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# Solar position within Monet's Houses of Parliament

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Paintings from Monet's Houses of Parliament London series have been analysed for the quantitative information they contain, by comparing the depicted position of the Sun with Solar geometry calculations. The positions of roofline features of the Houses of Parliament were measured to provide an internal scale for the determination of azimuthal and elevation angles of the Solar depictions. Despite some distortion of the painted motif, the internal scales were found to be approximately linear. The Solar positions were used to derive the dates and times of the depicted scenes. The results provide new information for assessing these paintings and are consistent with the known period Monet was in London, suggesting that they contain elements of accurate observation and may potentially be considered as a proxy indicator for the Victorian smogs and atmospheric states they depict. The four dates Monet reports observing the Sun over Parliament in 14 and 16 February and 9 and 24 March 1900, are all represented in the series. The analysis also enables Monet's vantage point from St Thomas' Hospital to be determined for the first time.

**Keywords: Solar position; Monet; Houses of Parliament; Victorian smog; proxy indicator**

## 1. Introduction

In this report, we investigate whether or not Monet's London series (1899–1905), which depict the landscape and atmospheric state of London at the turn of the twentieth century, contains real quantitative information. If they do, then these impressionist paintings may provide useful information in the analysis of the London fogs and air quality during this period. Previous studies have considered and discussed the possible use of works of art as proxy indicators for past meteorology, air pollution and climate (Lamb 1967; Neuberger 1970; Brimblecome & Ogden 1977; Thornes 1999; Brimblecombe 2000; Thornes & Metherell 2003). Contemporary records of air quality are few

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and limited and as a result much uncertainty remains as to the nature and causes of air pollution in this period (Brimblecombe 1988; Harrison 2006). The frequency and intensity of London's fogs reached a peak in the late 1880s, but steadily declined afterwards and by the time of the 'Great Fog' of 1952 had become rare. The sudden and unexpected appearance of the 1952 fog and the 4000 excess deaths that were shown to have arisen from it led to the 1956 UK Clean Air Act (Brimblecombe 1988). This ultimately led to the classical London fog being consigned to history. Monet's London series may represent the best coloured-record of the Victorian fogs. The colour of the fogs potentially provides spectral information on the transmitted and scattered light passing through the London atmosphere, which can in turn provide information on the nature and composition of the fogs. Processes such as Rayleigh scattering from ultrafine particles, Mie scattering from larger particles and absorption can give rise to such effects. Austin (1983) has described how light scattering from high-altitude dust injected into the atmosphere gave rise to the vivid sunsets and twilight glows associated with the 1883 volcanic eruption of Krakatoa. Waggoner *et al.* (1983) showed that it was particles rather than nitrogen dioxide that were responsible for the 'brown' urban haze over Denver.

Monet made three trips to London in the autumn of 1899 and in the Early months of 1900 and 1901, to paint his London series. The series show three views of Central London. Two views are from the Savoy Hotel; a southward view across Charing Cross Bridge towards Westminster on the west and Lambeth on the east and a Southeasterly view across Waterloo Bridge towards the industrialized South Bank. A third view is of the Houses of Parliament, westward from St Thomas' Hospital. As discussed by Seiberling (1988) and Wildenstein (1996*a*), Monet's attempts at rendering the atmospheric effects on the spot were made exceptionally difficult due to the transience and variability of the weather. Monet did not consider his London series as complete on returning from his final trip in 1901 and continued to work on them in his studio at Giverny (House 2005). The series were first exhibited 3 years later in the spring of 1904 in Paris. Among the 95 paintings of the series that still exist, only 12 are dated between 1899 and 1901, 61 are dated between 1902 and 1905 and 22 are undated, suggesting that Monet dated his works according to when he completed them or when he sold them. It is not possible to say how many of the canvasses brought back from London were predominantly finished and how many, if any, were painted entirely in Giverny. Consequently, there is a great deal of doubt as to whether or not these paintings are authentic impressions of real observations taken from nature.

In this report, we test Monet's paintings to see whether or not they contain any quantitative information that can be validated and hence assess their value as potential observational records. We do this by examining the position of the Sun within the Houses of Parliament London series. This series was begun on Monet's second visit in 1900 and was painted during the late afternoon from St Thomas' Hospital. The towers and spires of the Parliament skyline provide markers for determining the position of the depicted Sun within the paintings, from which dates and times can be derived. These can then be compared to the known dates Monet was present in London.

Table 1. Details of the Houses of Parliament Series from Wildenstein 1996*a*). All titles begin with: London, Houses of Parliament.

