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RECOVERY OF NINETEENTH-CENTURY TOKYO/OSAKA METEOROLOGICAL DATA IN JAPAN

M. ZAIKI,[a]* G. P. KÖNNEN,[b] T. TSUKAHARA,[a] P. D. JONES,[c] T. MIKAMI[d] and K. MATSUMOTO[e]

[a] *Kobe University, Faculty of Cross-Cultural Studies, Tsurukabuto 1-2-1, Nada-ku, Kobe-shi 657-8501, Japan*
[b] *Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands*
[c] *Climatic Research Unit (CRU), University of East Anglia, Norwich NR4 7TJ, UK*
[d] *Tokyo Metropolitan University, Department of Geography, Minami-Ohsawa 1-1, Hachioji-shi, Tokyo 192-0397, Japan*
[e] *Tokyo Women's Medical University, Kawata-cho 8-1, Shinjyuku-ku, Tokyo 162-8666, Japan*

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ABSTRACT

We have recovered instrumental temperature and pressure observations from Tokyo covering the periods 1825–1828, 1839–1855, and 1872–1875; from Yokohama covering the periods 1860–1871 and 1874; from Osaka covering the periods 1828–1833 and 1869–1871; and from Kobe covering the periods 1869–1871 and 1875–1888. The newly recovered records contain data before the 1870s, which is a period where, until recently, no instrumental data in Japan were believed to exist. Their addition to the previous backward extension of Japanese series, as based on the recently recovered intermittent Dejima/Nagasaki series 1819–1878, implies that the nineteenth-century extension of the Japanese instrumental record no longer contains major temporal gaps. The recovered data were used for a preliminary calculation of the west-Japan temperature (WJT) series, which is a representative temperature series for the area. The existence of a warm epoch in the 1850s over W-Japan and a downward temperature trend till the early twentieth century, as previously inferred from documentary data, is confirmed from the WJT data. The pressure data implies that the temperature differences between the nineteenth and twentieth centuries are at least partly caused by a change in atmospheric circulation.

KEY WORDS: early instrumental data; instrumental meteorological record; climate change; nineteenth century; Japan

1. INTRODUCTION

The global temperature rise of about 0.6 °C over the twentieth century (Jones *et al*., 1999) is presently common knowledge. Knowledge of a more remote past is one of the keys to interpreting the present and to forecasting the future. The urgent need for more reliable data on climate variability in the pre-twentieth-century period has lead to various attempts to reconstruct the climate with the aid of early instrumental data, documentary data, and natural proxy indicators (e.g Jones and Mann, 2004). A primary problem of the early instrumental period is the poor coverage outside Europe in the period before the mid-nineteenth century (Lamb, 1995).

Japan is regarded as one of the many blank spots in the pre-1900 world, as the official meteorological network started only in the 1870s. Prior to 1872, no Japanese meteorological records were thought to exist apart from visual data documented in diaries (Mikami, 1988; Mikami *et al*., 2000) of Japanese administrators at many places in Japan. Until recently, it was believed that the only pre-1872 instrumental data regarding Japanese climate were taken by the Dutch in the settlement of Dejima (Nagasaki). Recently, however, it was (re)discovered (Amano, 1952, 1953; Tsukahara, 2005) that for a few places in Japan, most noticeably Edo (Tokyo) and Osaka, sub-daily weather records were taken routinely by Japanese scientists. These Japanese

* Correspondence to: M. Zaiki, Kobe University, Faculty of Cross-Cultural Studies, Tsurukabuto 1-2-1, Nada-ku, Kobe-shi 657-8501, Japan; e-mail: zaiko@comp.metro-u.ac.jp

meteorological observations were associated with the development of astronomical research by the so-called 'Dutch Study' scholars, as a result of Japan's modernization and the introduction of modern western instruments. As these data, on the one hand, partly overlap with the Dejima data, while on the other, fill some of its gaps, a search was started to recover them from Japanese archives and elsewhere.

As a follow-up of the work to evaluate and homogenize early nineteenth-century Japanese observations taken at Dejima (Können *et al*., 2003), we present here the evaluation of the recovered nineteenth-century instrumental data from Tokyo, Yokohama, Osaka, and Kobe. The availability of the 1819–1878 temperature and pressure observations taken at the five locations indicates the potential for constructing a nineteenth-century instrumental temperature and pressure series for the western Japan region.

The significance of data recovery in Japan reaches further than just being an extension of the Japanese instrumental record back in time. First, the recovered series happens to be in a region of the world that is poorly covered by instrumental data; second, it overlaps with the long daily series of visual weather reports of 1700–1868 as documented in diaries of Japanese administrators at many places in Japan (Mikami, 1988; Mikami *et al*., 2000).

2. DATA SOURCES AND DESCRIPTION

The data found are from Tokyo, Yokohama, Osaka, and Kobe. The distance between Tokyo and Osaka is about 400 km, while that between the stations in Tokyo and Yokohama, as well as between the stations in Osaka and Kobe, does not exceed 30 km. Therefore, we grouped the data of Tokyo and Yokohama together and that of the Osaka/Kobe stations together. Figure 1 shows the locations of the various sites where pre-1875 observations were taken and Figure 2 shows the present status of the availability of the pre-1870 data, including that of the previously recovered Nagasaki (Dejima) data (Können *et al*., 2003).

2.1. *Tokyo/Yokohama area*

2.1.1. Tokyo (palace series): 1825–1828. These observations were probably taken in 'Nagasakiya', which was a hotel specifically for foreign visitors. The hotel was located near the Shogun Palace in Edo (35° 41′16″N, 139° 46′16″E, 4.0 m above MSL (mean sea sevel). Only three fragments of the obviously longer series have

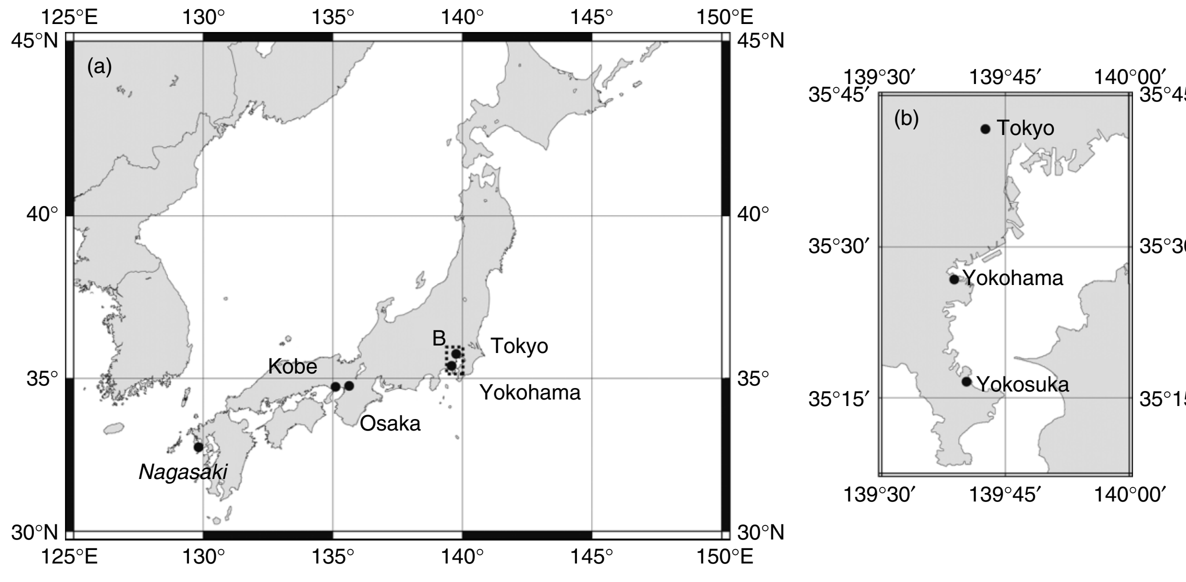

Figure 1. Location of the pre-1872 observation sites in Japan (Map (a). The Tokyo/Yokohama area indicated by a dashed line in the Map (a), and enlarged in Map (b), showing the relative distance of Tokyo, Yokohama, and Yokosuka)

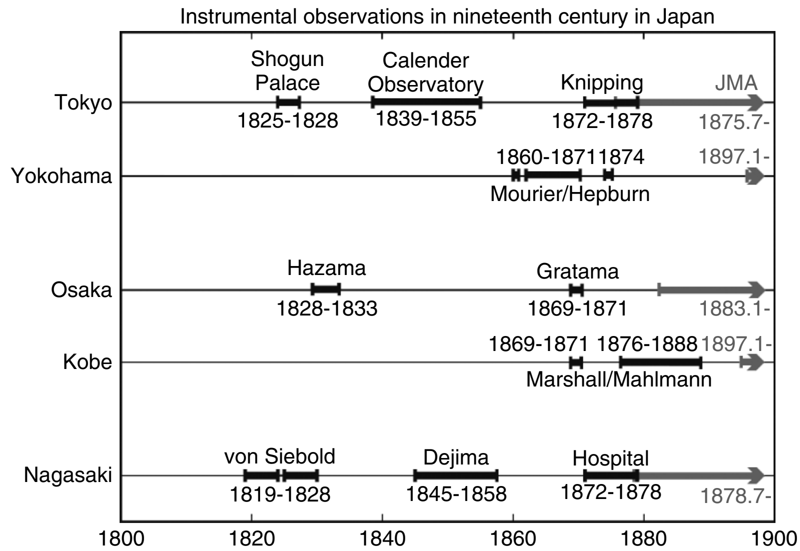

Figure 2. Pre-1900 availability of meteorological data in Japan. Grey: official meteorological stations from JMA (Japanese Meteorological Agency). Black: data taken before the foundation of JMA. The sub-series are named by their observer or location. The Nagasaki data (last row) are discussed in Können *et al*. (2003)

been found so far. They are referred to here as the 1825 list, the 1826 list, and the 1828 list, respectively. The 1825 list (covering the period 22 December 1824–21 December 1825) is in the von Siebold documents (von Siebold, undated, 20 123–20 147; the documentation numbers are according to the von Siebold catalogue by Vera Schmidt (1989)). The 1826 list (covering 7 February 1826–26 January 1827) was found in the University Library of Leiden in the Netherlands (Anonymous, 1826). The 1828 list (covering 22 August 1827–10 August 1828) is available from the 'Seiushoukou-hyo' collection 1828, kept in the Japan National Archives. The 1826 and 1828 lists are in Japanese; the 1825 list is in German. The German 1825 list (in von Siebold's handwriting) is apparently a transcription of the original Japanese lists, made by von Siebold during his stay at the Palace of the Shogun in Edo in 1826.

