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# The Greenwich Photo-heliographic Results (1874 – 1976): Initial Corrections to the Printed Publications

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**Abstract.** A new sunspot and faculae digital dataset for the interval 1874 – 1955 has been prepared under the auspices of the NOAA National Geophysical Data Center (NGDC). This digital dataset contains measurements of the positions and areas of both sunspots and faculae published initially by the Royal Observatory, Greenwich, and subsequently by the Royal Greenwich Observatory (RGO), under the title *Greenwich Photo-heliographic Results (GPR), 1874 – 1976*. Quality control (QC) procedures based on logical consistency have been used to identify the more obvious errors in the RGO publications. Typical examples of identifiable errors are North versus South errors in specifying heliographic latitude, errors in specifying heliographic (Carrington) longitude, errors in the dates and times, errors in sunspot group numbers, arithmetic errors in the summation process, and the occasional omission of solar ephemerides. Although the number of errors in the RGO publications is remarkably small, an initial table of necessary corrections is provided for the interval 1874 – 1917. Moreover, as noted in the preceding companion papers, the existence of two independently prepared digital datasets, which both contain information on sunspot positions and areas, makes it possible to outline a preliminary strategy for the development of an even more accurate digital dataset. Further work is in progress to generate an extremely reliable sunspot digital dataset, based on the long programme of solar observations supported first by the Royal Observatory, Greenwich, and then by the Royal Greenwich Observatory.

**Key words** Greenwich photo-heliographic results · Positions and areas of sunspots and faculae · New digital dataset · Quality control procedures · Printed publications · Typographic errors · Initial corrections

## 1. Introduction

The present paper is the third in a set of three companion papers. The first paper (Paper 1) by Willis et al. (2013a) provides a succinct summary of the essential background information that is required to understand the nature of the typographic, systematic and isolated errors in the different datasets containing the printed and digital versions of the *Greenwich Photo-heliographic Results (GPR), 1874 – 1976*. The second paper (Paper 2) by Willis et al. (2013b) considers the existence of systematic and isolated errors in the original Royal Greenwich Observatory (RGO) sunspot digital dataset (RGO–SDD), which is available to the scientific community online at some national data centres (e.g., the NOAA National Geophysical Data Center and the UK Solar System Data Centre). Paper 2 also contains an appendix that outlines a rigorous procedure for checking the original sunspot digital dataset (RGO–SDD), which has yet to be implemented. This third paper (Paper 3) considers the errors in the more recently available RGO sunspot and (&) faculae digital dataset (RGO–S&FDD). It is shown that some of these errors result from typographic errors in the printed versions of the *Greenwich Photo-heliographic Results (GPR), 1874 – 1976*.

As noted in Section 3 of Paper 1, this more detailed digital dataset, which also includes information on solar faculae (up to the end of 1955), has been prepared under the auspices of the NOAA National Geophysical Data Center (NGDC), Boulder, Colorado. Most importantly, the information in the "Measures of Positions and Areas of Sun Spots and Faculae" section of the RGO publications (see Section 3 of Paper 1) is now available online at the NGDC, Boulder, Colorado (http://www.ngdc.noaa.gov/stp/solar/greenwich.html; use the 'Solar White Light Faculae' link). This digital dataset (RGO–S&FDD) is likely to be of great importance to the scientific community in the future. However, although the sunspot and faculae data were allegedly key-entered twice, any typographic errors in the RGO printed observations, bulletins and annals (RGO–POBA) still have to be corrected. The purpose of this paper is to explain how quality control (QC) procedures have been used to identify and correct such typographic errors.

Two important characteristics of the sunspot and faculae digital dataset (RGO–S&FDD) were noted in Section 6 of Paper 1. First, the positions and areas of faculae were presented in the RGO printed publications (RGO–POBA) only up to the end of 1955 and at the present time the sunspot and faculae digital dataset (RGO–S&FDD) does not include any data for the interval 1956 – 1976. Second, the positions of faculae were given in both polar and heliographic coordinates in the interval 1874 – 1917 but only given in polar coordinates in the interval 1918 – 1955. The heliographic coordinates in this second interval could obviously be calculated from the polar coordinates, using the mathematical equations presented in Paper 2, but they are not actually presented in the RGO printed publications. Therefore, for simplicity, this initial study is restricted to the typographic errors in the printed publications that occur during the interval 1874 – 1917.

As noted in Section 5 of Paper 1, the format of the sunspot and faculae digital dataset (RGO–S&FDD) is similar to the format of the original sunspot digital dataset (RGO–SDD). It should be noted again here, however, that the latter dataset (RGO–SDD) provides only average daily values of the areas and positions for each sunspot group, whereas the former dataset (RGO–S&FDD) provides separate daily values of these quantities for each individual component of a sunspot group up to the end of 1915, as in the printed observations, bulletins and annals (RGO–POBA). Therefore, for sunspot observations in the interval 1874 – 1915, it is necessary to derive weighted averages of these individual components in the RGO–S&FDD before the two separate digital datasets can be compared (see Section 6 of Paper 1). These weighted averages are formed using the whole-spot (umbral plus penumbral) area of each individual component of a sunspot group as the appropriate weight, which is the normal procedure adopted in the preparation of the *GPR* for the subsequent interval 1916 – 1976.

The average position coordinates of a sunspot group are calculated using Equation (1) of Paper 1. Thus the method of position determination is essentially based on weighted areas, using the whole-spot (umbral + penumbral) area as the appropriate weight.

Before discussing the quality control procedures used in the present study, it is helpful to review briefly some previous papers on the analysis of errors in the position measurements of sunspot groups, especially those that relate directly, or even indirectly, to the *GPR*. Several of the papers cited in the remainder of this section identify possible limitations of the data included in the *GPR*. In general terms, it is always important to question the integrity of long-term datasets. Researchers should be cautious and attempt to understand all the limitations and subtleties of each individual dataset.