| catalogue | title | date on painting | collection |
|---|---|---|---|
| W1596 | Effect of Sun in the Fog | 1904 | private |
| W1597 | Sunlight Effect | 1903 | Brooklyn Museum, New York, NY |
| W1598 | Sunset | 1903 | National Gallery of Art, Washington DC |
| W1599 | Symphony in Rose | undated | private |
| W1600 | Towers of Westminster | undated | The Art Institute of Chicago |
| W1601 | Symphony in Blue | 1903 | High Museum of Art, Atlanta, GA |
| W1602 | Sunset | 1904 | Kaiser Wilhelm Museum, Krefeld, Germany |
| W1603 | Sunset | 1902 | private |
| W1604 | Sunset | 1903 | private |
| W1605 | Stormy Sky | 1904 | Musée des Beaux-Arts, Lille, France |
| W1606 | Reflections on the Thames | 1905 | Musée Marmottan, Paris |
| W1607 | Sunset | 1904 | Kunsthaus Zürich, Switzerland |
| W1608 | Fog Effect | 1903 | Musée des Beaux-Arts, Le Havre, France |
| W1609 | Fog Effect | 1903 | The Metropolitan Museum of Art, New York, NY |
| W1610 | Effect of Sunlight in the Fog | 1904 | Musée d'Orsay, Paris |
| W1611 | Fog Effect | 1904 | Museum of Fine Arts, St Petersburg, Florida, FL |
| W1612 | The Seagulls | 1903 | Art Museum, Princeton University, New Jersey, NJ |
| W1613 | The Seagulls | 1904 | Pushkin Museum, Moscow |
| W1614 | Evening Effect | 1903 | private |

## 2. Methodology

### (*a*) *General considerations*

It was not possible to work with the original paintings and so measurements were taken from photographic plates, predominantly those published in Wildenstein (1996*a*). We use Wildenstein's cataloguing index for labelling Monet's paintings and letters, adding the prefaces W and L, respectively. We note here that all quotations from Monet's letters in this article are translated from the original French (Wildenstein 1996*b*). Hence, the Houses of Parliament series are represented by paintings W1596 to W1614. Table 1 gives additional information for these paintings. There are 19 paintings in this series and we report on the analysis of nine of them for which the Sun is depicted. Five of these paintings show direct representations of the Sun in the sky (W1596, W1602, W1604, W1607 and W1610), where the complete Solar disc is contained within the paintings, while three others appear to show partial Solar discs coupled with strong reflections on the Thames indicative of direct sunlight (W1597, W1605 and W1606). The other painting (W1599) that was analysed does not appear to show the Sun, but its position was inferred from the gradation of the lighting of the sky.

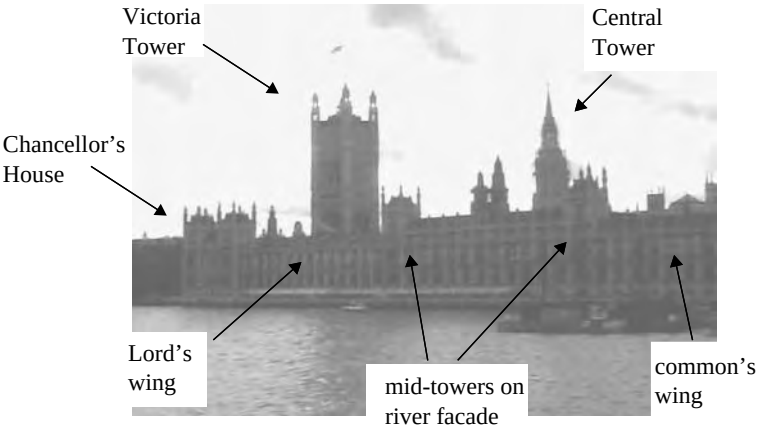


Figure 1. The Houses of Parliament with the major features referred to in the text labelled.

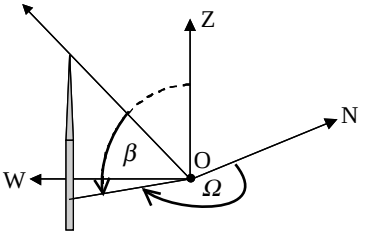


Figure 2. Azimuthal ($\Omega$) and elevation ($\beta$) angles of a Houses of Parliament rooftop feature with respect to observers' vantage point, O. The azimuthal angle ($\Omega$) is the angle between the projections onto the local horizontal plane of the rooftop feature and true north (taken clockwise from N). The elevation angle ($\beta$) is the vertical angle between the rooftop feature and the local horizontal plane. N and W are the north and west directions in the local horizontal plane and Z is the local zenith direction.

To measure the position of the Sun 'within' the paintings, an internal measurement scale was constructed. The Houses of Parliament, the motif of the paintings, was used to provide this scale. Figure 1 is a digital image showing the Houses of Parliament as it appears today and photographed from a position that appears to capture its orientation in the paintings. The roofline consists of many identifiable features, including towers, spires and pinnacles and these were used to provide a 'horizontal' (azimuthal) and 'vertical' (elevation) internal scale for the paintings. The azimuthal and elevation angles are defined in figure 2.

The angular scales used are relative to the specific observation point and can only be determined if Monet's exact position in St Thomas' Hospital is identified. This is considered in §2*b*.

### (*b*) *Monet's vantage point*

Although it is known that Monet painted the Houses of Parliament from a room and terrace within St Thomas' Hospital (Seiberling 1988; Wildenstein 1996*a*) his precise location within the hospital has to date, as far as we are aware, not been identified. Figure 3 shows the hospital and the Parliament as they appeared in the late

nineteenth century. There were six ward pavilions (blocks 2–4 and 6–8) and an administrative block (block 1), which was located to the north of the site and close to Westminster Bridge (Cook 2002). According to Isaacson (1978), the Houses of Parliament were painted within a rectangular format, aligned with the vertical and the horizontal, indicating Monet was directly opposite to the building, placing him in block 4 or 6 of the hospital. Isaacson also notes that, in contrast to this, the disposition of the towers indicates the line of vision must have been at approximately 45° to Parliament, which appears to be the consensus view, placing Monet in block 1 or 2.