The day and year count in the lists is according to the Japanese (lunar) calendar of those days; in the 1825 list, a column with the western day count is added. However, in the 1826 list, the observation year is never mentioned, although the document description of the Leiden Library indicates that the document originates from the second half of the 1820s. Fortunately, the list contains nine reports of severe earthquakes, which occurred on 22 February, 14/15/24 March, 16/28 May, 7 June, 21 July, and 12 September in the Japanese calendar. These events enable us to fix the year of the observation. Comparison with the historical earthquake records (Earthquake Research Institute, University of Tokyo, 1984) yields for 1826 an exact match of the dates for eight earthquakes out of the nine reported within the historical record, the latter containing a total number of 15 earthquake reports in 1826 in Tokyo.

All lists contain temperature and pressure observations, usually taken three times a day. The observation times are denoted as morning, noon, and evening (Table I). As the time reckoning is according to the Japanese (solar) local time (LT), these times refer to astronomical sunrise, solar noon, and sunset, respectively. Details regarding the conversion of the Japanese calendar and time reckoning are discussed in Amano (1952, 1953).

Pressure measurements are the same in the three lists, but the units are not specified. Values are given as three digits. In the Japanese documents, a decimal point is specified after the first digit; in the von Siebold lists, the decimal points are omitted. The daily values typically range from 2.70 to 3.50 (in the Japanese notation). As the metric system was accepted only in mid-nineteenth century in Europe (Middleton, 1964), the unit is apparently either the French inch (27.07 mm) or the English inch (25.4 mm). From a comparison of the day-to-day standard deviation in all 35 Palace full observing months with the average day-to-day standard deviation in the modern Tokyo 1991–2001 series, we found that the Palace pressure unit is 25.5 ± 0.8 mm.

Table I. Observation hours for Palace, Calendar observatory, and Knipping in Tokyo. The different observation schedules are labelled as Ta and Tb. In the pressure correction column, Temp., SL, and G refer to temperature, sea level, and gravity adjustments, respectively. ○ indicates that the adjustments are applied in this study and ● indicates that the adjustments had already been applied in the original observations

Period	Schedule (JST)	Mark	Pressure corrections		
			Temp.	SL	G
Palace (4.0 m above MSL)					
1824/12/22–1825/12/21	Morgen, Mittag, Abend[a]	Ta	○	○	○
1826/02/07–1827/01/26	Mo, Mi, Ab[a]	Ta	○	○	○
1827/08/22–1828/08/10	Morning, Noon, Evening[a]	Ta	○	○	○
Calendar observatory (1838-: 20.0 m, 1842/06-: 6.5 m above MSL)					
1838/12/17–1855/02/17	Morning, Noon, Evening[a]	Ta	○	○	○
Knipping (7.0 m above MSL)					
1872/09–1875/12	6:40, 13:40, 20:40	Tb	○	●	○

[a] The observations based on the Japanese local time.

This, together with use of the decimal (rather than duodecimal) notation (Middleton, 1964; Können *et al.*, 2003), led us believe that the English inch (25.4 mm) is the likely unit.

Comparison of the mean Palace pressure with the climatological Tokyo data indicates an offset of 26.95 ± 0.02 in. in the absolute Palace scale if the gravity and the temperature adjustments are ignored in the modern Tokyo data. This gives a strong hint that an integer value of the bias is exactly 27 in. A possible explanation for such an integer bias stems from the design of the stick barometers made in Britain in the early nineteenth century, which often had a scale that starts at 28 in. and ends at 31 in. (see e.g. Figure 5 and 6 of Bolle, 1983). Our conjecture is that the Dutch delivered such a barometer to the Shogun court, and that the Japanese renumbered the scale, starting according to the customs at the time in which the number 1 rather than the zero to represent the lowest (28 in.) level. If our decoding key to the units is fully correct, then the transformation into millimetres reads (barometer unit $+ 27) \times 25.4$ mm, so that e.g. 3.10 units on the barometer scale correspond to 762.0 mm.

No explicit description is found about the type of the instruments. However, there is strong evidence that the instruments were gifts from the Dutch, as the observing times of the day (morning, noon, and evening) in the headings of the Japanese 1826 list are written in the Dutch language. Neither the data nor the lists gave any hints that an instrument was replaced in the observing period. No reduction to temperature, height, or gravity seemed to have been applied to the pressure data.

No other instrumental observations apart from temperature and pressure are found in these Tokyo lists, but in the 1826 and 1828 lists, the observations are systematically augmented by visual weather and wind observations as well as with the above-mentioned reports of the earthquakes.

2.1.2. Tokyo (Calendar series): 1839–1855 (Reiken-koubo collection). These observations were taken by the Tokugawa government bureau of Astronomy for Calendar Making of Edo. Till 1 April 1842, this bureau was located at 35° 42′49″N, 139° 44′35″E, 20.0 m above MSL. After a fire on 2 April (Amano, 1953), the bureau was re-established on 1 June 1842 at 35° 41′32″N, 139° 45′9″E, 6.5 m above MSL, which is about 2 km SSE from the first location. The original handwritten lists of observations, stored in the National Astronomical Observatory in Japan, are not accessible, but contemporary handwritten copies of these lists are available from the National Archives of Japan (Reiken-koubo, 1838–1855). The meteorological observations consisting of temperature, pressure, and weather were taken in the period 17 December 1838–16 February 1855 with a gap after 1 April 1842 because of the fire. The visual meteorological observations as well as the instrumental astronomical observations were resumed on 1 August 1842, but the temperature was not recorded again until 21 March 1844. For pressure, the observations started even later, on 30 December 1844. This seems to suggest that the meteorological instruments were seriously damaged. No documentation about the meteorological instruments or their location in the observatory survived. It seems likely, however, that, like in the Palace observatory, the instruments came from the traditional annual gifts from the Dutch to the Shogun.

The observations were basically taken three times a day, namely, morning, noon, and evening and occasionally at midnight (Table I). The schedules operated according to the Japanese (lunar) calendar and the temporal hour. Temperature is recorded in full degrees Fahrenheit; the pressure values, although the notation clearly says Japanese conventional inches (30.3 mm), are clearly in English inches (25.4 mm) instead. The pressure is rounded to the second decimal.

Amano (1953) claims that the Calendar thermometer was inside a building. However, inspection of the diurnal variation in the temperature data suggests otherwise. As no peculiarities are found in the temperature series, no corrections have been applied to the temperature data other than a height correction and a correction for the unevenly distributed observation hours.

Figure 3(a) shows the raw Calendar pressures after conversion from inches to hectopascals. It possesses various problems. First, it is biased over the entire period by no less than 10 hPa (modern annual mean pressure in Tokyo is 1014.2 hPa); second and more seriously, it shows various jumps between 13 May 1845 and 26 September 1848, degrading the variability by a factor of about 4, and a reversal of the annual cycle.

Statistical evaluation of the two periods outside the degraded part shows consistency in the data. In accordance with the height difference of 14 m, the bias in the pre-1845 data (−14 hPa after temperature reduction) with respect to the modern climatology is 2 hPa larger than the bias in the post-1848 (−12 hPa). This consistency suggests that the barometer was repaired after the fire rather than being replaced by a new one because the behaviour of the data for the pre-1845 and the post-1848 lookalike with only a systematic error. Additionally, in the Edo era when no connections to foreign countries existed except for the Netherlands, Japanese science technology did not have the ability to manufacture meteorological instruments. The number of meteorological instruments at the time in Japan was quite limited, so it is reasonable to believe that the barometer was repaired, rather than replaced.

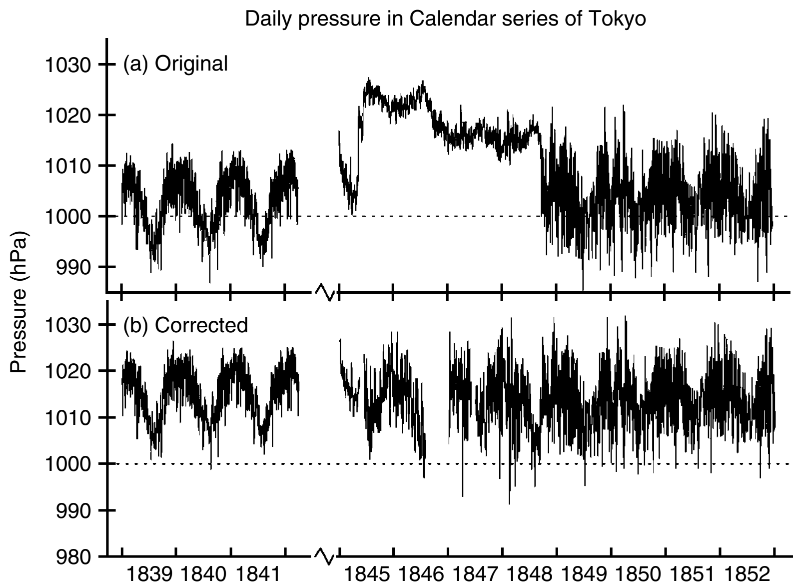

Figure 3. Time series of daily pressure taken at the calendar observatory in Tokyo 1839–1852. (a): raw data (converted from inches to hectopascals); (b): corrected for biases and, in the period 1845–1848, for changes in scales and floating zero points of the scales (see text for discussion that this period may be less reliable)

Although the structure of the 1845–1848 pressure data differs completely from the other periods and its variance is small, there are no reasons to assume that the data refers to something other than pressure, e.g. to temperature in some strange units. As in the remainder of the observations, the readings seem to be in English inches. The reported values are between 29.10 and 30.34 in.

