 1882 to the end of 1888, means being taken for each rotation of the Sun and for each period of 5 rotations. It is to be noted that the daily photographic record of the Sun's surface has been made practically complete since the beginning of 1882 by means of Indian or Mauritius photographs supplementing the Greenwich series.

The discussion of probable error in measures of areas and positions of spots on 8-inch photographs, and of personality in measures of areas of spots and faculæ on 4-inch photographs, which was printed in the Introduction to the Spectroscopic and Photographic Results for 1885, is being completed by discussions of probable error in measures on 4-inch photographs and of personality in measures on 8-inch photographs. The former has been completed, and a comparison of the probable errors for 4-inch and 8-inch photographs indicates that the measurement of areas of spots, expressed in millionths of the Sun's visible hemisphere, is sensibly as accurate for the 4-inch as for the 8-inch photographs, notwithstanding the circumstance that the former are on only half the scale of the latter; and that the probable error of the means of two measures of distance and position angle on the 4-inch photographs, as printed in the Photographic Results, though double that on the 8-inch photographs, is less than a unit in the last

figure. It does not appear, therefore, that the precision of measurement of areas and positions has been practically increased by the adoption of the larger-scale photographs.

To supplement the Greenwich record in the earlier years, 118 photographs of the Sun taken at Harvard College, Cambridge, U.S.A., between the dates 1874 Dec. 9 and 1875 Dec. 31, have been received through the Solar Physics Committee, and of these 63 have been measured in duplicate, and the measures completely reduced to fill up gaps in the Greenwich series. Ten photographs taken at Ely between 1874 Jan. 1 and Feb. 25 have also been received, but, as there are no means for determining the zero of position angle, it appears doubtful whether they can be utilized with advantage.

IV. Magnetic Observations :—

The changes in the three magnetic elements of declination, horizontal force, and vertical force, are continuously recorded by photography with the three magnetometers, absolute values of the declination, horizontal force, and dip being obtained from time to time to give the values for the reference lines on the photographic registers.

The accuracy of the measure of absolute declination by the upper declination-magnet depends on the condition that this magnet should be vertically over the lower magnet. But the arrangements are such that with the gradual decrease of declination, the upper magnet has to be shifted more and more to the west, in order that it may be viewed by its theodolite, the position of which on its pier cannot be altered. In order to determine whether the consequent change in the relative position of the two magnets has in late years increased to such an extent that any measurable mutual influence would exist, the upper magnet has on two different occasions (once in the year 1887, and once recently) been temporarily removed to the ante-room where its influence would be quite insensible. On both occasions the photographic register of the lower magnet showed no perceptible change of position. Conversely the removal of the lower magnet would not influence the position of the upper one (that used for absolute measure).

The diurnal range of temperature in the Magnet Basement has for many years past been kept within very small limits, but with the existing arrangements it had not been found practicable to keep the mean temperature in summer down to that which is maintained in winter, or to raise the latter to the ordinary temperature of summer. In order to equalize the winter and summer temperatures, and thus to remove any possible annual effect of temperature on the magnetic registers, two additional copper gas stoves were fitted up last January in the east and west arms of the basement near the horizontal and vertical force magnets respectively, and by the use of these, in combination with the central stove, the temperature of the basement has been maintained very closely at

67° Fahrenheit since the beginning of February. This is about the average summer temperature of the basement. It was found by experiment that the copper stoves exerted no perceptible influence on the magnets.

The earth-current wires were thoroughly repaired during the winter, portions of the Angerstein Wharf and Blackheath branches being renewed concurrently with the telegraph wires on this portion of the South-Eastern Railway, under the supervision of Mr. Leonard. Since then the Post Office authorities have put the connections with the Observatory into better order, but the resistances of the circuits do not seem to be much improved, the values found by recent tests ranging from 217 to 267 ohms for the Angerstein Wharf—Lady Well circuit, 7½ miles in length, and from 197 to 217 ohms for the Blackheath—North Kent East Junction circuit, 5 miles long. Taking approximate values of these resistances and combining them with measures of the motion on the photographic sheet given by a current from a standard Daniell cell with a known resistance in circuit, it is found that for both circuits a difference of potential of 1 volt between the earth plates is represented by about 1·0 inch on the photographic sheets, or about 0·55 inch on the lithographed plates in the 'Greenwich Observations.' The earth-current wires were tested for identity on May 6 and again on May 10, when it was found that the Blackheath and North Kent East Junction branches had been interchanged, the effect of this being to reverse the direction of movement on the sheet. It appears that this interchange occurred on 1888 January 2, but as no tracings have yet been made of the earth-current sheets for 1888, it will cause no difficulty.