Several paintings of this series show in reasonable detail three pinnacles of the Victoria Tower. We have analysed eight of the paintings that show the pinnacles in good detail (W1596–8, W1602 and W1606–9) and from their relative positions, we obtain an observers orientation of $49.3 \pm 1.5°$ with respect to the Thames facade. This possible range of line of sights (figure 3) places Monet in block 1, the administrative block of the hospital.

We note here that the near 'rectangular format' of the motif considered by Isaacson (1978) is not necessarily a gross distortion of the building, but may be a reasonable impression of reality under conditions of back illumination and foggy conditions. Under these conditions, the building perspective can be flattened due to the loss of surface detail and the merging within shadow of the building base and the river Thames. However, our analysis does indicate that there has been some specific distortion of the motif.

Monet's vantage point from within the administrative block was identified by analysis of his letters and examination of historical architectural drawings of the hospital. The part of the hospital that Monet was given access to, he described as, 'I do not have a room there, but rather an immense reception room where I will leave my materials, because it will be necessary for me to paint in the open air, or at least on a covered terrace' (L1505). Although the ward pavilions (blocks 2–4 and 6–8; figure 3), built four storeys high, had riverfront terraces on each floor, these were for patient use and connected to patient wards. The administrative block was somewhat similar in general design to the ward pavilions, but only the second floor contained a riverfront terrace. This terrace was connected to the Governors' Hall, a two-storey high meeting room with a domed roof (figure 4 and see fig. ESM1 in the electronic supplementary material). The dimensions of the hall were 36 by 52 ft and 36 ft high at its highest point (architectural drawings HO1/ST/A/166/020 and 054, London Metropolitan Archive). It is the only 'room' that could have been described as 'immense'. The terrace was 38 ft above the public footway along the Thames Embankment and approximately 37 ft in length and fairly narrow, with less than 3 ft of floor space from the partition wall to the terrace palisade. The partition separating the Governors' Hall from the terrace contained three sash windows and access to the terrace would have been possible via the central window, which had dwarf doors beneath it (HO1/ST/A/166/092, London Metropolitan Archive). Only the area of the terrace in front of the windows would have provided Monet with an unobstructed view of the Houses of Parliament due to the presence of columns built into the terrace palisade (figure 4 and fig. ESM1).

Hence, we identify Monet's vantage point in St Thomas' Hospital to the second floor terrace of the Governors' Hall in the administrative block and to one of three locations along the terrace. It is most likely that Monet positioned

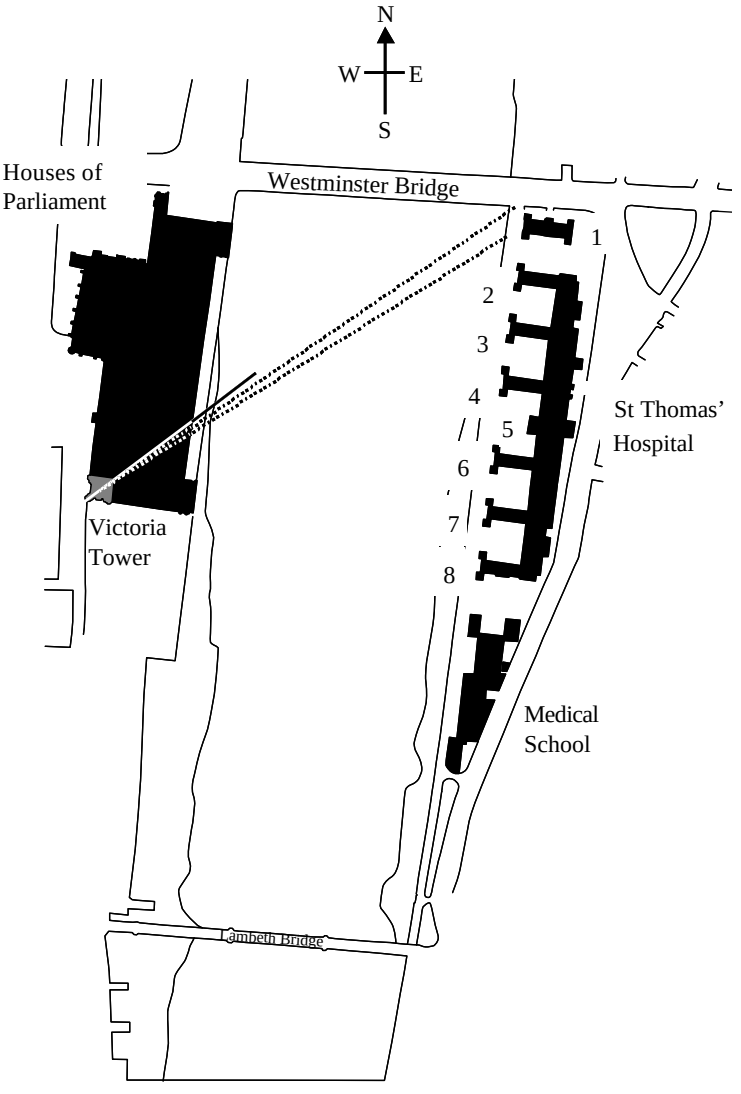


Figure 3. St Thomas' Hospital and the Houses of Parliament in the late nineteenth century (based on Ordnance Survey 1 : 2500 scale Middlesex Plan Sheet XVII. 14, first edition 1894–1896). The solid line bisects the Victoria Tower and Thames facade at 45°. The dashed lines indicate the possible range of Monet's line of sight obtained from analysis of the orientation of the Victoria Tower within the paintings.