A possible explanation for the strange values and the small variance might be an operational error in the observation routine. Given the likely origin of the instrument, it is plausible to assume that the Calendar barometer was similar to the barometers operated in those days by the Dutch in Dejima. These were of the siphon type with a movable scale (Stamkart, 1849, see also the Dejima station instruction in the letter of 21 February 1844 by Wenckebach, in von Siebold (undated), documents 20 254–20 271). It could be that the reports referred to readings at the lower end of the siphon, which is the number that had to be subtracted from the reading at the upper end. If the diameter at the lower end of the siphon was 40% larger than at the upper end, the lowering of the variance would be explained. The readings should be close to zero, but it is possible that the observers added 30 in. to the readings, being an important number in inch-based barometers. Applying such a 'correction' would be similar to the floating zero-point practice in the Palace pressure series, discussed above. Given the isolation of the Japanese observers from the rest of the world, a mistakenly resumed observation routine like the one we describe here may have easily occurred after the long interruption between 1842 and 1844.

If these conjectures are correct, the readings R of the degraded period should be transformed into pressure P by $P = C - AR$, where A is the inflation factor to be applied to the standard deviation and a C is a constant. From the comparison of the within-month variability of the data before and after the 1848 break, A was determined to be 3.7 by trial and error. Using a χ^2-test on the standardized monthly anomalies, the constant C was found to be 4771 if expressed in hPa. Application of this formula indicates realistic values from December 1847 onwards and makes the pre- and post- 26 September values look statistically alike. However, in order to make the data in the degraded period consistent with the remainder of the Calendar series, 5 hPa has to be added to C for January and November 1847; another 22 hPa, for December 1845 through July 1846; and another 6 hPa, for 14 June to 30 November 1845. In the period from August to December 1846, as well as between 13 May and 13 June 1845, the bias changes irregularly so that the data are useless. Finally, the daily data of June 1846 shows a non-realistic behaviour and is regarded by us to be useless. Before 13 May 1845, the reading looks realistic.

There are no reasons to assume *a priori* that the jumps in C and hence in the bias of the readings on the (inverted) scale stem from an instrumental cause. Instead, they could be related with another assignment of the number 30 (in.) on the scale at the lower end of the siphon. The jumps of 5 and 22 hPa, corresponding to 0.15 and 0.65 in., respectively, may be caused by a change in zero point introduced by the observer.

Figure 3(b) shows the pressure after the reductions described have been applied. Although the figure looks realistic, the numbers for the suspect period May 1845 to September 1848 have to be used with extreme care only. First, they rely on the conjectures outlined above, which have still to be proven correct. Second, it is not clear whether more breaks are hidden in this period. Third, the data for this period are probably not suitable for trend studies because of the calibrations of the biases on the basis of modern data. Fourth, although the annual cycle agrees with Dejima (the only other meteorological station available during this time in Japan), the positive correlation between the pressures of Tokyo and Nagasaki, as apparent in the modern Tokyo/Nagasaki data as well as in the Palace/von Siebold 1826–1828 data and the Calendar/Dejima 1848–1854 data, is not visible in the Calendar/Dejima data covering the period 1845–1848.

Normally, each of the qualifications above could be sufficient ground to delete the 1845–1848 data entirely from the analysis. Nonetheless, we included the monthly values in the tables. The reason is that the data and its day-to-day variability may contain some information about the frequency distribution of the circulation over Japan, which is not obtainable otherwise by the lack of any other Japanese readings in that period apart from Dejima.

2.1.3. Tokyo Knipping (1872–1878). E. Knipping, a mathematician at the Tokyo University, published detailed lists of daily meteorological observation taken at 35° 41′N, 139° 47′E, and 21.5 French feet (7.0 m) above MSL. His list contains pressure, temperature, vapour pressure, humidity, wind, cloud, and precipitation for the period September 1872–February 1873 (Knipping, 1873–1876), March–December 1873 (Knipping, 1876–1880a). Monthly summaries from September 1872 to December 1878 are reported in the same volumes, so that Knipping apparently continued his observations after the establishment in July 1875 of the nearby (3.5 km WSW) official Tokyo Meteorological Observatory operated by the Japanese Meteorological Agency (JMA). This provides an overlap of no less than 3.5 years between these series.

The observation hours of Knipping are 7 : 00, 14 : 00, 21 : 00 LT, where Tokyo LT = UTC + 9 : 20 (Table I). Temperature is reported in Reaumur ($1^{\circ}R = 1.25\,^{\circ}C$); pressure readings are in French inches (27.07 mm) divided in lines according to the duodecimal system (12 lines = 1 in.), and reduced to 0 °C by applying the thermometer readings. Details about the instruments used are reported in Knipping, (1876–1880b). The same article describes the result of a comparison of Knipping's instruments against JMA's as well as a comparison of Knipping's and JMA's monthly temperatures and pressures of 1876–1877.

Monthly values of Knipping's temperature and pressure observations are published in two contemporary sources (Rein, 1876; Hann, 1878). The Rein table runs from December 1872–March 1875 and the Hann table, from December 1872–November 1876. The temperature values in both tables till December 1875 prove to be identical to Knipping's. However, the pressure values in Rein's and Hann's tables show a constant bias with respect to Knipping's: for Rein the bias is −2.0 mm (−2.6 hPa) and for Hann's, it is +0.2 mm (+0.27 hPa). The reason for these −2.0/+0.2 mm offsets could not be found.

Hann (1878) claims that the data from January 1876 onwards are taken by H.B. Joyner, a person known to be employed by the first official Tokyo Meteorological Observatory (JMA, 1975). The station's coordinates written above Hann's table (35° 40′N, 139° 44′E, 24 m above MSL) refers actually to Joyner's site rather than Knipping's and coincides with the location of the first official Tokyo observatory. Comparison of the Hann's table with the JMA Tokyo observation readings indicates that the 1876 data in Hann's table were indeed taken by JMA.

Rein's (1876) publication of monthly values in the Tokyo area contains another list of temperature and pressure observations, which were taken by G. Hochestetter and covers the period December 1871–November 1874. The site of the observations was the Japanese Mining Department at Nagata–Machi in Tokyo. Knipping (1876–1880b) also mentions the existence of this series and indicates that the observations continued after November 1874. Neither of the two references gives coordinates for Hochestetter's site, but maps of Tokyo in the nineteenth century show that the Mining building was 2.5 km SW of Knipping's location, at about 10.0 m above MSL. No details are documented about Hochestetter's instruments or observation schedules.

Hochestetter's temperatures and pressures strongly co-vary with Knipping's. In the overlapping period December 1872–November 1874, the summer temperatures of Hochestetter are higher than those of Knipping by about 2 °C, indicative probably of insufficient screening from radiation. The pressures are high by 5.9 hPa on average. By lack of observational details, there are few possibilities to correct these data. Therefore, for our analysis of the Tokyo data of the 1870s, we basically used Knipping's, but augmented in the pre-Knipping year (December 1871–November 1872), by Hochestetter's data. The monthly Hochestetter temperatures were corrected by the mean differences by month of Knipping/Hochestetter in the overlapping period; the pressures were reduced by 5.9 hPa. The reliability of the Hochestetter's extension of Knipping's is clearly inferior, but for the same reasons as in case of the 1845–1848 Calendar data, we did include the pre- December 1872 Hochestetter data in our tables.

2.1.4. Yokohama/Yokosuka: 1860–1874. In addition to the Tokyo series, a set of series from Yokohama and the nearby town Yokosuka (Figure 1) exists. It consists of five partly overlapping series, taken at different locations which are spread out over a N–S area of about 25-km length and 6-km width. The centre of this area is about 25 km SSW of the first Tokyo JMA station. The observers are P. Mourier (covering the year 1865), P.A.L. Savatier (December 1866–January 1868), J.C. Hepburn (1860, 1863–1869), and Sandwith (1874). The fifth series, covering 1870, is by an unknown observer. We treat these series subsequently.

A daily series December 1864–November 1865, located at 35° 27.3′N, 139° 40.2′E, 3 m above MSL, was taken by P. Mourier, a French Navy doctor working at the Yokohama ironworks. His published records (Mourier, 1866) contain pressure (in millimetres, reduced to sea level and 0 °C) and temperature readings (maximum and minimum temperatures as well) for 7 : 00, 10 : 00, 16 : 00, and 22 : 00 LT, where Yokohama

LT = UTC + 9 : 20 (Table II), and, additionally, humidity and precipitation. It is reported that the instruments were calibrated at Paris in May 1864, and the observations were carefully taken to the north of the house in the yard, 2.0 m above the ground, and shaded by double umbrellas. Monthly summaries of Mourier's lists are published by Jelinek and Hann (1872a) and again by Rein (1876), who erroneously reported an observation height of 7.0 m.