A small electric hand lamp (with secondary battery) has been substituted for the wax taper formerly used for reading the thermometers of the horizontal and vertical force magnets, and has been found very convenient as well as much safer.

The magnetic reductions are completed to the following stages :—

The eye-observations of the upper declination magnet, and of the horizontal and vertical force magnets, are completely reduced to the end of 1888. The time-scales for declination, horizontal force, and vertical force are complete to the end of 1888, and the base line values, deduced from eye-observations, are entered on the photographic sheets for declination and horizontal and vertical force.

The hourly ordinates of the photographic curves are read out to the end of 1888 for vertical force, and the daily and hourly means are taken to March, and the time-scales for earth-currents are laid down. The declination and horizontal force ordinates are not yet read out. The dip observations are completely reduced to the present time, and the deflexion observations for absolute measure of horizontal force to the end of 1888. The temperature of the magnet basement at every hour has been read off from the sheets of the Richard thermograph to the end of 1888, and the daily and hourly means have been taken.

The following are the principal results for the magnetic elements for 1888 :—

Approximate mean declination . .	17° 40′ West.
Mean horizontal force . .	3·9480 (in British units). 1·8204 (in Metric units).
Mean dip	67° 24′ 26″ (by 9-inch needles). 67° 25′ 33″ (by 6-inch needles). 67° 26′ 16″ (by 3-inch needles).

In the year 1888 there were only three days of great magnetic disturbance, but there were also about twenty other days of lesser disturbance, for which tracings of the photographic curves will be published, as well as tracings of the registers on four typical quiet days.

V. Meteorological Observations :—

The continuous registration of meteorological phenomena has been maintained as usual, and all the instruments are in good order with the exception of the Thomson Electrometer. The springs of the pressure plate of Osler's anemometer were found to be in a bad state last autumn, and they were removed on October 31. New springs made by Messrs. Troughton & Simms, were mounted on November 28, and after some alterations were brought into use on December 12. The scale of pressures with the new springs has been carefully determined and is quite satisfactory, being sufficiently open for the small pressures and gradually closing up as the pressure increases, so that the highest pressures can be registered within the range available on the paper. The new thermograph has continued to work well since it was brought into use, after repair by Mr. Kullberg, on 1887 October 11.

In April, Mr. W. H. Dines obligingly tested the Robinson anemometer, as well as the smaller instrument formerly in use, on his whirling machine, 23 sets of experiments being made at velocities ranging from 10 to 50 miles an hour for the large anemometer, and from 7 to 34 miles an hour for the small one, which was placed nearer the centre of the whirling machine. It would appear that the theoretical factor 3·00 used for converting the movement of the cups into velocity of the wind is too large for both instruments, especially with high velocities, and that the registered velocities of the wind are consequently too great, as has been found in the case of other instruments. For further comparison of the indications of the two instruments, the old anemometer has been mounted by the side of that now in use, and readings of both are taken daily.

The Thomson electrometer having been in use for more than ten years, and the metal parts being much corroded, it was removed by Messrs. Elliott for thorough repair in July last. On remounting the instrument in August it was found that the character

of the record was quite changed, the ordinary movements being insensible, though pretty strong negative indications are still shown during thunderstorms or heavy rain. It was further noticed that when a positive charge from an electrophorus is put in, the movement is in the wrong direction, and it would seem that there is something quite anomalous in the action of the instrument, the cause of which has not yet been traced.

The register with the Osler anemometer from March 12 to May 12 was unsatisfactory, as the paper supplied for use at the former date did not correspond with the pattern and proved to be quite unsuitable. The whole of the impression of these forms has, therefore, been rejected, and a new supply, printed on paper similar to that which has been found satisfactory in past years, has been used from May 12.

The meteorological reductions are in the following state:—The observations of barometer, thermometers, anemometers, rain gauges and sunshine recorder (corrected where necessary, for instrumental error) are reduced up to the present time. On the photographic sheets all the time-scales are laid down, and the hourly ordinates are read out for the dry and wet bulb thermometers to the end of 1888. The table of principal changes in the direction of the wind for 1888 is completed.

The mean temperature of the year 1888 was 47°·7, being 1°·6 below the average of the preceding forty-seven years. The highest air temperature in the shade was 87°·7 on August 10, and the lowest 18°·4 on February 2. The mean monthly temperature in 1888 was below the average in all months excepting May, November, and December. In March, April, July, and October it was below the average by 3°·6, 3°·6, 4°·4, and 3°·9 respectively, and in November it was 4°·0 above the average.