himself centrally along the terrace, since he would have been able to make use of the space within the central access area onto the terrace. For the determination of Solar azimuthal and elevation angles, we assumed that Monet was positioned centrally along the terrace in front of the central access. The lateral error is about $\pm 12$ ft if Monet took up positions on the side locations. Today, although blocks 1–4 are no longer in existence, blocks 5–8 and the medical school survive.

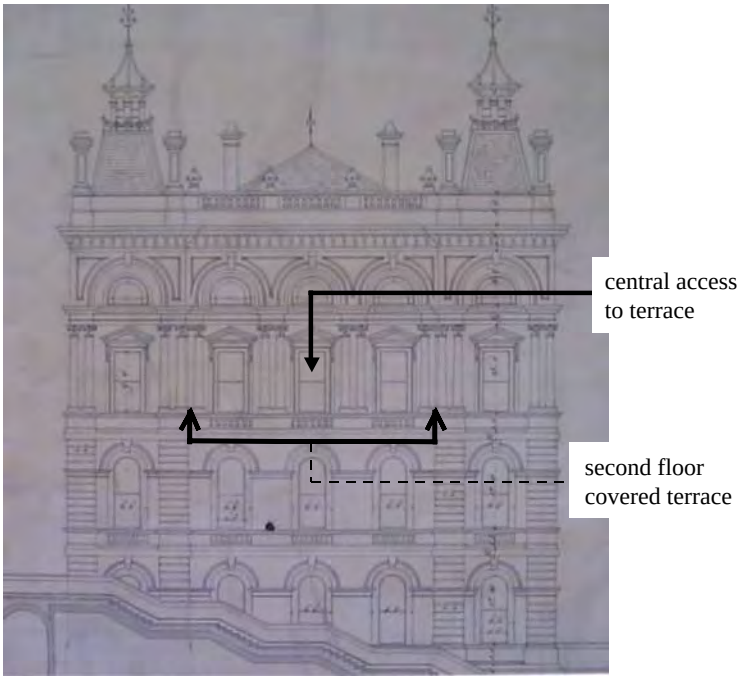


Figure 4. Architectural drawing showing the west elevation of the administrative block.

### (*c*) *The internal measurement scale for determining Solar position within the painted scenes*

Once Monet's vantage point had been located, an internal measurement scale was determined for each painting analysed, where the painted roofline features were spatially mapped making use of historical maps, architectural drawings and actual measurements on existing parts of the buildings. The roofline features of the Houses of Parliament used for determining azimuthal and elevation scales in the analysis of the paintings included: (i) the corner pinnacles of the Victoria Tower, the mid-towers and the Chancellors House, (ii) the Central Tower and the smaller spires; and (iii) the roof of the Lord's wing and the roof section between the mid-towers.

The azimuthal angles were determined using a historic ordnance survey map (Ordnance Survey 1 : 2500 scale Middlesex Plan Sheet XVII. 14, first edition 1894–1896), where specific roofline features and Monet's vantage point were identified by reference to architectural plans (Folder NA Work 29/100, National Archives; HO1/ST/A/166/020, London Metropolitan Archive) and aerial photographs.

The elevation angles were determined by first measuring the relative heights of the roofline features of the Houses of Parliament with respect to the second floor of the existing block 6 of St Thomas' Hospital, using an Abney level (Stanley London) for angular elevation measurements and the ordnance survey plan map for horizontal measurements. These relative heights also correspond to the relative heights with respect to the second-floor terrace of the original block 1, since the second floors of blocks 1 and 6 were at the same height (HO1/ST/A/166/050,77, London Metropolitan Archive). This enabled the determination of elevation angles

with respect to Monet's vantage point. It was assumed that Monet's eye level was five and a quarter feet above the terrace floor (J. House 2005, personal communication). Both the narrowness of the terrace and Monet's letters indicate that he painted the Houses of Parliament in a standing position. The largest error in the relative height determinations arose from the Abney level elevation readings (estimated $\pm$ 15 min arc).

Using this internal scale for azimuthal and elevation angles, the Solar azimuthal ($\Omega_p$) and elevation angles ($\beta_p$) were determined corresponding to the location of the centre of the Solar depiction. The accuracy to which the centre could be determined was estimated at about quarter the estimated Solar disc diameter. The overall error contained this error as well as the estimated error in determining the internal measurement scales.