Wöhl (1983) compared the heliographic coordinates of several small but stable sunspots in June and September 1979, as determined at five different observatories: Locarno, Kanzelhöhe, Debrecen, Dietzenbach and SOON. He concluded that a careful inspection of possible systematic differences is needed when comparing sunspot-position data and rotation data based on observations made at different observatories. However, he indicated that results presented in the papers by Balthasar and Wöhl (1980) and Arévalo et al. (1982) suggest that the data in the *GPR* are rather homogeneous for the entire interval 1874 – 1976. Balthasar and Wöhl (1983) compared the sunspot positions of small sunspots observed at Debrecen and Locarno, as well as the positions of recurrent spots from the *GPR* (1940 – 1976). They investigated the Wilson depression in sunspot structure and its influence on rotation velocities. Balthasar, Lustig, and Wöhl (1984) found that the Wilson depression influences the determination of sunspot rotation velocities and that stable recurrent sunspots exhibited a constant rotation velocity. Using these findings, they demonstrated that it is possible to determine the effect of incorrect solar image radii on the determination of sunspot rotation velocities and showed how to make the necessary corrections. These authors used Kanzelhöhe and Locarno data for May and September 1982, as well as 27 stable recurrent sunspots selected from Kanzelhöhe and Greenwich data (1950 – 1976). To avoid errors introduced when using an incorrect value for the solar radius, they computed spot positions relative to their passages through the central solar meridian.

Using Greenwich data, Brajša et al. (2004) investigated the solar-cycle-related variation of solar rotation for the interval 1874 – 1976. The measurements were extended with the USAF/SOON and NOAA data for the interval 1977 – 1981. The pattern of this variation revealed a higher rotation rate than the average at the minimum of solar activity and perhaps also at the maximum. Utilising the method of residuals (Gilman and Howard, 1984), these authors found that the residuals for the first four years (1874 – 1877) were significantly lower than those for the rest of the data (see their Figure 1); they attributed this discrepancy to some form of systematic error. Further research is required to determine the factors that influenced the determination of the first four residuals and this research should make proper allowance for significantly fewer solar photographs being available for the first four years of the Greenwich data.

Poljančić et al. (2010) compared selected *GPR* data for 1972 (16 spot groups: 4 single spots and 12 complex groups) with Kanzelhöhe data, and selected SOON data for 1993 (29 spot groups: 13 single spots and 16 complex groups) with Kanzelhöhe data. Rotation velocities were calculated and compared. Centre-to-limb effects were noted and minimized by using different central meridian distance cutoffs. Poljančić et al. (2011) continued the investigation initiated in the previous paper by including data from more observatories. Data for 1972 are from the *GPR*, and the Kandilli, Kodaikanal and Kanzelhöhe observatories. Data for 1993 are from SOON, Debrecen, Kodaikanal, and Kanzelhöhe observatories. Again Kanzelhöhe was the reference basis for the comparisons. Synodic rotation velocities were determined by the daily-shift method. The authors presented the differences in longitudes, latitudes and computed angular velocities, and looked for asymmetries in the distributions. They claimed the occurrence of some systematic differences of the sunspot group positions and rotation velocities suggests the need for a more detailed analysis of data accumulation procedures. In a recent paper, Baranyi, Kiraly and Coffey (2013) have studied the indirect comparison of Debrecen and Greenwich daily sums of sunspot areas, using data from the *GPR*, and the Debrecen, Kislovodsk, Pulkovo, and SOON observatories. They have found systematic deviations in long-term sunspot area datasets and have also estimated time-dependent cross-calibration factors.

## 2. Quality Control Procedures

Quality control (QC) procedures have been used at the NOAA National Geophysical Data Center (NGDC) to check and correct the more detailed RGO sunspot and faculae digital dataset (RGO–S&FDD) and thereby also check and correct the RGO printed observations, bulletins and annals (RGO–POBA). Data that were keyed in by a contractor (Image Entry, Kentucky) as part of a data rescue effort, as well as the additional data prepared by a different contractor for the interval 1878 – 1885 (Section 3 of Paper 1), have been reformatted into the solar region format employed at the NGDC, using a QC reformat program. As an initial check, this reformat program halts whenever the format is incorrect. Suspect data are checked against the original data in the printed RGO publications (RGO–POBA) and the reformat program run again. Then the decimal day is converted to hours and minutes and heliographic (Carrington) longitude is converted to an angular distance (the variable $\psi$ in Paper 2) measured East (negative) or West (positive) from the central solar meridian.

Next, specific tests are made for logical consistency, as follows:

Test 1: The data for each day should be from the same observatory (station) and hence have the same single-letter code (which is defined and discussed in Section 5 and Appendix B of Paper 1).

Test 2: The date should be consistent for a given month: this check is important when converting from a day number in the year to a calendar date.

Test 3: Date and time should be logical (month must be between 1 and 12; day must be between 1 and 31; and the time of observation must be between 00:00 and 24:00 UT).

Test 4: Latitude must be between 0 and 70 degrees and be preceded by 'N' (North) or 'S' (South); angular distance from the central meridian must be between 0 and 90 degrees and be preceded by 'E' (East) or 'W' (West). The signs 'N', 'S', 'E' and 'W' are used in the QC computer programs developed at the NGDC; the corresponding signs '+', '–', '–' and '+' are used in the digital datasets.

Test 5: No data other than a space can be in a field designated a blank.

Test 6: The addition of individual sunspot and faculae areas for a day should equal the total area in the summation line.