The mean daily motion of the air in 1888 was 296 miles, being 12 miles above the average of the preceding twenty-one years. The greatest daily motion was 790 miles on March 11, and the least 57 miles on December 31. The only recorded pressures exceeding 20 lbs. on the square foot were 31 lbs. on March 11, and 21 lbs. on August 28.

During the year 1888 Osler's anemometer showed an excess of about 19 revolutions of the vane in the positive direction N., E., S., W., N., excluding the turnings which are evidently accidental.

The number of hours of bright sunshine recorded during 1888 by the Campbell-Stokes sunshine instrument was 1068, which is about 250 hours below the average of the preceding eleven years, after making allowance for difference of the indications with the Campbell and Campbell-Stokes instruments respectively, and it is 333 hours below that of 1887 recorded with the same instrument. The aggregate number of hours during which the sun was above the horizon was 4465, so that the mean proportion of sunshine for the year was 0·239, constant sunshine being represented by 1. A comparison has been made of the records of the Campbell and Campbell-

Stokes instruments for the 12 months from 1886 June 1 to 1887 May 31, with the result that the former registered 1256 hours of bright sunshine, while the latter registered 1364. It would appear, therefore, that the indications of the former instrument require to be multiplied by the factor 1·086 to make them comparable with those of the latter.

The rainfall in 1888 was 27·5 inches, being 2·9 inches above the average of the preceding forty-seven years.

The barometer reductions, 1874–76, and thermometer reductions, 1869–76, filling up the gap in the Greenwich series, are finished, and the results will appear in the volume for 1887.

VI. Printing and Distribution of Greenwich Publications :—

The volume of Greenwich Observations 1886 and the separate copies of the Results, together with the Spectroscopic and Photographic Results for 1887 were distributed last October.

The printing of the volume for 1887 is not yet complete, though the whole of it is in type, except the Magnetical and Meteorological Introduction, and a portion of the Ten-Year Catalogue. The first four sheets of the latter (to 7^h R.A., containing 1200 stars) are in type, and the first two of these have been sent for press. The Barometer Reductions 1874–1876, and Thermometer Reductions 1869–1876 are also in type.

As regards the volume for 1888, the whole of the Altazimuth section has been passed for press, and the copy for press of the Spectroscopic Results is in the printer's hands.

The increase in the bulk of the annual volume of 'Greenwich Observations' is material evidence of the increase in the current work of the Observatory, both in observations and in computations, but the preparation year by year of a steadily increasing mass of figures as copy for press, and the careful revision of these figures in the proof sheets, in itself causes additional pressure on the staff of the Observatory. In the volume for 1881 considerable reductions were made in the printing by omissions and condensation, but I do not see my way to doing more in this direction without giving up the fundamental principle of printing the original observations as well as the deductions from them, a sacrifice which I should be very loath to make, although it would undoubtedly somewhat relieve the congested state of the Observatory. The severity of the pressure on our existing staff may be judged from the fact that the number of pages in the 'Greenwich Observations' (closely-printed quarto tables of figures) has increased year by year from 796 in 1881 to 1078 in 1886, the last completed volume. In the volume for 1887, the Ten-Year Catalogue and the Meteorological Reductions have further increased the bulk, representing increased work in computations, and in preparing for press.

VII. Chronometers, Time Signals, and Longitude Operations :—

The number of chronometers and deck watches now being tested at the Observatory is 208 (159 box chronometers, 20 pocket chronometers, and 29 deck watches), 3 of which belong to the Indian Government, and the remainder to the Navy. The annual competitive trial of chronometers commences on July 6, and the trial of deck watches on October 26.

In the year ending 1889 May 10 the average daily number of chronometers and deck watches being regularly rated was 212, the total number received was 668, the total number issued was 601, and the number sent for repair was 282.

The following comparison shows the increase in these numbers since 1851 :—

	1851–1855.	1881–1885.	1888.
Average number being rated	97	190	221
Average number received yearly	291	475	654
Average number issued yearly	270	494	599
Average number sent for repair yearly ...	127	267	288

It will be seen that the work on chronometers has doubled in thirty years, and that there has been a further and more marked increase in the last five years, causing great pressure on the Observatory staff.

The annual trial of chronometers was more severe than in former years, as the chronometers have been tested in the oven at temperatures of 80° and 85°, as well as at temperatures of 95° and 97° Fahrenheit, so that any residual secondary error of compensation would be made evident in the range of temperature from 42° to 98°. Notwithstanding this, the performance of the chronometers generally has been very good, the first 23 (out of 47 sent in for trial) coming up to the standard for Naval service. The first six chronometers, as judged by their trial numbers, performed on the average better than the corresponding chronometers in any previous year, except 1886, when the conditions of the trial were not so severe.