### (*d*) *Determination of dates and times*

Once the azimuthal and elevation angles of the Solar depictions had been measured (as described above), the corresponding dates and times were determined by comparison with calculated Solar track information for this location. The Solar track information was obtained from the Astronomical Applications Department of the US Naval Observatory (http://aa.usno.navy.mil/data/docs/AltAz.html) and the overall accuracy of the calculated Solar positions is of the order of 0.1° (determined for each minute of the day). The Solar tracks were calculated for the years 1900 and 1901 and the latitude and longitude specified for St Thomas' Hospital was 51°30′ N and 0°07′ W, respectively. The dates and times of the depicted scenes were determined through a simple weighted least squares procedure in which the variance; $((\Omega_p-\Omega_0)/\sigma(\Omega_p))^2+((\beta_p-\beta_0)/\sigma(\beta_p))^2$ was minimized, where subscripts p and 0 correspond to the painted and calculated Solar positions, respectively, and $\sigma(\Omega_p)$ and $\sigma(\beta_p)$ are the estimated errors in the Solar azimuthal ($\Omega_p$) and elevation angles ($\beta_p$).

## 3. Results

An example of the derived internal scale is shown in figure 5 which gives azimuthal and elevation angle plots for the roofline features in painting W1596. The actual painting is shown in figure 6. The azimuthal angle scale (figure 5*a*) showed good overall linearity across the Houses of Parliament. However, the Victoria Tower was thinned by about 30% on average compared to the surrounding features. Such a thinning has previously been noted (Isaacson 1978; Wildenstein 1996*b*). The elevation angle scale (figure 5*b*) also showed fairly good linearity. An exception to this linearity was the apparent elevation of the Central Tower, which was generally lower than expected when compared to other roofline features. As a result, only the roofline features to the left of this tower were used for determining elevations. It was also found that the roofline features had been somewhat 'stretched upward' compared to the azimuthal direction (by about 17% in this case) and compared to the building below the roofline.

Using the derived internal scale, it is possible to superimpose Solar tracks over the paintings. Figure 6 gives an example of this, where the Solar tracks were obtained as described in the previous section. The year specified for these tracks was 1900. The calculated sunrise and sunset times were consistent with the

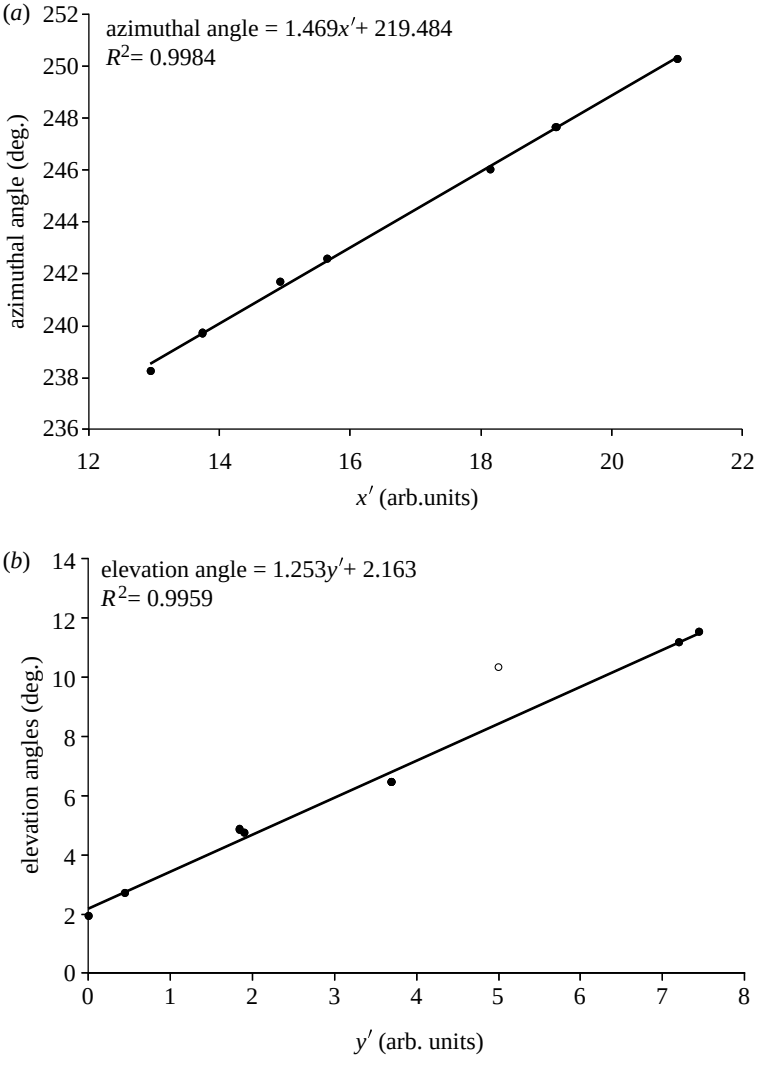


Figure 5. Internal measurement scales for painting W1596. (*a*) Azimuthal angle: the figure shows a plot of azimuthal angle against 'horizontal' length position, $x'$ (parallel to the roofline) of roofline features within the painting. (*b*) Elevation angle: the figure shows a plot of elevation angle against 'vertical' length position, $y'$ (parallel to the axis of the Victoria Tower) of roofline features. The open circle data point corresponds to the elevation of the Central Tower and was not included in the fit—see text for further details. The lines of best fit and corresponding equations, which form the internal scales, are also shown, where $R^2$ is the square of the Pearson correlation coefficient.