All errors resulting from the key-entry of data are corrected before proceeding with further checks. Then the date of central meridian passage (CMP) of every sunspot is computed and the date of central meridian passage of each group (GCMP) or region (RCMP) is calculated. Data are next sorted according to the date of the central meridian passage of the group (or region). For each sunspot group, the dates of central meridian passage (GCMP) must be consistent, as must the heliographic latitudes. Typical examples of identifiable errors found in the data are North versus South errors in specifying heliographic latitude, errors in specifying heliographic (Carrington) longitude, errors in the dates and times, errors in sunspot group numbers, errors in the summation process, and the occasional omission of solar ephemerides.

## 3. Errors in the Published Greenwich Photo-heliographic Results

The typographic errors that have been identified so far in the published *Greenwich Photo-heliographic Results (GPR)* for the interval 1874 – 1917 are listed in Table 1. Typographic errors in the interval 1874 – 1877 refer to the later publication titled *Photo-heliographic Results, 1874 – 1885* (Royal Observatory, Greenwich, 1907) rather than the earlier annual publications. Most of the errors in Table 1 have been found using the quality control (QC) procedures employed at the NGDC, as outlined in the previous section. However, a few errors have been found or resolved by visual inspection of the printed publications. The erroneous entries in the Greenwich publications (RGO–POBA) are identified by the calendar date (year, month and day) and the Greenwich Civil time at which the relevant solar photograph was taken, expressed by the day number of the year and decimals of a day, reckoning from midnight at the commencement of the year. For all the errors listed in Table 1, January 01 was taken to be Day 0 in the *GPR*. To avoid any possible ambiguity or uncertainty, the page, line and column numbers of each error in the *GPR* are also presented. It should be noted that the column numbers given in Table 1 correspond to columns 1 to 20 across the printed page in the *GPR*, whereas the column numbers (1 or 2) in the published Errata printed in the *GPR* refer to the left-hand and right-hand "columns" of the printed page respectively.

The necessary changes to the *GPR* are specified by listing both the incorrect entry ('change from') and its correct replacement ('change to'). In addition, the type of error is identified in each case and a reason is given for the required change. Any information gleaned from the "Footnotes" in the *GPR* is indicated by placing '(F)' after the appropriate information presented in the final column of Table 1. Similarly, any information gleaned from the "Ledgers" section in the *GPR* is indicated by placing '(L)' in the final column. Likewise, the symbol '(M)' is placed in the final column if a proposed change has been checked using the mathematical equations (see Paper 2), and '(E)' is placed in the final column if a solar ephemeris value has been obtained from a separate source. In addition, if any value of a physical quantity, derived from the solution of the mathematical equations presented in Paper 2, differs significantly from the value assigned after making the most logical and simplest correction to the printed value in the *GPR*, the "mathematical" value is presented in the final column of Table 1 followed by '(M)'. Only one discrepancy of this particular type has been found so far. On 1908 November 22 (Greenwich Civil Time = 326.124), the heliographic latitude of one of the components of Sunspot Group Number 6569 is given in the *GPR* as − 10.2º, whereas the latitudes of all other components of this group are positive and around + 10.0º. The simplest conclusion is to assume that the heliographic latitude should be changed from − 10.2º to + 10.2º, as indicated in Table 1. With this minor change, the revised entry passes the QC tests defined in Section 2. However, the solution of the mathematical equations presented in Paper 2, based on the assumption that the radial distance (0.698) and position angle (286.8º) are correct, indicates that the heliographic latitude should be changed to + 13.0º (and the heliographic longitude should be changed from 64.2º to 64.7º). The significant discrepancy in heliographic latitude on 1908 November 22 can only be resolved satisfactorily once the more rigorous tests outlined in the Appendix to Paper 2 have been implemented separately for the sunspot and faculae digital dataset (RGO–S&FDD).

It is perhaps surprising that so many of the entries in Table 1 have arisen from errors in the summation process, since it is relatively easy to check arithmetic addition. Some arithmetic errors identified by the QC procedures presented in Section 2 have been corrected in the publications of the Royal Greenwich Observatory. For example, five apparent summation errors in 1894, which were identified by the QC procedures, are nullified (already rectified) by the Errata at the beginning of the publication *Greenwich Spectroscopic and Photographic Results, 1894* (Royal Observatory, Greenwich, 1897). This discrepancy has arisen because not all of the Errata in the printed *Greenwich*

*Photo-heliographic Results* have yet been implemented in the sunspot and faculae digital dataset (RGO–S&FDD).

Of course, an apparent error in the summation process could be the result of an error in an individual entry for a sunspot or faculae area, rather than in the arithmetic addition process itself. As a single illustrative example, the apparently dubious entry (1 *nf*) for the facular area associated with Sunspot Group Number 5954* on 1906 August 27 (238.647) is "printed" in the faculae-area column of the *Greenwich Photo-heliographic Results, 1906* (Royal Observatory, Greenwich, 1909) in a way that suggests the true value might possibly be in the range 100 – 199. Such uncertainties could only be resolved by consulting the original worksheets, if they still exist, or else by re-analysing the original photographs of the Sun. Nevertheless, each entry in Table 1 identifies a real error in the printed *Greenwich Photo-heliographic Results (GPR)*, although it may eventually transpire that the type of error specified in Column 10 of this table has to be revised.