A daily series from Yokosuka (35° 16′N, 139° 38′E; 12.5 m above MSL, 25 km S of Mourier's station) covers the period December 1866–January 1868 (Savatier, 1870). The observer, P.A.L. Savatier, was a French Navy doctor also working at the Yokosuka ironworks in the period 1866–1875 (Nishibori, 1986). The daily series contain temperature, vapour pressure, relative humidity, cloud condition, wind at 8 : 00 and 16 : 00 LT, and precipitation throughout. The daily temperature averages derived from the 6 : 00, 10 : 00, 13 : 00, 16 : 00, and 22 : 00 LT observations are reported from April 1867 onwards (Table II). Although the Savatier's report precisely describes the calibrations applied to the barometer, no pressure readings are in the list.

Monthly values of temperature, precipitation, and day counts of various weather conditions (fine, cloudy, and wet days) for two separate periods (December 1859–November 1860; December 1863–November 1864) are published by Jelinek and Hann (1874). The observer, Hepburn, was a US medical doctor. Hepburn's 1859/1860 observations were taken at the temple Soko-ji (35° 30′N, 139° 38′E, 5.6 m above MSL, about 2 km north from the Mourier's site) where he started his medical treatments. The observation hours are Sunrise and 14 : 00 LT. The observation in the 1863/1864 list was carried out at the hospital (35° 26′N, 139° 39′E, 3.0 m above MSL, about 3 km southeast from Mourier's site), which Hepburn had established in 1862 in the foreign settlement of Yokohama. The observation hours are 7 : 00, 14 : 00, 21 : 00 LT. The averages of the 1864 list were calculated as (7 : 00 + 14 : 00 + 2 × 21 : 00)/4. Although 7-year-monthly-averaged values for the extended period December 1862–November 1869 are published (Jelinek and Hann, 1875; Hann, 1878), no monthly averages for these individual years are included. Jelinek and Hann (1874) states that the 1859/1860 data were published in R. Fortune's book *Yedo and Peking*; the 1863/1864 list came from an obscure source, namely the Sanitary (Health) Report for 1864 of the Army Medical Department. The original Hepburn records have not yet been found.

A second list of monthly values comes from the foreign settlement of Yokohama, covering December 1873–November 1874 and is published by Rein (1876). The observer is Sandwith, about whom no details are known other than that he was a lieutenant in the British Military. The place of observation is 35° 26′N, 139° 39′E, 30.5 m above MSL. This location is very close to the Hepburn's second site. The list contains monthly pressure, temperature, relative humidity, and precipitation. No information about the observational

Table II. Same as Table I, but for Yokohama and Yokosuka

Period	Schedule (JST)	Mark	Pressure corrections		
			Temp.	SL	G
	Hepburn/Mourier (3.0 m above MSL)				
1859/12–1860/11	Sunrise, 14	Ya	–	–	–
1863/12–1864/11	6 : 40, 13 : 40, 20 : 40[a]	Yb	–	–	–
1869/12–1871/03	6 : 40, 13 : 40, 20 : 40[a]	Yb	●	●	○
1863/12–1869/11	6 : 40, 13 : 40, 20 : 40[a]	Yb	–	–	–
1864/12/02–1865/11/30	6 : 40, 9 : 40, 15 : 40, 21 : 40	Yc	●	●	○
	Sandwith (30.5 m above MSL)				
1873/12–1874/11	not mentioned		●	●	○
	Savatier in Yokosuka (12.5 m above MSL)				
1866/12–1868/01	7 : 40, 15 : 40	Yd	●	○	○

– , No pressure observation.
[a] The average temperature is calculated by (6 : 40 + 13 : 40 + 20 : 40 × 2)/4.

schedules is provided. According to our examination, no reductions to the pressure readings seem to have been applied, not even a temperature reduction. The original reports have not been found so far.

Finally, a Yokohama monthly series for December 1869–March 1871 (35° 27′N, 139° 40′E, the height is not indicated) is published by Jelinek and Hann (1872b). The table is based on a communication by K.W. Gratama, the same person who took measurements in Osaka (see the following text). One can believe that the observer might be someone else. The Gratama series can be considered as an extension of the Mourier series, because the reported geographical coordinates in the Gratama series agree with Mourier's. If so, the height would be 3.0 m above MSL. The list contains monthly pressure, temperature at 7 : 00, 14 : 00, and 21 : 00 LT, and precipitation. The temperature averages are calculated according to the formula $(7:00 + 14:00 + 2 \times 21:00)/4$. Although there is no statement about data reductions, the pressure values seem to be reduced to sea level and 0 °C.

2.2. *Osaka/Kobe area*

2.2.1. Osaka (Hazama collection): 1828–1833. These observations were taken in a house of the Japanese scientist Hazama Shigeyoshi (1786–1838) at Osaka (34° 40′N, 135° 31′E, 4.0 m above MSL). Thermometer readings (in full degrees Fahrenheit) referred to the temperature inside the building (Amano, 1952). As for the Tokyo 1825–1828 case, the information content of these data is therefore only of qualitative nature. The pressure units, although again written in Japanese conventional inches (30.3 mm), are apparently English inches (25.4 mm). This is proved by comparing the values converted from Japanese to English inches with the JMA data.

The observations ran from 21 January 1828–4 April 1833. The pressure and temperature observations were taken basically once every day from 21 January 1828–29 August 1831, six times a day from 30 August 1831–19 February 1833, and ten times for the most frequent period from 20 February 1833–4 April 1833 (Table III). However, the schedules and frequencies of observations are shifting irregularly day by day, throughout these periods. The observations for morning and noon are only available from these entire periods (see Ob in Table III). The dates in the list were according to the Japanese (lunar) calendar and schedules according to Osaka local time (Amano, 1952, 1953), which is UTC + 9 : 20.

2.2.2. Osaka (Gratama): 1869–1871. A daily pre-1875 Osaka series of 4-month length (August–November 1869) is published in the KNMI Yearbook (1869) (see also Jelinek and Hann, 1871). It refers to readings taken by the Dutch chemist and medical doctor K.W. Gratama. He had taught physics and chemistry at Nagasaki Hospital in 1866 and settled in Osaka in May 1869 to found a school for physics and chemistry. The observation hours in his list are 8 : 00, 12 : 00, and 22 : 00 LT, where Osaka LT can be considered to be the same as Japan Standard Time (JST) = UTC + 9 : 00 (Table III). An extension of the Gratama series

Table III. Same as Table I, but for Osaka

Period	Schedule (JST)	Mark	Pressure corrections		
			Temp.	SL	G
	Hazama (4.0 m above MSL)				
1828/01/21–1831/08/29	Noon (Morning or Noon)[a]	Oa	○	○	○
1831/08/30–1833/02/19	Morning and Noon[b]	Ob	○	○	○
1833/02/20–1833/04/04	Morning and Noon[c]	Ob	○	○	○
	Gratama (15.0 m above MSL)				
1869/08–1871/01	8 : 00, 12 : 00, 22 : 00	Oc	●	●	○

[a] The observations based on the Japanese local time.
[b] The observations taken six times daily at most, but not the observation schedule changes irregularly.
[c] The observations taken ten times daily at most, but not the observation schedule changes irregularly.

December 1869 till January 1871 is published by Rein (1876) as averages for each calendar month over the available observation years of that month. Consequently, the December and January values represent in his list averages over 2 years. It is plausible to assume that the observation schedule remained unchanged throughout Gratama's observing activities. The published values are apparently the mean over his 3 observation hours. In the light of the Dutch procedures of those days (Können *et al.*, 2003), the barometer is likely to be reduced for station height and temperature, but not for gravity. Gratama left Osaka in April 1871. As the modern Osaka series starts only in January 1883 (CMO, 1954), there is a 12-year gap between the Gratama series and the Osaka observatory series.

2.2.3. Kobe: 1869–1888. Daily observations were taken at Kobe, about 30 km west from Osaka, for the period 29 September 1869–1 December 1888 with a gap from 27 December 1871 till 21 December 1875. The observer for the 1869–1871 period is unknown. From 1876, the observer was J. Marshall; after his death on 7 August 1887, J.J. Mahlmann took over. The observers were Kobe harbour masters. The observations were taken in the foreign settlement of Kobe (34° 41′36″N, 135° 11′10″E, 4.0 m above MSL). The data were published in 'Hiogo-News' which was an English newspaper, while the original handwritten lists from 6 January 1877 till 20 July 1887 are preserved and kept at Kobe Marine Meteorological Agency (Marshall, undated). The overlapping data from the newspaper and the originals turned out to be identical. The observations in the earlier period (1869–1871) were taken once a day at 12 : 00 LT; those from 1876 at 9 : 00 LT, where Kobe LT can be considered to be the same as JST = UTC + 9 : 00 (Table IV). The readings from 29 September 1869–28 December 1871 consist of air temperature and pressure; those from 29 December 1871–1 December 1888 additionally contain maximum, minimum, and wet bulb temperatures. It is reported that the pressure readings were reduced to M.S.L. Marshall claimed that the temperature observations were taken in the shade and in open-air condition (Hiogo-News, 1869–1888).

The pressure readings in the first observing period (29 September 1869–26 December 1871) exhibit a strong bias. A jump in the pressure readings is apparent after an 8-day break occurring in October 1870. Using a χ^2-test on the standardized monthly anomalies, the biases are +7.6 hPa for the period 29 December 1869–10 October 1870 and −9.5 hPa for the period 29 October 1870–4 February 1872. For the second observing period (22 December 1875–1 December 1888), no bias is detected in the pressure.