For the annual trial of deck watches, 1888 Nov. 24 to 1889 Feb. 6, 32 watches were entered, and of these 17 were purchased for the Navy, the first 8 being classed "A," or equal in performance (on the 12 weeks' trial) to an average box chronometer. In future the duration of the trial will be increased to 16 weeks, viz., 6 weeks in the ordinary temperature of the room, 4 weeks in the oven, temperature 80° to 85° (the watches being tried in positions during the two middle weeks) and finally 6 weeks in the room.

Two chronometers have been tested for the Austrian Government, and four pocket chronometers for the Government of British Guiana.

There has been no failure in the automatic drop of the Greenwich time-ball, but on one day the ball was not raised on account of the violence of the wind.

The automatic drop of the Deal time-ball failed on thirteen days owing to interruption of the telegraph connections, and on one day high wind prevented the raising of the ball. There has been no case of failure of the 1 p.m. signal to the Post Office Telegraphs.

No return signals have been received from the Devonport time-ball clock since April 23, when, as I understand, the clock was cleaned and the contact-springs accidentally put out of adjustment. Up to that date the daily signal had been received regularly since the date of last Report, except on 42 days, of which 14 were Sundays. The apparent error of the clock-signal (after daily correction of the clock by the help of a time-signal from Greenwich) was under $0^s{\cdot}2$ on 66 per cent. of the days of observation, under $0^s{\cdot}5$ on 92 per cent., between $0^s{\cdot}5$ and $1^s{\cdot}0$ on 7 per cent., and it exceeded 1^s on 1 per cent.

No further action has been taken as regards the proposal to establish hourly time-signals at the Lizard, as with the present pressure on the staff there would be great difficulty in making the necessary arrangements for securing the efficiency of such a time-service.

In the year ending 1889 May 10, there have been failures on 33 days in the automatic signals from the Westminster clock. The error of the clock was insensible on 33 per cent. of the days of observation, 1^s on 28 per cent., 2^s on 28 per cent., 3^s on 8 per cent., and 4^s on 3 per cent.

The transfer to the Post Office Telegraphic Department of the maintenance of the Observatory telegraph wires, batteries, and connections for communicating time-signals, which was proposed in June 1887, has been carried out, and the renewal of wires and apparatus is now practically complete. The work was commenced early in January and has occupied much more time than was originally anticipated. The Post Office authorities will now take charge of the wires and batteries up to test boards fitted near the various instruments and clocks, these latter remaining of course in our care. The new test boards fitted up by the Post Office will be of great use in localizing faults in the telegraphic circuits.

The re-determination of the difference of longitude between Greenwich and Paris was carried out last autumn, the Submarine Telegraph Company having courteously placed a spare wire at our disposal each night from 8 to 12, and the Post Office having provided the services of a clerk, and the use of a wire to London, where it was joined on to the Submarine wire, so as to give direct communication with Paris. Observations were made in four groups of three nights each (or the equivalent in half nights). An English and a French observer were stationed at each end, each with a separate instrument and chronograph, and the pairs of observers were interchanged twice, to eliminate any change in the personal equations during the progress of the work. The pairs of English and French instruments were similar, and the signals as well as the

star transits were recorded on similar chronographs. On a full night each observer recorded about forty star transits, reversing his instrument three times, and exchanged signals twice (near the beginning and end of the evening) with his compatriot at the other end of the line, and once with the other observer. At Greenwich the transits were referred to the Sidereal Standard clock, and comparisons with the large Greenwich chronograph enable the ordinary determinations of clock-error with the transit-circle to be utilized as well as those specially made with the portable transits. With this object transits of clock stars with the transit-circle were usually taken by four observers on each night during the longitude operations. The actual stations were the Front Court of the Royal Observatory and the Observatory of the Service Géographique de l'Armée at Paris, the position of which with reference to the Paris Observatory has been accurately determined. Commandants Bassot and Defforges were the French observers, and Mr. Turner and Mr. Lewis the English. The observations lasted from September 23 to November 15, and 18 nights of observation at both stations are available, the two English observers having observed at Greenwich 653 transits of clock stars and 165 of azimuth stars, and at Paris 778 transits of clock stars and 165 of azimuth stars. All of these, as well as the signals exchanged, have been read out from the chronograph registers and the reductions are far advanced. Subsidiary investigations of the value of a revolution of micrometer screw, of intervals of wires, of form of pivots, and of errors of the axis-level have consumed much time, the last-named having been a long and tedious discussion.