In the context of examining the original material, the quality control (QC) procedures defined in Section 2 have very occasionally identified a candidate error that could only be confirmed or rejected conclusively by examining the original photograph of the Sun. Since all the photographs of the Sun examined for the interval 1874 – 1917 have ultimately resulted in rejection of the candidate error, it suffices to consider a single illustrative case. Figure 1 shows the distribution of sunspots on the solar disk for the particular day 1897 February 03 (33.298). It should be noted that the day number in the year has been corrected to 33 (January 01 is defined to be Day 0) in the labelling of this photograph, which was taken at the Dehra Dun Observatory in India (I). The current QC procedures identify one component of Sunspot Group Number 4518, with heliographic latitude – 14.6º, as being a candidate error because all other components of this sunspot group are significantly closer to the solar equator. However, the largest component of this sunspot group is at heliographic latitude – 4.5º and the existence of a very small sunspot (having just penumbral area) at latitude − 14.6º is clearly indicated by the (red) arrows in Figure 1 and the inset figure (lower left), which shows Sunspot Group Number 4518 significantly magnified. Therefore, it is concluded that the entries for Sunspot Group Number 4518 on 1897 February 03 are correct in the printed *Greenwich Spectroscopic and Photographic Results, 1897* (Royal Observatory, Greenwich, 1898). This single example serves to illustrate the great care that was taken in measuring sunspot positions and areas on the original solar plates; only a contact print of the original solar plate is now available for 1897 February 03, as shown in Figure 1. However, this example also serves to illustrate the time-consuming nature of manual checks of the original photographs and hence the need for accurate semi-automatic procedures for checking the digital datasets.

As emphasised in Section 5 of Paper 1, researchers referring directly to the *printed* copies of the *Greenwich Photo-heliographic Results (GPR)* should note that in the early years (up to the end of 1884) time was reckoned from Greenwich Mean Noon (Solar Time) and not Greenwich Midnight (Civil Time). Likewise, in the early years (up to 1881 December 21) angles were measured in degrees and minutes not decimal degrees. As also noted in Section 5 of Paper 1, the scope for confusion between these different ways of measuring time and angles is compounded by the fact that an improved and supplementary printed version of the "Measures of Positions and Areas of Sun Spots and Faculae" section of the *GPR* for the interval 1874 – 1877 was issued much later in the publication titled *Photo-heliographic Results, 1874 – 1885* (Royal Observatory, Greenwich, 1907), in which time is reckoned from midnight and angles are measured in decimal degrees. In the sunspot and faculae digital dataset (RGO–S&FDD) stored at the NOAA National Geophysical Data Center (NGDC), all times are reckoned from Greenwich Midnight (Civil Time) and all angles are given in decimal degrees. However, it should be noted that January 1 is defined to be Day 0 in the sunspot and faculae digital dataset (RGO–S&FDD) but is defined to be Day 1 in the original sunspot digital dataset (RGO–SDD).

The policy adopted in this investigation is to identify the minimum number of amendments that are required to make the *Greenwich Photo-heliographic Results (GPR)* essentially correct and logically self-consistent. Therefore, no attempt has been made at this stage to improve upon the accuracy achieved by the scientists who measured the positions and areas of sunspots and faculae on the original photographs of the Sun. Similarly, no real attempt has yet been made to correct essentially insignificant numerical errors in the printed RGO publications. Moreover, despite the emphasis in this paper on errors in the RGO printed observations, bulletins and annals (RGO–POBA), the actual error rate is still remarkably low. An estimate of the total number of individual entries in the section of the GPR titled "Measures of Positions and Areas of Sun Spots and Faculae" for the interval 1874 – 1917 is 1.6 million. The total number of erroneous entries listed in Table 1 is 83 (if misplaced lines and missing solar ephemerides are ignored), which corresponds to an average error rate of less than 1 in 19000 (< 0.006%). If simple arithmetical errors are ignored, this average error rate is less than 1 in 31000 (< 0.004%), which represents a truly remarkable achievement by all those involved in the analysis of solar photographs during the interval 1874 – 1917, and also by all those involved in printing the corresponding *GPR*. It should be noted, however, that there is a significantly larger number of omissions, resulting from sequences of missing (or omitted) values in the printed *GPR*, which are not considered in the present paper.

Table 1 has deliberately been restricted to identifiable errors in the interval 1874 – 1917 because a variety of factors combine to make the earlier sunspot observations less reliable than the later ones. However, it should be noted that the QC procedures have not identified any erroneous entries before 1880, possibly at least in part because the very early data (1874 – 1877) were re-issued in corrected form in 1907 and most of these revisions have been incorporated in the sunspot and faculae digital dataset (RGO–S&FDD). However, it seems likely that some further errors will eventually be identified in the interval 1874 – 1917. It is anticipated that the corresponding error rate for the interval 1918 – 1976 will be appreciably smaller than that for the interval 1874 – 1917. Of course, the QC procedures only identify errors that can be detected using the logical criteria defined in Section 2; these procedures are unable to identify minor typographical errors that do not exhibit any such logical inconsistencies. In addition, certain other minor errors such as the obvious omission of the decimal point in the printed *GPR* have been corrected automatically when the data were keyed in and therefore cannot be identified subsequently using the QC procedures. Clearly, it would be possible to extend and refine the various logical criteria used in these QC procedures, as indicated in the Appendix to Paper 2. For example, it would be possible to check that the Sun was above the horizon at the specified observatory at the recorded time of the solar photograph.