2.3. Japan Meteorological Agency: 1875 – present

The observational details of the JMA stations Tokyo, Yokohama, Osaka, and Kobe are listed in Table V. Although some of observatories moved their location in the past, all of the stations are currently still in operation. A brief history of these stations reads as follows.

The Tokyo observatory was founded on 1 July 1875 and has been moved once on 1 January 1950. We refer to the two locations as Tokyo observatory I (20.4 m above MSL) and II (5.8 m above MSL), respectively. The Yokohama observatory I (4.3 m above MSL) was founded on 1 January 1897 and has been moved once to what we call here Yokohama observatory II (38.3 m above MSL) in 1 November 1927. The Osaka observatory (5.6 m above MSL) was founded on 1 January 1883 and has been moved three times. These locations are referred to as Osaka observatory I, II, III, and IV, respectively. The Osaka observatory II (3.0 m above MSL) was effective from 1 September 1910; Observatory III (8.0 m above MSL), from 1 July 1933;

Table IV. Same as Table I, but for Kobe

Period	Schedule (JST)	Mark	Pressure corrections		
			Temp.	SL	G
	Marshall/Mahlmann (4.0 m above MSL)				
1869/09/29–1871/12/26	12 : 00	Ka	●	●	○
1875/12/22–1888/11/01	9 : 00	Kb	●	●	○

Table V. Observation hours for Tokyo, Yokohama, Osaka, and Kobe observatories of Japan Meteorological Agency. The different observation schedules are labelled as TA/TB, YA/YB, OA/OB, and KA/KB. In the column labelled MARK, 'standard' refers to the 24-hourly observations

Start	Schedule (JST)	Mark
Tokyo observatory I (20.4 m above MSL)		
1876/06/01	9:30, 15:30	TA
1877/09/13	3:30, 9:30, 15:30, 21:30	TB
1878/01/01	3,6,9,12,15,18,21,24	TC
1886/01/01	1,2,3, . . .,22,23,24	standard
Tokyo observatory II (5.8 m above MSL)		
1950/01/01	6,14,22	TD
1960/01/01	1,2,3, . . .,22,23,24	standard

Start	Schedule (JST)	Mark
Yokohama observatory I (4.3 m above MSL)		
1897/01/01	2,6,10,14,18,22	YA
Yokohama observatory II (38.3 m above MSL)		
1927/11/01	2,6,10,14,18,22	YA
1940/01/01	6,14,22	YB
1960/01/01	1,2,3, . . .,22,23,24	standard

Start	Schedule (JST)	Mark
Osaka observatory I (5.6 m above MSL)		
1883/01/01	6,14,22	OA
1886/01/01	2,6,10,14,18,22	OB
1889/01/01	1,2,3, . . .,22,23,24	standard
Osaka observatory II (3.0 m above MSL)		
1910/09/01	1,2,3, . . .,22,23,24	standard
Osaka observatory III (8.0 m above MSL)		
1933/07/01	1,2,3, . . .,22,23,24	standard
1940/01/01	6,14,22	OA
1960/01/01	1,2,3, . . .,22,23,24	standard
Osaka observatory IV (23.0 m above MSL)		
1968/01/01	1,2,3, . . .,22,23,24	standard

Start	Schedule (JST)	Mark
Kobe marine observatory (58.3 m above MSL)		
1897/01/01	1,2,3, . . .,22,23,24	standard
1918/01/01	2,4,6,10,14,18,22	KA
1940/01/01	6,14,22	KB
1960/01/01	1,2,3, . . .,22,23,24	standard

Observatory IV (23.0 m above MSL), from 1 January 1968. The Kobe observatory (58.3 m above MSL) was founded on 1 January 1897.

The monthly average data from the establishment years of each observatory from surface monthly processing (SMP) data were supplied by JMA.

3. DATA HOMOGENIZATION

The data homogenization was undertaken as before (Können *et al.*, 2003): a correction to temperature and pressure readings was applied to account for the uneven distribution of the observation hours through the day. The same procedure was applied to the JMA modern data, where appropriate. A height correction for temperature was applied to outside temperature throughout the period from the nineteenth century up to the present. Pressure was then reduced to sea level, standard gravity, and to 0 °C with aid of the tables by Kämtz (1832). In the cases in which barometer-attached thermometer readings were not available, the reported air temperature was used instead to reduce the pressures to 0 °C.

To check the homogeneity of all recovered series, the Standard Normal Homogeneity Test (SNHT; Alexandersson, 1986), the Buishand Range test (Buishand, 1982), and the Pettitt test (Sneyers, 1995) were run over the entire series (JMA and their nineteenth-century extensions) of annual, seasonal, and monthly pressures and temperatures. For the motivation of the choice of these three location-specific homogeneity tests, see Wijngaard *et al.* (2003). Prior to these calculations, the annual temperatures and pressures were adjusted for the biases discussed in the previous sections. As the Osaka/Gratama and Hazama series are too short or too fragmentary to be applied to the tests, only the homogeneity tests for the other three locations are considered.

None of these tests was able to detect for Tokyo an inhomogeneity in the temperature or pressure series around 1876, which is the year where the transition from the nineteenth-century unofficial observations to the JMA Observatory occurs. The homogeneity tests applied on monthly, seasonal, and annual series all fail to give any indication that points to 1876 for Tokyo as being suspect. From this result, we infer that it is meaningful to extend the Tokyo observatory series; 1876–2001 backwards in time by the composite Palace/Calendar/Knipping series 1825–1876 (1878).

If these tests are run only over the nineteenth-century period, all pressure series of these three locations and temperature series for Yokohama/Yokosuka and Kobe pass them successfully (at the 1% confidence level). For the temperature series for Tokyo (Palace and Calendar), the Buishand and SNHT tests indicate a break in all months for January–April and October–December at the transition of the two series. This is assumed to be due to a possible direct solar exposure on the thermometer. However, for the annual temperature series of 1825–1876 for Tokyo, none of the tests was able to detect an inhomogeneity. From these evaluations, it is concluded that all the series of pressure as well as of temperature can be regarded to possess a reasonable level of homogeneity for the nineteenth century; so no additional adjustments were applied.

4. TEMPERATURE/PRESSURE TIME SERIES; CROSS CHECKS

Figures 4 and 5 show the annual pressure and temperature time series for each location where pre-JMA data are available now. Appendices A1–B4 give the monthly values of the recovered temperature and pressure series. Although Figures 4 and 5 show that the pre-JMA period now have some data, the coverage in time and space is still rather fragmentary. Nevertheless, as we will show in the next section, even these sparse data allow for the development of a preliminary representative series of temperature over western Japan.

A quality check of the pre-JMA data by means of a comparison with other series is not possible, because of the large distance of the closest-by parallel running stations (Peking or Shanghai). However, Mikami (1996) and Mikami *et al.* (2000) collected and digitized daily visual weather reports as documented in diaries of Japanese administrators at many places in Japan. These reports usually run from the mid-seventeenth century till the end of the Edo period (1868). One of the observation sites happens to be close to Tokyo. Mikami (1996)

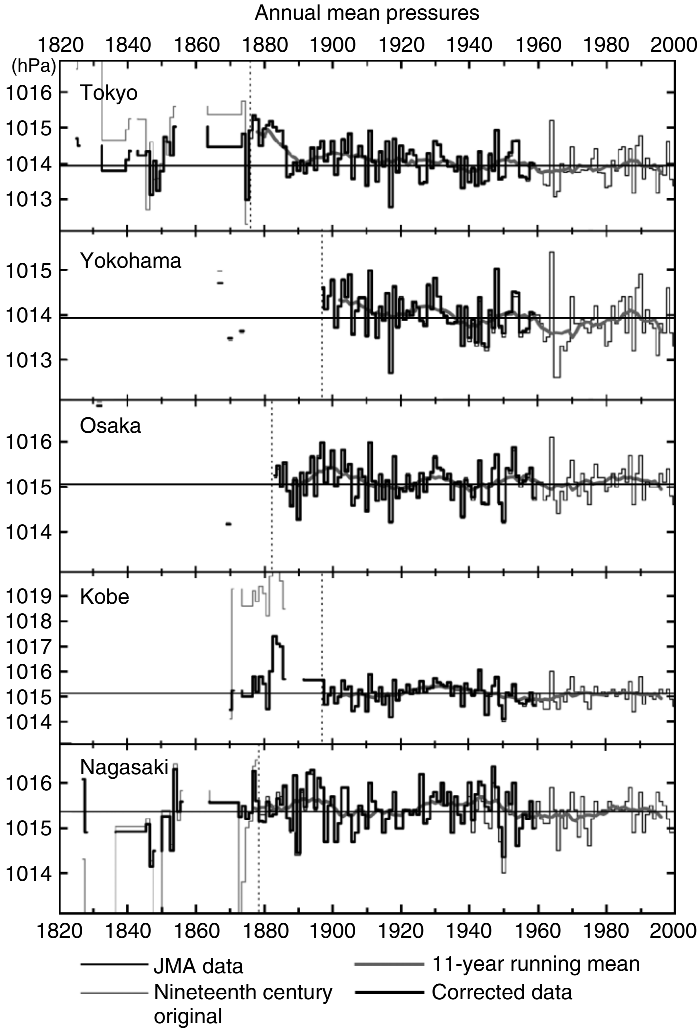

Figure 4. Time series of annual mean pressures in Tokyo, Yokohama, Osaka, Kobe, and Nagasaki for the period 1820–2000. The Nagasaki data (last row) are from Können *et al*. (2003). The dotted vertical lines are the establishment years of the JMA observatory for each location. The thin black lines indicate JMA data, the thin grey lines indicate original recovered data in the nineteenth century, the thick black lines indicate corrected data in this study, and the thick light-grey lines represent an 11-year running mean over the JMA data. The thick horizontal lines are the 1901–2000 averages

showed that the number of rainy days in Tokyo correlate well with the temperature for July. The availability of the dairy-based reconstructed July temperature series of the nineteenth century enables a comparison of the instrumental data with the independent data.