corresponding sunrise and sunset times reported in historical issues of The Times daily newspaper. In the painting shown in figure 6, the Sun is depicted to the upper right of the Victoria Tower. The internal scale was used to determine Solar azimuthal ($\Omega_p$) and elevation angles ($\beta_p$) of $\Omega_p = 243.67 \pm 0.45°$ and $\beta_p = 13.18 \pm 0.60°$. The errors are estimated and mainly arise from uncertainty in determining the centre of the Solar disc in the painting and also contain our estimates of the accuracy of the internal scale. The corresponding dates and times determined for

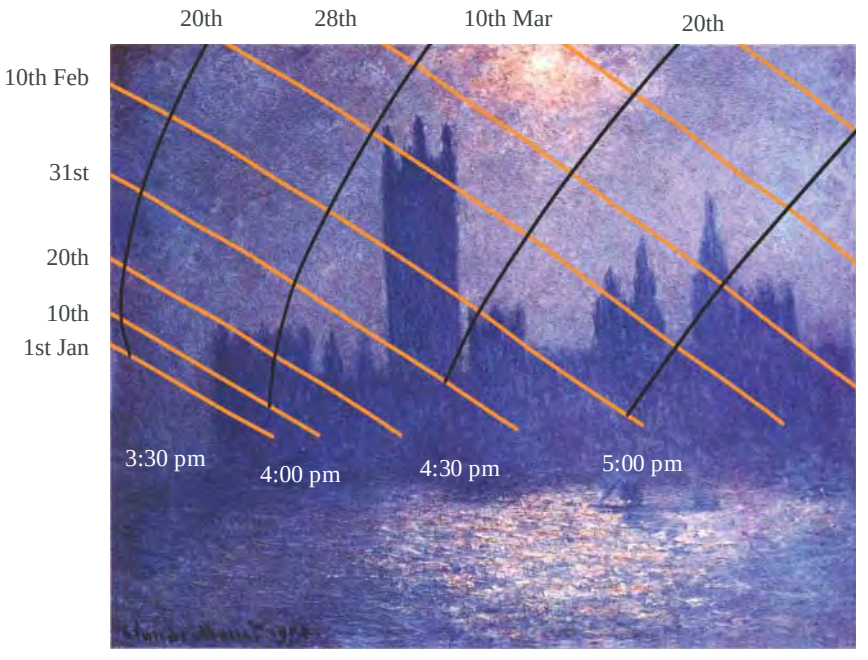


Figure 6. Solar tracks superimposed over Monet's 'London, Houses of Parliament, Effects of Sun in the Fog' (W1596).

the painting shown in figure 6 was $7\pm^{2\ \text{day}}_{1\ \text{day}}$ March and $16:17\pm^{2\ \text{min}}_{3\ \text{min}}$, respectively, for the year 1900. Essentially, the same results were obtained for 1901.

Figure 7 shows painting W1602 with a superimposed Solar track for 18 February 1900 that passes through the centre of the Solar disc as well as Solar tracks for two days before and after this date. In this painting, the Solar disc is more clearly delineated compared to the painting shown in figure 6 and is lower on the horizon. The Sun appears to be viewed through a thicker fog layer in this case and there appears to be no strong reflections. We determine a Solar disc diameter of $0.83\pm0.15°$ from the painting. The expected Solar disc diameter would be in the range 0.50–0.55°, but atmospheric scattering phenomena can give the appearance of larger values. The other paintings that contain depictions of the Sun tend to have larger apparent Solar diameters.

Table 2 gives our determinations of Solar azimuthal and elevation angles together with the corresponding dates and times for the nine Houses of Parliament paintings for which we were able to determine Solar positions. The analysed paintings are ordered according to the determined dates. The majority of the dates occur in February from about mid-February onward and there are only two paintings representing scenes in March. There are no Solar depictions that correspond to dates in January, early February and April.

## 4. Discussion

The determined dates of the paintings all lie within the known period Monet was in London in 1900 and 1901 (Wildenstein 1996*a*). The times lie within the late

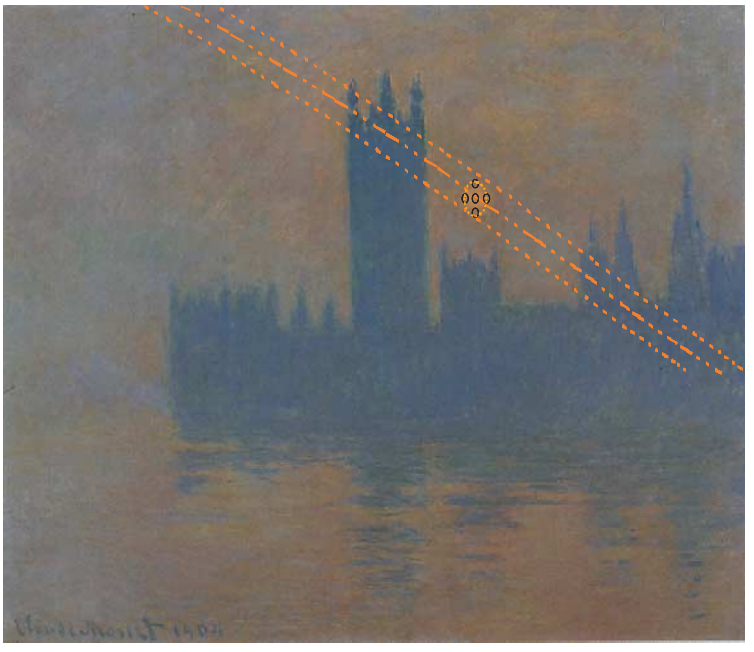

Figure 7. Locating the Solar position for Monet's 'London, Houses of Parliament, Sunset' (W1602). Three Solar tracks are shown corresponding to 18 February 1900 ± 2 days. Indicated in the figure is the estimated error boundary in determining the Solar position.