**4. Summary and Conclusions**

Quality control (QC) procedures have been used to check and partially correct the more comprehensive sunspot and faculae digital dataset, which is available online at the NOAA National Geophysical Data Center (NGDC), Boulder, Colorado, USA (http://www.ngdc.noaa.gov/stp/solar/greenwich.html; use the 'Solar White Light Faculae' link). This dataset contains information on the positions and areas of both sunspots and faculae up to the end of 1955 (see Section 3 of Paper 1). Since this second sunspot digital dataset (RGO–S&FDD) was prepared more recently from the RGO printed observations, bulletins and annals (RGO–POBA), by a well understood and carefully monitored process, the QC procedures can also be used to check and correct the printed *Greenwich Photo-heliographic Results, 1874 – 1976.* These QC procedures are based on specific checks for logical consistency (Section 2). Typical examples of identifiable errors are North versus South errors in specifying solar latitude (e.g., illogical and inconsistent movement of a sunspot group from one solar hemisphere to another), errors in specifying Carrington longitude (e.g., the sunspot group is apparently on the invisible side of the Sun), errors in dates and times, errors in sunspot group numbers, arithmetical errors in the summation process and the occasional omission of solar ephemerides. Table 1 presents the identifiable errors found so far in the published *GPR* for the interval 1874 – 1917. Although it is anticipated that fewer errors will exist in sunspot observations acquired after 1917, further work is in progress to identify the corresponding errors in the interval 1918 – 1976. Although Table 1 appears to list an appreciable number of errors (83), the corresponding total number of individual data entries in the interval 1874 – 1917 is about 1.6 million and hence the overall error rate in the printed *Greenwich Photo-heliographic Results, 1874 – 1917* is remarkably small (< 0.006%). However, the corresponding omission rate, resulting from sequences of missing values in the printed *Greenwich Photo-heliographic Results, 1874 – 1917*, is significantly higher but has yet to be investigated quantitatively.

Despite the fact that the number of errors found so far in the printed *Greenwich Photo-heliographic Results* is remarkably small, it seems inevitable that some further errors will eventually be identified in the interval 1874 – 1917. The detection of errors depends crucially on the precise nature of the quality control procedures that are implemented (see Section 2). As these procedures are refined (see Appendix to Paper 2) further errors are likely to be identified. Even minor refinements to the quality control procedures, such as the examination of the original solar photographs on problematic days (see Section 3), can result in corresponding minor changes to the sunspot and faculae digital dataset (RGO–S&FDD). Moreover, it should be noted that the errors in the printed publications have been identified by applying quality control procedures to the RGO–S&FDD, which itself is not yet entirely free from errors. In particular, some of the published Errata in the printed Royal Greenwich Observatory (RGO) publications have not been fully implemented in this digital dataset. The task of correcting all the errors and omissions in the printed RGO publications (RGO–POBA) and the two associated digital datasets (RGO–SDD and RGO–S&FDD) is a massive undertaking that could not possibly be accomplished in a single paper. Indeed, the present paper is merely an initial attempt to identify some of the more obvious errors in the printed *Greenwich Photo-heliographic Results* for the restrictive interval 1874 – 1917. The corresponding errors in the interval 1918 – 1976 have yet to be identified.

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**Legend for the Figure**

**Figure 1** A modified contact print showing the distribution of sunspots on the solar disk for the particular day 1897 February 03 (Day Number = 33.298). It should be noted that the day number in the year has been corrected to 33 (January 01 is defined to be Day 0) in the labelling of this photograph. The inset figure shows an enlargement of Sunspot Group Number 4518. The image shown is adapted from a contact print located at Cambridge University Library (Royal Observatory Solar Plate Contact Print MS.RGO.51/3838). The original solar plate was acquired at the Dehra Dun Observatory, Uttar Pradesh, India (I). (Figure 1 is reproduced by kind permission of the Syndics of Cambridge University Library.)

**Table 1** Identifiable errors in the printed *Greenwich Photo-heliographic Results (GPR)* for the interval 1874 – 1917, found using the quality control (QC) procedures employed at the NOAA National Geophysical Data Center (NGDC) and also by visual inspection of the printed publications (RGO–POBA). The erroneous entries in the printed Greenwich publications are identified by the calendar date (year, month and day), the Greenwich Civil time at which the relevant photograph was taken (expressed by the day number of the year and decimals of a day, reckoning from midnight at the commencement of the year: January 01 is defined to be Day 0) and the page, line and column numbers in the printed *GPR* for the year specified in the date. To avoid any possible ambiguity, complete calendar dates and times are given as well as the page, line and column numbers in the relevant publications. It is important to note that the column numbers in the following table correspond to columns 1 to 20 (maximum) across the printed page in the *GPR*, whereas the column numbers (1 or 2) in the printed "Errata" in the *GPR* refer to the left-hand and right-hand columns (sides) of the printed page. The necessary changes to the published results are specified by listing both the incorrect entry ('change from') and its correct replacement ('change to'). Moreover, in each case the type of error is identified and an explicit reason is given for the required change. Information gleaned from the "Footnotes" in the printed *GPR* is indicated by placing '(F)' after the extracted information presented in the final column of the table. Similarly, information gleaned from the "Ledgers" section in the printed *GPR* is indicated by placing '(L)' in the final column. Likewise, the symbol '(M)' is placed in the final column if a change has been checked using the mathematical equations (see Paper 2) and '(E)' is placed in the final column if a solar ephemeris value has been verified or obtained from a separate source. Moreover, if any value derived using the mathematical equations is significantly different from the "minimally-corrected" value in the printed *GPR*, the mathematical value followed by '(M)' is presented in the final column.

| Date | | | G.M.T. | Page | Line | Column | Change | | Type of Error | Reason for the Change |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | (Civil) | Number | Number | Number | From | To | | |
| 1880 | Feb | 13 | 43.437 | 65 | 26 | 18 | (1886) | (1885) | Summation error | Incorrect arithmetic (Facular area) |
| 1882 | Feb | 02 | 32.162 | 44 | 14 | 10 | (3013) | (3017) | Summation error | Incorrect arithmetic (Facular area) |
| 1882 | Jul | 25 | 205.189 | 66 | 16 | 20 | (2434) | (2034) | Summation error | Incorrect arithmetic (Facular area) |
| 1882 | Oct | 31 | 303.402 | 78 | 18 | 20 | (2187) | (2178) | Summation error | Incorrect arithmetic (Facular area) |
| 1882 | Dec | 02 | 335.252 | 84 | 26 | 10 | (2549) | (2587) | Summation error | Incorrect arithmetic (Facular area) |
| 1883 | Jul | 28 | 208.400 | 97 | 47 | 20 | (1645) | (1635) | Summation error | Incorrect arithmetic (Facular area) |