Figure 6 compares the instrumental July temperatures of the Tokyo series with those of the reconstructed temperatures from the diaries of the Ishikawa's family in the western suburbs of Tokyo kept from generation to generation since 1721 (Mikami, 1996). There are 20 years of overlapping data. The biggest differences are seen in the 3 years at the beginning of the instrumental series in the early nineteenth century. An insufficient radiation screening of the Palace thermometer is a likely reason. The overlapping 17 years from 1839 onwards agree better and show a positive correlation of $r = 0.72$. Given the fact that the correlation between July rainy day counts and temperatures is -0.70 (Mikami, 1996), this correlation could not expected to be any better.

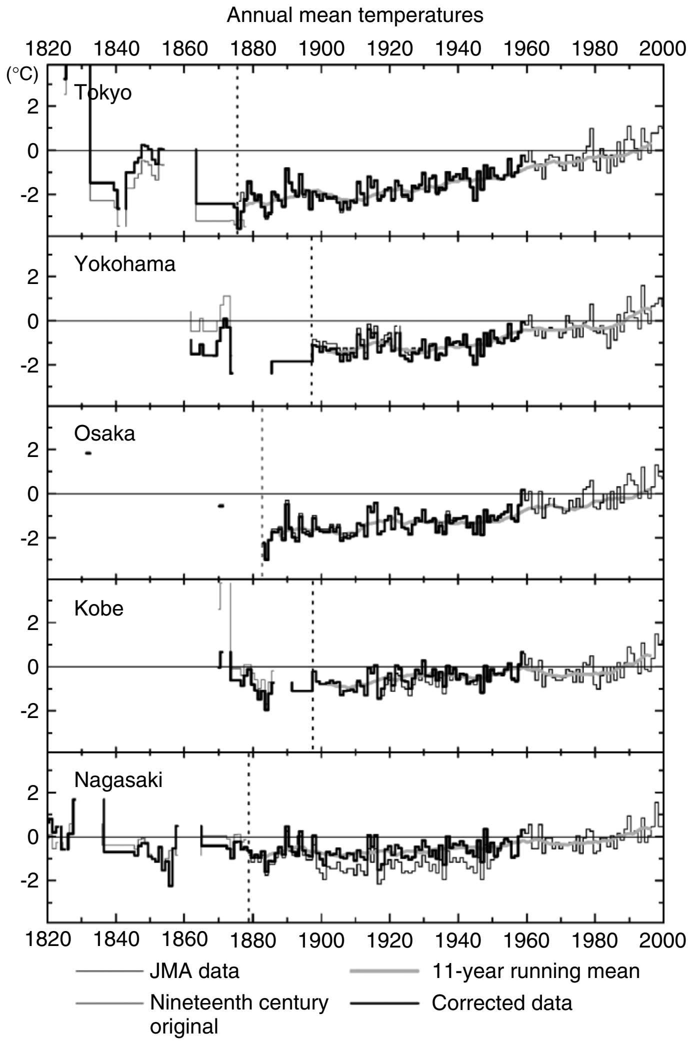

Figure 5. Time series of annual mean anomaly temperatures at Tokyo, Yokohama, Osaka, Kobe, and Nagasaki for the period 1820–2000, relative to 1971–2000. The Nagasaki data (bottom) are from Können *et al*. (2003). The dotted vertical lines are the establishment years of the JMA observatory for each location. The thin black line indicates JMA data, the thin grey line indicates original recovered data in the nineteenth century, the thick black line indicates corrected data in this study, and the thick light-grey line represents an 11-year running mean. The 1828–1833 Osaka data are omitted as they are indoor readings

5. CONSTRUCTION AND PRELIMINARY ANALYSIS OF COMPOSITE TEMPERATURE SERIES REPRESENTATIVE FOR WEST JAPAN

5.1. Introduction

The search for long metrological data series is a vital component of reconstructing the past climate. Many long instrumental data, mostly from European countries, have been developed (see e.g. Camuffo and Jones, 2002). The Central England Temperature (CET) series is recognized as the longest instrumental temperature series and a model for the development of long climatological time series. Manley published the CET series for the period from 1698–1952 (Manley, 1953) and then for 1659–1973 (Manley, 1974). Parker *et al*. (1992) constructed a daily version of the CET from 1772. The CET represents a series of area-averaged temperature over Central England. The modern part of CET (from 1878 onwards) is calculated as the average of three stations. These stations are not always the same during the pre-1878 period. In the pre-1878 period, the

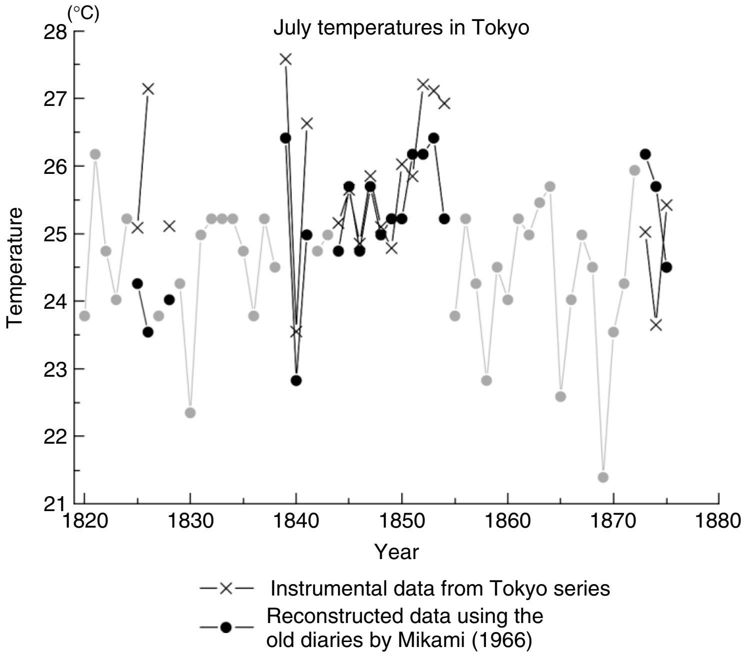

Figure 6. Time series of monthly temperatures for July for the period 1820–1880, comparing instrumental data (crosses) with reconstructed temperatures on basis of diary data (dots) for Tokyo. Reconstructed temperatures in years that are also observed instrumentally are indicated by black dots and the other reconstructed temperatures are indicated by grey dots. The reconstructed temperatures are from Mikami (1996)

number of stations that make up the average is basically one. A reduction of the variance has been applied to the single-station part of the series to make it consistent with the remainder of the series (see for details Parker *et al*., 1992). The CET series is now routinely updated by the Hadley Centre.

Although several countries have undertaken efforts to aggregate old measurements from different series to a long-term temperature series, the results are usually only developed for a certain location and presented as point station data. Examples are the Central Belgium Temperature (CBT) series (Demarée *et al*., 2002) which runs from 1767 onward and the so-called Zwanenburg/de Bilt (Labrijn, 1945) series for the Netherlands, which runs from 1706. The reason for not making a composite series similar to CET is that the stations that underlie the series are usually not very far from each other. If the underlying stations are at greater mutual distance, it can be beneficial to apply the CET approach instead.

The nineteenth-century series for Japan, reported here, from Tokyo, Yokohama, Osaka, Kobe, and Nagasaki cover most of the nineteenth century, albeit with poor spatial resolution. The distance between Tokyo and Nagasaki is about 900 km. In this situation, an aggregation of the series from the various locations into one representative series would be useful to make the data suitable for further study and trend analysis. In the next section, the long-term temperature series is presented by aggregating the recovered series into one single time series, representative of an area over west Japan (W-Japan) that is bounded by Tokyo and Nagasaki (130–140 °E), which we call the *west-Japan temperature (WJT) series*.

5.2. Methods

We define the modern WJT series as the arithmetic average of 11 stations (Fushiki, Nagano, Mito, Iida, Choshi, Sakai, Hamada, Hikone, Nagasaki, Miyazaki, and Tadotsu), all of which are located in the region defined by the five pre-JMA stations of Tokyo, Yokohama, Osaka, Kobe, and Nagasaki. The distance across the area of these 11 stations is about 900 km, compared with 300 km that make up the CET series. The 11 stations selected are considered to be of high quality and to be little influenced by urbanization and, therefore, are also used for the calculation of the present-day climatology by JMA. If one or more stations are missing, we calculate the WJT from the remaining stations, in the way we describe below. This is only the case for data before 1900.

For the pre-JMA period, the calculation of WJT will be based on stations that are nowadays strongly affected by the urban heat effect. This brings the recovered Tokyo data available for analysis. This is fortunate, as there are so few pre-JMA stations available. Of the available stations – in total six – only rarely more than two of them run parallel (Figure 2), whereas Tokyo and Nagasaki are most prominently present. As the (indoor-based) Hazama data of Osaka (1828–1833) had to be omitted from the calculation, the WJT relies more heavily on Nagasaki and Tokyo than Figure 2 suggests. As the 1825–1828 data of Tokyo and the 1819–1823 Nagasaki temperatures were omitted from the analysis because the measurements were spoiled by either sun exposure or by the fact that they were taken indoors, the pre-JMA-extended WJT starts in 1825 but comprises only 33 entire years of data in the 50 years till 1874.