Table 2. Solar positions and corresponding dates and times for nine paintings. $\Omega$ and $\beta$ are Solar azimuthal and elevation angles in degrees, respectively, for the depicted Sun. The Solar geometry calculations used for determining the dates and times were for the year 1900. The same dates and essentially the same times (to within about 1 min) were obtained for 1901.

| painting | $\Omega$ (deg.) | ±(deg.) | $\beta$ (deg.) | ±(deg.) | date | ±day | time | ±min |
|---|---|---|---|---|---|---|---|---|
| W1607 | 231.47 | 0.45 | 10.90 | 0.60 | 13 Feb | −3/+1 | 15.44 | −3/+2 |
| W1605 | 228.88 | 1.00 | 13.36 | 1.00 | 15 Feb | −4/+4 | 15.30 | −5/+5 |
| W1610 | 231.45 | 0.60 | 11.90 | 0.80 | 15 Feb | −3/+3 | 15.42 | −4/+3 |
| W1599 | 249.84 | 1.10 | 1.19 | 1.00 | 17 Feb | −4/+4 | 17.09 | −7/+6 |
| W1602 | 241.73 | 0.45 | 6.75 | 0.55 | 18 Feb | −2/+1 | 16.28 | −2/+2 |
| W1606 | 234.40 | 0.90 | 13.46 | 1.10 | 23 Feb | −4/+3 | 15.48 | −5/+5 |
| W1604 | 245.67 | 0.45 | 6.66 | 0.55 | 24 Feb | −2/+1 | 16.41 | −3/+2 |
| W1596 | 243.67 | 0.45 | 13.18 | 0.60 | 07 Mar | −1/+2 | 16.17 | −3/+2 |
| W1597 | 254.51 | 0.65 | 13.2 | 0.85 | 23 Mar | −3/+2 | 16.46 | −4/+4 |

afternoon—early evening period and this is also consistent with the period of the day Monet visited the hospital. The dates are determined to a good precision. To further test the accuracy of these dates, more detailed information is needed on the dates Monet was working at the hospital and the likelihood of a sunset being observed from this location. The best source of information in this respect, are the observations and notes contained within Monet's letters (Wildenstein 1996*b*). Monet wrote frequently to his wife during his 1900 and 1901 campaigns to London, describing his progress on the London series, the weather as well as

Table 3. Dates of paintings consistent with Monet's letters. Dates in which Monet reported observing the Sun over Parliament are unbracketed. The bracketed dates are less certain but possible.

| painting | 1900 (letters) | 1901 (letters) |
|---|---|---|
| W1607 | 14 Feb | (11–13) 14 Feb |
| W1605 | 14 (15) 16 (19) Feb | (11–13) 14 Feb |
| W1610 | 14 (15) 16 Feb | (12–13) 14 Feb |
| W1599 | 14 (15) 16 (19–21) Feb | (13) 14 Feb |
| W1602 | 16 (19) Feb | — |
| W1606 | (19–24, 26) Feb | — |
| W1604 | (22–24) Feb | — |
| W1596 | 9 Mar | — |
| W1597 | (20,21) 24 Mar | — |

other matters and they form the bulk of the available letters. These letters were translated and analysed providing an independent source of information from that contained within the paintings themselves (see appendix A in the electronic supplementary material). Another independent source of information is the daily weather records for London during this period and we are presently gathering and comparing this data with the observations reported in Monet's letters. A preliminary analysis of the weather data indicates that there is a close consistency between Monet's letters and the reported weather conditions. However, the weather data does not generally provide sufficient information to determine whether or not a sunset was visible from Monet's vantage point.

Table 3 gives the possible dates of the paintings consistent with Monet's letters of the 1900 and 1901 campaigns. There are only fours dates in 1900 in which Monet specifically refers to observing the Sun from the hospital and these are 14 and 16 February and 9 and 24 March. The dates in brackets in this table correspond to periods where Monet was or may have been working at the hospital and where the Sun may have been observed, but was not specifically mentioned (see appendix A). Monet's 1901 campaign was not particularly successful, with a delay in getting his paintings through customs, extended periods of poor weather (15–26 February and 5–8 March) and ill health (pleurisy) from 10 March to about 28 March.

As shown in table 3, excellent agreement is found between the dates derived from the paintings and the information contained in Monet's letters. The four dates for which Monet wrote in his letters that he had observed the Sun over the Houses of Parliament are all represented in the series. This demonstrates that these paintings do indeed contain quantitative information, where dates of the depicted scenes have been determined and validated against an independent information source. A consideration of the two visits in 1900 and 1901 suggests that all the paintings analysed were first created in 1900.