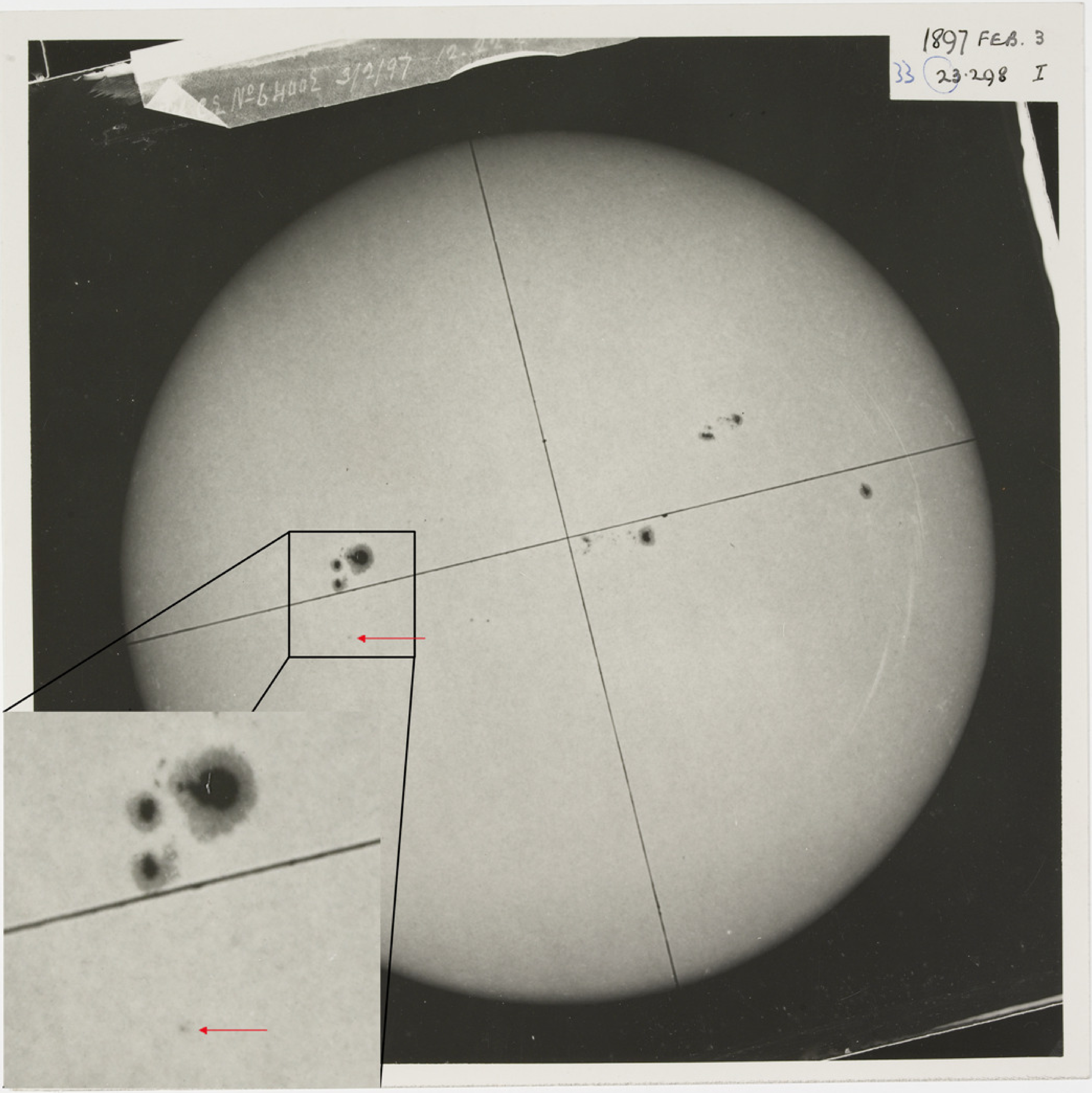
| Date | | | G.M.T. | Page | Line | Column | Change | | Type of Error | Reason for the Change |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | (Civil) | Number | Number | Number | From | To | | |
| 1883 | Nov | 18 | 322.204 | 115 | 30 | 07 | + 15.9 | − 15.9 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1883 | Dec | 11 | 344.538 | 119 | 22 | 10 | (2711) | (2701) | Summation error | Incorrect arithmetic (Facular area) |
| 1884 | Jun | 29 | 180.430 | 75 | 25 | 01 | 177.930 | 179.930 | Day number error | Day number wrong for Jun 29 (180.430 G.M.T) |
| 1884 | Aug | 09 | 221.436 | 80 | 11 | 10 | (757) | (857) | Summation error | Incorrect arithmetic (Facular area) |
| 1884 | Sep | 16 | 259.458 | 86 | 04 | 20 | (2541) | (2320) | Summation error | Incorrect arithmetic (Facular area) |
| 1884 | Dec | 08 | 342.262 | 101 | 07 | 20 | (2145) | (2149) | Summation error | Incorrect arithmetic (Facular area) |
| 1884 | Dec | 22 | 356.489 | 104 | 14 | 03 | b | 1561b | Group No. error | Group number incomplete (F) |
| 1884 | Dec | 22 | 356.489 | 104 | 15 | 03 | c | 1561c | Group No. error | Group number incomplete (F) |
| 1885 | Feb | 12 | 42.545 | 41 | 33 | 20 | (1878) | (1886) | Summation error | Incorrect arithmetic (Facular area) |
| 1885 | Aug | 16 | 227.407 | 82 | 19 | 10 | (1969) | (1869) | Summation error | Incorrect arithmetic (Facular area) |
| 1887 | Apr | 29 | 118.285 | 31 | 05 | 16 | 68.3 | 8.3 | Longitude error | Facula would be on invisible side of Sun (M) |
| 1887 | Aug | 02 | 213.588 | 39 | 21 | 19 | (49) | (449) | Summation error | Incorrect arithmetic (Whole-spot area) |
| 1887 | Aug | 19 | 230.586 | 41 | 19 | 07 | − 10.0 | + 10.0 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1887 | Dec | 05 | 338.436 | 48 | 05 | 08 | (87) | (89) | Summation error | Incorrect arithmetic (Umbral area) |
| 1888 | Jan | 13 | 12.307 | 23 | 11 | 03 | Blank | 2030 | Group No. error | Group number omitted (see line number 14) |
| 1888 | Jan | 13 | 12.307 | 23 | 12 | 03 | 2030 | 2030a | Group No. error | Incorrect group number (see line number 14) |
| 1888 | Jan | 13 | 12.307 | 23 | 13 | 03 | 2030a | 2029a | Group No. error | Incorrect group number (see line number 14) |
| 1888 | Jan | 13 | 12.307 | 23 | 14 | 03 | 2029a | Blank | Group No. error | Group number assigned to a facular observation |