For the calculation of the series, the station data were transformed into anomalies with respect to the 1971–2000 climatology. If the station number is less than 11, then a correction was applied to the station-averaged value that implies a reduction of variance. This was done via the method described by Parker *et al.* (1992) and Osborn *et al.* (1997), so the series becomes homogeneous to a similar level as with CET.

In brief, the method works as follows. First, to deal with the positive correlation of nearby temperature readings, the effective number of stations n' is calculated by

$$n' = \frac{n}{1 + \overline{r}(n-1)} \tag{1}$$

where $\overline{r}$ is the annual average of the correlation coefficients between monthly temperatures measured simultaneously at each station of the n different stations, all possible combinations being taken. In the twentieth-century WJT, $n = 11$, yielding $n' = 1.23$ for the annual average.

For the pre-1900 WJT series (where $1 \leq n \leq 5$), average exhibits a significantly larger monthly variance than the 11-station mean. To correct for this, the nineteenth-century monthly temperature anomaly series is multiplied by a factor b, where $0 < b < 1$, which results in the reduction of the variance, as required. Second, a separate value of b is required for each month. None of the WJTs for 1901–1930, 1931–1960, and 1961–1990 have variance ratios indicating significant variance differences at the 95% level (with unity as the null hypothesis), comparing between each period by month. The data used to calculate b, for the pre-1900 period, were chosen by assuming that two 30-year periods of monthly temperatures should have similar variances for the same period. The 30-year (1901–1930) monthly temperatures for five stations also confirm that there is no significant variance ratio at the 95% significance level (with unity as the null hypothesis) between these five stations. On these assumptions above, the two 30-year sample periods for the cases of $1 \leq n \leq 5$ and $n = 11$ stations were the periods 1901–1930 and 1931–1960, respectively. The value of b for each calendar month i is defined as follows:

$$b_i = \frac{\overline{b}_1}{\overline{b}_2} b_{2i} \tag{2}$$

where $\overline{b}_1$ and $\overline{b}_2$ are the annual means of b_{1i} and b_{2i}, respectively. b_{1i}^2 is calculated by

$$b_{1i}^2 = \sigma_{11i}^2 / \sigma_{ni}^2 \tag{3}$$

where σ_{11i}^2 is the variance of monthly temperature of 11 stations for 1931–1960 and σ_{ni}^2 is that of n stations ($1 \leq n \leq 5$) for 1901–1930 separately for each corresponding month i. Then, from Equation (1) with $n = 11$, the b_{2i}^2 is

$$b_{2i}^2 = \frac{1}{n'} = \frac{1 + 10\overline{r}_i}{11} \tag{4}$$

Here, the value of $\overline{r}_i$ is calculated from the 1931–1960 standard normal period for each calendar month i.

Thus, the factor b_i is calculated for each year according to the station number n (≤ 5) that makes up the pre-WJT series of that year.

5.3. Results and discussion

The annual and seasonal WJT series from the 1820s to 2000 are shown in Figure 7. This figure also shows the number of stations used each year. This series is adjusted by month for changes to station numbers (see above). To show how well individual sites correlate with the average, annual correlations between Nagasaki and Tokyo (separately) with WJT over 1901–2000 are 0.91 and 0.86 respectively. Table VI shows the trends as calculated for three sub-periods of the WJT series: the nineteenth century (I), the twentieth century till 1960 (II), and the period of warming thereafter (III).

For period I (pre-1900), the temperatures for all seasons show a slightly downward trend (Figure 7). Averaged over period I, the rates of the WJT change for this period are negative for all seasons (−0.11 °C/decade for annual mean temperature; Table VI). Although there are a number of gaps in the series in the nineteenth

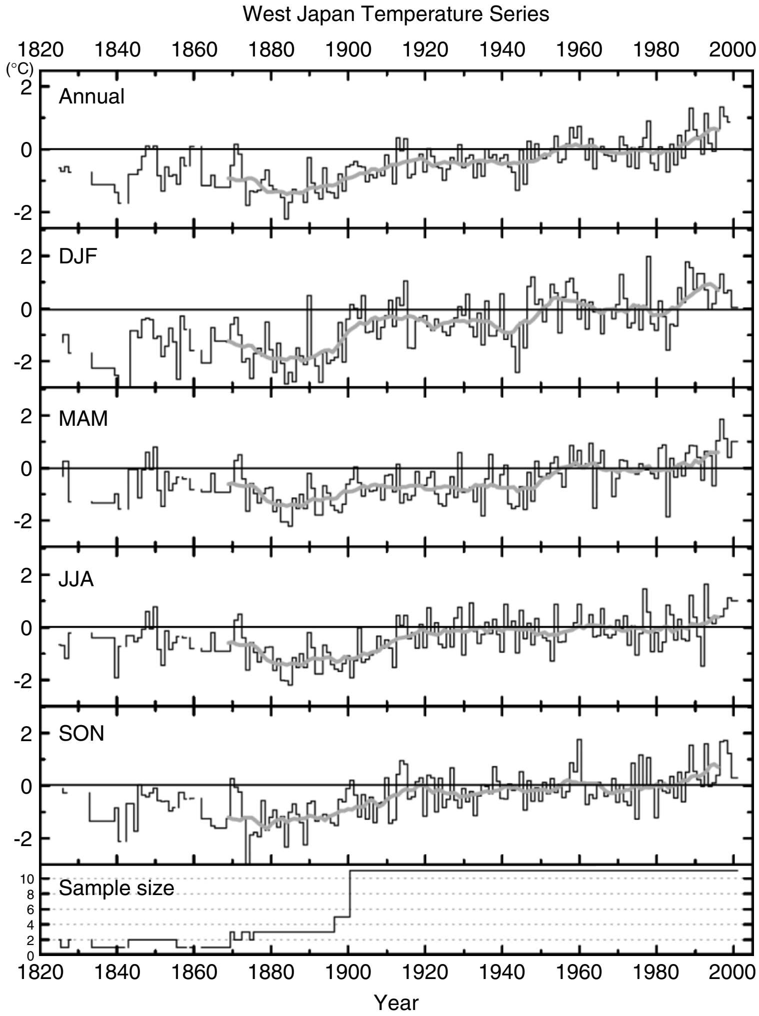

Figure 7. The west-Japan temperature (WJT) series by seasons and year for the period of 1820–2000, relative to the 1971–2000 period. Sample size indicates the number of stations used in the WJT calculation. Before 1900, WJT values were derived from the available five-station data recovered in this study, applying the variance reduction. After 1900, the values were calculated from 11 JMA observatories (see text)

Table VI. The linear trend of the west-Japan temperature (WJT) series over the periods I, II and III (°C/decade)

Period	Annual	DJF	MAM	JJA	SON
I (1820–1900)	−0.11	−0.07	−0.10	−0.12	−0.11
II (1901–1960)	0.11	0.11	0.09	0.14	0.09
III (1961–2000)	0.21	*0.30*	0.18	0.10	0.27

Roman, 99% significance level.
Italic, 95% significance level.

century, especially for the first 25 years, all the seasonal trends are significant up to the 95% level. The negative trends in this period compare well with the trend inferred from temperature reconstructions based on the daily weather descriptions in old diaries. The temperature trend in the reconstructed July temperatures for 1801–1900 in Tokyo (Mikami, 1996) is −0.07 °C/decade, and that in the January temperatures for 1801–1868 in Nagasaki (Mikami *et al*., 2000) gives −0.01 °C/decade. In general, the temperatures as reconstructed from the old diaries confirm the reality of the cooling trend for temperature over the nineteenth century as found in the instrumental data as well as the course of fluctuations derived from the calculations with the WJT series, including the warm period of the 1850s.

Very few other reconstructed temperatures from the old diaries are available. Although such temperatures are estimated values from earlier work, we do not have access to the values themselves. Usually, the results refer to a limited number of periods and seasons, and to some specific location only, therefore, they do not allow for year-to-year comparisons with WJT but do allow for a comparison of the broad features of climate of the period under consideration. Mizukoshi (1993) provides winter temperatures from 1800–1880 for Tsu, Mie prefecture, reconstructed from the frequency of the typical winter pressure pattern as inferred from the weather descriptions. The data are representative of the southern part of the Tohoku region to the southwestern island of Kyushu. Although the negative trend in winter temperature is not quantitatively confirmed from this data, the sources imply that the beginning of the nineteenth century saw frequent occurrences of severe winters, whereas the 1860s saw an increased occurrence of mild winters. In Kawamura (1993), a negative trend is seen in the March temperatures from 1855–1868, as estimated from the blossoming dates of cherry flowers in Tosa, Kochi prefecture. Maejima and Tagami (1986) provide reconstructed winter/summer weather types, which are reconstructed by the weather hazard records of old diaries in Japan. They present the frequency of five weather types based on the spatial distribution of climatic hazard over Japan (1, hot summer; 2, west Japan cool and north Japan hot summer; 3, north cool and west hot summer; 4, cool summer and mild winter; 5, cold winter) from the sixth to nineteenth centuries till 1900. For the nineteenth century, there were 62 cold winters out of the 71 records reported to have occurred. The distribution of these weather types over the nineteenth century shows a persistence of cold winters in the first half of nineteenth century and relatively normal occurrences of each summer type throughout the nineteenth century.

In general, it can be concluded that those reconstructed temperatures and their trends are at least in qualitative agreement with the features in the WJT and in a number of cases even more than that.

For the period II during 1901–1960, the trend turns into a warming one for all seasons. The annual mean rate of the WJT change over this period is 0.11 °C/decade (Table VI), with the one for summer (JJA) the largest. Period III (1961–2000) shows the warming trends increased by a factor of 2 with respect to period II. The increased warming is highly significant, even though this period contains only 40 years, compared to 60 years for the period II. The largest rate is seen in winter (DJF) (Table VI). The temperature rise in the area for which the WJT is representative seems to start during the beginning of the twentieth century.