Although our analysis of the Victoria Tower alignment shows that Monet was located in block 1 of St Thomas' Hospital (see §2b), we have also for comparison determined dates assuming that Monet was in fact in block 2 of St Thomas' Hospital (see figure 3). As previously mentioned, Monet painted from a covered terrace and block 2 had covered terraces facing the river on each floor (from the ground floor to

Table 4. Solar positions and corresponding dates for alternate vantage points in block 2 of St Thomas' Hospital. $\Omega$ and $\beta$ are Solar azimuthal and elevation angles in degrees, respectively, for the depicted Sun. The azimuthal angles, $\Omega$, are the same for each floor, only the elevation angle, $\beta$, changes. It was assumed that Monet was centrally located along the terraces.

| | | first floor | | | second floor | | | third floor | | |
|---|---|---|---|---|---|---|---|---|---|---|
| painting | $\Omega$ (deg.) | $\beta$ (deg.) | date | time | $\beta$ (deg.) | date | time | $\beta$ (deg.) | date | time |
| W1607 | 235.4 | 12.5 | 22 Feb | 15.52 | 11.8 | 21 Feb | 15.53 | 11.1 | 19 Feb | 15.55 |
| W1605 | 232.5 | 14.9 | 24 Feb | 15.37 | 14.3 | 22 Feb | 15.38 | 13.6 | 21 Feb | 15.39 |
| W1610 | 235.4 | 13.5 | 24 Feb | 15.49 | 12.9 | 23 Feb | 15.51 | 12.2 | 21 Feb | 15.52 |
| W1599 | 255.5 | 2.3 | 29 Feb | 17.19 | 1.3 | 27 Feb | 17.23 | 0.3 | 25 Feb | 17.25 |
| W1602 | 246.7 | 8.0 | 28 Feb | 16.38 | 7.2 | 26 Feb | 16.41 | 6.4 | 25 Feb | 16.43 |
| W1606 | 238.6 | 15.0 | 4 Mar | 15.55 | 14.4 | 3 Mar | 15.57 | 13.8 | 1 Mar | 15.59 |
| W1604 | 251.1 | 8.0 | 7 Mar | 16.51 | 7.1 | 5 Mar | 16.54 | 6.3 | 3 Mar | 16.56 |
| W1596 | 249.1 | 14.8 | 18 Mar | 16.26 | 14.2 | 17 Mar | 16.27 | 13.6 | 15 Mar | 16.29 |
| W1597 | 260.6 | 14.3 | 4 Apr | 16.58 | 13.7 | 2 Apr | 17.00 | 13.0 | 1 Apr | 17.02 |

the third floor). Assuming these different vantage points, table 4 gives the corresponding dates of the painted series. The errors in the dates are essentially the same as those given in table 2, for corresponding paintings, but the dates themselves have been shifted to later in the year by between 6 and 11 days. Vantage points corresponding to the first floor (and ground floor) of block 2 include dates outside of the period Monet was known to be painting from St Thomas' Hospital. There is also no match up with the dates Monet reports having observed sunsets over the House's of Parliament. For example, for the third-floor terrace vantage point, there are no paintings corresponding to the dates 14 February and 9 and 24 March. This provides confirmation that Monet painted from block 1 and not block 2 of St Thomas' Hospital.

Finally, the precision of the derived timings given in table 2 needs some comment. It has been estimated that only 45 min were required for Monet to paint Impression, Sunrise in 1872 (Art that shook the world: Monet's Impression, Sunrise 2001). The surface area of the canvasses used for the Houses of Parliament series were about 2.5 times greater than that for Impression, Sunrise ($81\times92$ in. compared to $48\times63$ in.; Wildenstein 1996*a*). Hence, one estimate of the time needed to complete one of the paintings would be 2.5 times that needed for Impression, Sunrise, i.e. just under 2 h. It is likely, as indicated in his letters, that Monet would have prepared each canvass with sketches of the Houses of Parliament motif beforehand and then painted in the atmosphere, including the Sun while observing the atmospheric effect. It seems reasonable that not more than a few minutes would have been taken to paint in the Sun and the timings and dates given in table 2 would correspond to this moment. The painting of the surrounding atmosphere and associated colours probably represents a time average of about 20–30 min, during which time the Sun would have moved by several degrees. He would have then worked on each painting on later days whenever the effects reappeared during a similar positioning of the Sun. However, the reappearance of the specific effects did not occur often due to the transience and variability of the weather. Monet was aware of the changes in the

Solar course with each passing day and realized that if the course changed too much he would not be able to get similar observable effects. This was the reason why he returned in 1901, but that campaign was not particularly successful due to bad weather and ill-health (see appendix A in the electronic supplementary material).

In summary, we have shown that these paintings contain real quantitative information that can be used to determine Monets' vantage point and the dates of the depicted scenes. This shows that the paintings were based on actual observation or impressions made during Monet's London visits rather than created from imagination or pure memory in his studio in Giverny. What remains to be assessed in detail are the accuracy and information content of other aspects of the paintings such as the colours of the atmosphere. However, the fact that we have demonstrated that the paintings contain quantitative information does provide some support to the contention that Monet's aim was to capture as accurately as he could the observed visual effect, and hence provides confidence in a continuation of our analysis of these paintings as a potentially accurate visual record of the urban atmosphere of Victorian London.

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