In connection with the re-determination of the Greenwich–Paris longitude, provision has been made for the determination of the difference of longitude between Greenwich and Dunkerque, and it has been arranged that the operations shall begin early in June. The observations will be made by one French observer (Commandant Defforges) and one English (Mr. Turner), and it is intended to obtain eight complete nights of observation at both stations, the observers being twice interchanged. Commandant Defforges also proposes to determine the difference of latitude between Greenwich and Dunkerque.

While stationed at Greenwich last autumn, Commandant Defforges took the opportunity of swinging his reversible pendulums, which were firmly mounted in the Safe Room, to determine the absolute force of gravity at Greenwich in connection with the French series of determinations.

The Indian invariable pendulum has recently been mounted under General Walker's supervision in the Record Room at Greenwich for observations similar to those made in India, in the United States, and at Kew. It is intended to commence the swings without delay, all arrangements being now complete, and a detailed programme of observation having been drawn up by General Walker. By these two operations the French and Indian pendulum determinations will be connected through Greenwich.

VIII. Personal Establishment :—

The Staff of Assistants remains the same as at the date of the last Report, and is thus constituted, the names in each class being arranged in alphabetical order :—

Chief Assistant—Mr Turner.

First-class Assistants—Mr. Criswick, Mr. Downing, Mr. Ellis (Superintendent of the Magnetic and Meteorological Branch), and Mr. Maunder.

Second-class Assistants—Mr. Hollis, Mr. Lewis, Mr. Nash, and Mr. Thackeray.

Mr. Turner supervises the whole of the work of the Observatory, with full power to act in all matters during my absence. Mr. Criswick is charged with the transit reductions and miscellaneous astronomical computations, and has during the past year carried out the experiments in stellar photography. Mr. Downing is responsible for the altazimuth and equatorial computations, and has the care of the library and manuscripts. Mr. Thackeray has charge of the meridian zenith-distance and zenith-tube reductions and the reading out of the chronograph transits. Mr. Lewis superintends the time department and chronometers, and has during the past year assisted Mr. Turner in the longitude operations and computations. Mr. Maunder is charged with the spectroscopic and photographic observations and reductions. Mr. Hollis has undertaken the photographic measures and reductions to complete the record for past years, and much of the work in connection with the Ten-Year Catalogue. Mr Power, a senior computer, has also rendered valuable assistance in the preparation of this Catalogue. In the magnetic and meteorological branch Mr. Ellis superintends the whole of the work, and is assisted by Mr. Nash, who has special charge of the meteorological reductions and instrumental adjustments.

Ten computers are attached to the astronomical branch, two to the spectroscopic and photographic, and five to the magnetic and meteorological.

My thanks are due to the members of the staff for their services in carrying on the work of the Observatory during the past year under circumstances of great pressure.

A gate-porter, a watchman, and a gardener complete the establishment. A foreman of works, with two carpenters and a labourer, and a skilled mechanic are also employed continuously.

IX. General Remarks :—

The increase of work in all branches of the Observatory, to which I have had to call attention on former occasions, has continued during the past year, and has caused very great pressure on our staff. Evidence of this will be found in the various sections of this Report, and it may be sufficient here to point out that the annual volume of "Greenwich Observations" has increased in bulk by 36 per cent. in the last five years, and that this represents at least an equivalent increase in the work of the Observatory.

The preparation of the Ten-Year Catalogue of 4059 stars, involving laborious discussions, which could not be dispensed with in the present state of astronomy, could hardly have been carried out with the existing staff of Assistants if it had not happened to synchronize with a minimum of sun-spots, and even under those favourable conditions it has occupied three years, the publication of the Catalogue having been seriously delayed.

The re-determination of the longitude of Paris was another duty which it was incumbent on us to undertake, and in connection with this the longitude of Dunkerque has to be determined this year. Both of these are laborious operations when superadded to the current work of the Observatory.

It may here be mentioned that the Observatory has been relieved of the charge of examining optical instruments for the Navy, which, in its recent developments, consumed much of my own time, and threatened to interfere seriously with our proper functions. But against this is to be set the increase of work in connection with chronometers and the close supervision necessary to secure the higher standard of efficiency now required in deck watches as well as in chronometers.

In order to meet the pressure of computing work, the Admiralty have authorized an addition to the grant for Computers, and their number has accordingly been increased; but this does not meet the difficulty felt in providing for the proper supervision of the growing work of the Observatory, which can hardly be carried on efficiently unless some means are taken to strengthen the supervising staff.

W. H. M. CHRISTIE.

ROYAL OBSERVATORY, GREENWICH,
1889 May 11.