| Date | | | G.M.T. | Page | Line | Column | Change | | Type of Error | Reason for the Change |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | (Civil) | Number | Number | Number | From | To | | |
| 1889 | Dec | 21 | 354.205 | 47 | 34 | 17 | – 24.3 | + 24.3 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1890 | Aug | 03 | 214.452 | 40 | 39 | 18 | (28) | (22) | Summation error | Incorrect arithmetic (Umbral area) |
| 1890 | Oct | 22 | 294.390 | 46 | 29 | 09 | (1196) | (1106) | Summation error | Incorrect arithmetic (Whole-spot area) |
| 1891 | Feb | 15 | 45.509 | 20 | 13 | 08 | (49) | (54) | Summation error | Incorrect arithmetic (Umbral area) |
| 1891 | Feb | 15 | 45.509 | 20 | 13 | 09 | (482) | (515) | Summation error | Incorrect arithmetic (Whole-spot area) |
| 1891 | Apr | 04 | 93.133 | 24 | 05 | 16 | 257.3 | 357.3 | Longitude error | Facula would be on invisible side of Sun (M) |
| 1891 | Jun | 22 | 172.473 | 35 | 39 | 13 | 2343 | 2243 | Group No. error | Gr. 2243: Jun 21 – 29; Gr. 2343: Nov 7 – 12 (F) |
| 1891 | Jun | 30 | 180.464 | 37 | 14 | 17 | – 15.5 | + 15.5 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1891 | Jul | 22 | 202.414 | 42 | 24 | 20 | (5506) | (6023) | Summation error | Incorrect arithmetic (Facular area) |
| 1891 | Aug | 05 | 216.474 | 44 | 25 | 20 | (1633) | (2633) | Summation error | Incorrect arithmetic (Facular area) |
| 1891 | Aug | 25 | 236.473 | 47 | 31 | 08 | (16) | (14) | Summation error | Incorrect arithmetic (Umbral area) |
| 1891 | Aug | 25 | 236.473 | 47 | 31 | 09 | (156) | (147) | Summation error | Incorrect arithmetic (Whole-spot area) |
| 1891 | Sep | 24 | 266.378 | 51 | 31 | 20 | (1820) | (1828) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Mar | 27 | 86.236 | 21 | 10 | 10 | (4099) | (4049) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Apr | 26 | 116.397 | 28 | 12 | 13 | 2495 | 2495* | Group No. error | Gr. 2495 in N. hem; Gr. 2495* in S. hem. (L) |
| 1892 | Apr | 27 | 117.522 | 28 | 36 | 13 | 2495 | 2495* | Group No. error | Gr. 2495 in N. hem; Gr. 2495* in S. hem. (L) |
| 1892 | May | 07 | 127.418 | 32 | 02 | 01 | 127.428 | 127.418 | Time of day error | Discontinuity in the time of day (L) |
| 1892 | Jun | 20 | 171.403 | 44 | 26 | 06 | 255.9 | 355.9 | Longitude error | Continuity and spot not at East limb of Sun (M) |

| Date | | | G.M.T. | Page | Line | Column | Change | | Type of Error | Reason for the Change |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | (Civil) | Number | Number | Number | From | To | | |
| 1892 | Jun | 30 | 181.415 | 47 | 16 | 06 | 336.4 | 236.4 | Longitude error | Sunspot would be on invisible side of Sun (M) |
| 1892 | Jul | 26 | 207.541 | 53 | 23 | 10 | (2412) | (3412) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Sep | 07 | 250.250 | 65 | 19 | 10 | (4217) | (4216) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Sep | 15 | 258.448 | 67 | 17 | 20 | (4199) | (4194) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Nov | 04 | 308.217 | 83 | 30 | 10 | (5186) | (5794) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Nov | 22 | 326.325 | 87 | 35 | 20 | (4089) | (4088) | Summation error | Incorrect arithmetic (Facular area) |
| 1892 | Nov | 30 | 334.421 | 90 | 24 | 20 | (2659) | (2759) | Summation error | Incorrect arithmetic (Facular area) |
| 1893 | Feb | 20 | 50.623 | 17 | 19 | 10 | (2683) | (2325) | Summation error | Incorrect arithmetic (Facular area) |
| 1893 | Jun | 03 | 153.408 | 52 | 27 | 08 | (349) | (339) | Summation error | Incorrect arithmetic (Umbral area) |
| 1893 | Oct | 19 | 291.443 | 106 | 17 | 16 | 243.3 | 343.3 | Longitude error | Facula would be on invisible side of Sun (M) |
| 1894 | May | 03 | 122.185 | 44 | 02 | 07 | – 20.4 | + 20.4 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1894 | Jun | 29 | 179.424 | 69 | 39 | 17 | + 10.9 | – 10.9 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1894 | Sep | 30 | 272.496 | 106 | 42 | 17 | + 11.1 | – 11.1 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1895 | Feb | 08 | 38.446 | 16 | 21 | 07 | – 18.1 | + 18.1 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1895 | May | 08 | 127.412 | 46 | 02 | 01 | 128.406 | 127.412 | Day and time error | Discontinuity in day number and time (L) |
| 1896 | Jun | 10 | 161.218 | 37 | 06 | 09 | (1019) | (1039) | Summation error | Incorrect arithmetic (Whole-spot area) |
| 1896 | Oct | 08 | 281.285 | 69 | 33 | 20 | (1228) | (2128) | Summation error | Incorrect arithmetic (Facular area) |
| 1896 | Nov | 23 | 327.208 | 80 | 13 | 16 | Blank | (244.4) | Omission error | Longitude of centre of solar disk omitted (E) |

| Date | | | G.M.T. | Page | Line | Column | Change | | Type of Error | Reason for the Change |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | (Civil) | Number | Number | Number | From | To | | |
| 1896 | Nov | 23 | 327.208 | 80 | 13 | 17 | Blank | (+ 1.6) | Omission error | Latitude of centre of solar disk omitted (E) |
| 1897 | Feb | 03 | 33.298 | 12 | 39 | 10 | (1504) | (1002) | Summation error | Incorrect arithmetic (Facular area) |
| 1897 | Nov | 28 | 331.185 | 62 | 06 | 10 | (756) | (356) | Summation error | Incorrect arithmetic (Facular area) |
| 1899 | Oct | 24 | 296.309 | 26 | 18 | 06 | (255.9) | (225.9) | Longitude error | Discontinuity in long. of centre of solar disk (E) |
| 1899 | Nov | 12 | 315.509 | 28 | 10 | 06 | 226.5 | 266.5 | Longitude error | Sunspot would be on invisible side of Sun (M) |
| 1901 | May | 31 | 150.187 | 04 | 04 | 17 | – 7.2 | + 7.2 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1902 | Oct | 11 | 283.146 | 11 | 22 | 01 | 282.146 | 283.146 | Day number error | Day number incorrect for Oct 11 |
| 1903 | Jun | 18 | 168.426 | 15 | 08 – 15 | 17 | | | Latitude errors | All latitudes misplaced downwards by one line |
| 1903 | Jun | 20 | 170.189 | 15 | 18 – 32 | 17 | | | Latitude errors | All latitudes misplaced downwards by one line |
| 1903 | Jun | 27 | 177.455 | 16 | 30 | 07 | – 18.8 | + 18.8 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1904 | May | 02 | 122.266 | 18 | 33 | 07 | – 14.7 | + 14.7 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1904 | May | 20 | 140.478 | 21 | 19 | 17 | – 13.5 | + 13.5 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1904 | Oct | 31 | 304.170 | 46 | 19 | 04 | 0.903 | 0.963 | Distance error | Consistent distances and longs for Gr. 5338 (M) |
| 1904 | Oct | 31 | 304.170 | 46 | 19 | 06 | 219.1 | 229.1 | Longitude error | Long. cannot decrease by 10° in one day (M) |
| 1904 | Oct | 31 | 304.170 | 46 | 25 | 07 | + 15.4 | – 15.4 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1904 | Nov | 18 | 322.185 | 48 | 10 | 16 | 330.4 | 300.4 | Longitude error | Abrupt discontinuity in longitude (M) |
| 1906 | Aug | 27 | 238.647 | 71 | 27 | 10 | (734) | (583) | Summation error | Incorrect arithmetic (Facular area). See Sect. 3 |
| 1908 | Apr | 03 | 93.509 | 20* | 19 | 03 | 6398 | 6393 | Group No. error | Gr. 6393: Apr 03–13; Gr. 6398: Apr 05–14 (F) |

| Date | | | G.M.T. | Page | Line | Column | Change | | Type of Error | Reason for the Change |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | (Civil) | Number | Number | Number | From | To | | |
| 1908 | Jun | 28 | 179.172 | 35* | 31 | 13 | 6463* | 6463 | Group No. error | Group 6463* existed only on June 23 (F) |
| 1908 | Aug | 15 | 227.389 | 45* | 13 | 16 | (224.5) | (244.5) | Longitude error | Discontinuity in long. of centre of solar disk (E) |
| 1908 | Sep | 28 | 271.610 | 58* | 29 | 07 | – 7.5 | + 7.5 | Latitude error | Sunspot in wrong hemisphere (discontinuity) (L) |
| 1908 | Nov | 05 | 309.166 | 65* | 09 | 03 | 6569a | 6562a | Group No. error | Gr. 6562: Nov 05–15; Gr. 6569: Nov 15–25 (F) |
| 1908 | Nov | 22 | 326.124 | 69* | 04 | 17 | – 10.2 | + 10.2 | Latitude error | Sunspot in wrong hemisphere: Lat. = + 13.0 (M) |
| 1911 | Sep | 10 | 252.456 | D 20 | 37 | 03 | 6964a | Blank | Group No. error | Group No. assigned to a facular area |
| 1911 | Sep | 10 | 252.456 | D 20 | 38 | 03 | Blank | 6964a | Group No. error | No Group No. for umbral and whole-spot areas |
| 1915 | Dec | 17 | 350.427 | D 90 | 20 | 03 | 7464a | 7564a | Group No. error | Gr. 7564: Dec 14–22; Gr. 7464: Oct 06–12 (F) |
| 1917 | Mar | 26 | 84.345 | D 19 | 42 | 05 | 281.1 | 218.1 | Longitude error | Facula would be on invisible side of Sun (M) |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33 23.298 I