The differences in temperatures in the nineteenth century compared with the twentieth century invoke the question of whether this can be attributed to a global effect or a regional (i.e. anomalous circulation) one. The pressure data are capable of providing a partial answer to this. The Tokyo–Nagasaki pressure difference can be considered as a proxy to the strength of the N–S airflow and the Tokyo–Nagasaki averaged pressure, an indicator of the cyclonicity. Hence, the data allows for a crude classification scheme of the circulation over the WJT region (Zaiki, 2004).

Preliminary analysis of the circulation data suggest that the lower temperatures in the nineteenth century can be at least partly attributed to the more frequent occurrences of increased anomalous N–S flow in mid-nineteenth century winters as well as in the late-nineteenth-century summer (Zaiki, 2004). A detailed study of the day-to-day or month-to-month variability of the nineteenth-century circulation data may shed more light on this issue.

6. DISCUSSION AND CONCLUSIONS

This study represents a significant extension of the modern JMA record backward in time and provides instrumental evidence for Tokyo, Yokohama, Osaka, and Kobe over a period when no other meteorological measurements were believed to be available. Detailed information about these recovered data in the nineteenth century has been documented in this paper. For the first part of the nineteenth century, the observations were taken by the Japanese observers rather than by the Europeans; for the second part, the situation is reversed. For the entire period, we were able to derive quantitative information about pressure. For temperature, the information is partly quantitative and partly qualitative.

Recovered data, together with the Dejima (Nagasaki) series 1819–1878 (Können *et al.*, 2003), were used for the preliminary calculation of the WJT series, which is a temperature series representative for the area. The WJT suggests an optimum in the 1850s, a negative trend in the late nineteenth century, and turning into a positive trend in the twentieth century. The reconstructed weather conditions from the old diaries coincide with the negative trends over the nineteenth century and the course of the fluctuations derived from the calculation results of the WJT series. The pressure series suggests that the differences between the nineteenth and twentieth centuries are at least partly caused by a change in atmospheric circulation.

The present study is a step in a long-term effort. It has been shown that there is a vast amount of quantitative data buried in old publications and archives, which should be recovered as part of the worldwide efforts to reconstruct the climate. As for Japan, it is assumed that the so-far recovered data represent only the tip of the iceberg, which can only be fully recovered over a number of years. Apart from the temperature and pressure data presented here, data regarding wind, clouds, precipitation, and humidity have also been recorded as meteorological data. Five years ago, no one had any notion of the existence of such data. It is plausible that further searches of the archives will unearth additional material. Multinational cooperation between scientists belonging to different disciplines is a major requirement for future progress in this area.

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Appendix A1. Monthly mean sea-level pressures in 1825–1878 for Tokyo. The data are reduced to 0 °C and standard gravity and corrected for the uneven distribution of the observation hours through the day. Units are (hPa − 1000). Uncertain values are italicized and the years are marked with an asterisk

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1825*	*13.3*	*19.9*	*19.2*	*18.1*	*16.3*	*14.2*	*12.0*	*15.3*	*15.8*	*19.8*	*19.5*	*17.3*
1826*	–	*19.2*	*18.4*	*17.1*	*18.4*	*14.5*	*11.5*	*11.5*	*15.1*	*20.1*	*22.5*	*15.4*
1827*	*14.1*	–	–	–	–	–	–	–	*17.4*	*20.1*	*20.4*	*18.8*
1828*	*18.0*	*14.5*	*17.2*	*15.9*	*16.3*	*14.7*	*12.4*	–	–	–	–	–
1839	18.9	19.9	15.6	15.4	14.5	11.3	6.7	7.0	13.4	16.1	19.4	19.1
1840	19.4	19.8	19.2	16.9	13.5	11.3	10.1	8.6	10.0	15.9	16.6	18.5
1841	20.1	19.7	20.1	17.8	14.9	10.8	7.6	7.7	11.8	15.9	17.8	18.4
1842	20.9	21.1	18.3	–	–	–	–	–	–	–	–	–
1843	–	–	–	–	–	–	–	–	–	–	–	–
1844	–	–	–	–	–	–	–	–	–	–	–	–
1845*	20.6	17.1	15.0	13.9	*14.1*	*20.4*	*9.8*	*11.9*	*11.5*	*15.7*	*18.9*	*18.9*
1846*	*15.1*	*16.6*	*16.9*	*14.6*	*11.3*	*7.8*	*6.4*	*23.1*	*20.8*	*18.5*	*18.0*	*16.5*
1847*	*16.4*	*17.3*	*16.8*	*12.5*	*15.6*	*15.5*	*10.8*	*10.4*	*11.3*	*16.3*	*16.6*	*16.5*
1848*	*16.5*	*16.4*	*12.3*	*12.3*	*15.4*	*12.9*	*6.5*	*5.1*	*16.9*	16.3	13.5	18.2
1849	14.7	16.5	17.0	14.5	12.4	9.0	8.9	10.0	10.2	15.7	17.9	15.9
1850	11.1	19.6	12.0	*17.6*	15.0	9.3	10.6	10.6	13.3	16.4	15.7	16.3
1851	15.9	15.5	16.8	15.8	14.1	10.7	10.9	11.5	14.3	15.1	17.4	17.3
1852	14.8	17.7	16.8	15.0	12.8	10.7	10.9	11.9	12.7	17.0	15.2	14.9
1853	16.4	18.9	16.0	15.8	13.6	11.5	12.4	14.0	13.0	16.8	17.5	17.4
1854	20.0	16.8	18.9	13.7	15.3	11.9	11.1	10.8	14.9	18.5	18.8	16.1
1855	12.7	–	–	–	–	–	–	–	–	–	–	–
1872	–	–	–	–	–	–	–	–	14.3	16.5	18.8	19.1
1873	17.0	15.9	14.9	17.6	13.8	12.2	11.6	13.4	13.3	17.8	18.0	19.0
1874	19.3	18.7	18.4	14.6	14.2	13.0	11.9	12.5	14.1	17.7	17.2	17.3
1875	15.0	15.2	17.1	13.3	15.0	10.6	4.2	9.1	8.9	13.1	13.8	11.9
1876	20.5	17.8	16.1	15.7	13.9	11.1	13.6	13.8	12.5	17.3	11.6	18.0
1877	17.8	14.4	11.4	17.0	14.3	10.2	11.5	9.7	13.6	13.7	17.9	18.0
1878	15.9	17.9	15.4	17.7	9.5	9.6	9.3	11.1	11.9	18.2	19.3	13.4

Appendix A2. Monthly mean sea-level pressures in 1859–1874 for Yokohama/Yokosuka. The data are reduced to 0 °C and standard gravity. Units are (hPa −1000)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1864	–	–	–	–	–	–	–	–	–	–	–	22.6
1865	15.3	16.1	19.0	14.4	13.5	9.7	6.4	10.8	15.1	15.0	18.5	–
1866	–	–	–	–	–	–	–	–	–	–	–	–
1867	–	–	–	–	–	–	–	–	–	–	–	–
1868	–	–	–	–	–	–	–	–	–	–	–	–
1869	–	–	–	–	–	–	–	–	–	–	–	16.4
1870	14.6	16.4	14.7	14.8	13.6	9.9	8.3	7.8	11.9	15.3	20.6	13.1
1871	14.0	14.5	17.2	–	–	–	–	–	–	–	–	–
1872	–	–	–	–	–	–	–	–	–	–	–	–
1873	–	–	–	–	–	–	–	–	–	–	–	13.3
1874	16.3	15.5	14.9	14.2	12.2	11.9	10.5	11.5	11.9	14.6	16.6	–

Appendix A3. Monthly mean sea-level pressures in 1828–1833 and in 1869–1871 for Osaka. The data are reduced to 0 °C and standard gravity. Units are (hPa − 1000). Uncertain values are italicized and the years are marked with an asterisk

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1828*	–	–	–	–	–	–	–	*9.0*	–	–	–	–
1829*	–	–	–	–	–	*9.4*	*7.6*	*7.8*	–	–	–	–
1830*	–	–	–	–	–	–	–	–	*15.1*	–	*20.3*	*24.7*
1831*	–	–	–	–	–	–	–	*11.5*	*16.5*	*21.1*	*22.9*	*24.7*
1832*	*22.8*	*20.2*	*19.9*	*15.4*	*14.3*	*10.6*	*12.9*	*12.3*	*17.3*	*18.5*	*22.5*	*21.9*
1833*	*25.7*	*23.4*	*20.6*	–	–	–	–	–	–	–	–	–
1869	–	–	–	–	–	–	–	11.9	13.4	15.1	19.6	17.9
1870	17.9	18.7	15.8	14.3	12.1	8.0	7.6	10.0	12.2	15.5	20.5	17.9
1871	17.9	–	–	–	–	–	–	–	–	–	–	–

Appendix A4. Monthly mean sea-level pressures in 1869–1888 for Kobe. The data are reduced to 0 °C and standard gravity. Units are (hPa − 1000). Uncertain values are italicized and the years are marked with an asterisk

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1869	–	–	–	–	–	–	–	–	–	14.3	19.3	22.2
1870*	*20.5*	*20.5*	*17.8*	*15.6*	*14.8*	*10.4*	*9.7*	*8.4*	*14.1*	*17.1*	*19.4*	*18.0*
1871*	*19.1*	*22.6*	*21.1*	13.7	11.8	10.1	7.7	7.6	10.2	*17.6*	*20.8*	18.2
1872	–	–	–	–	–	–	–	–	–	–	–	–
1873	–	–	–	–	–	–	–	–	–	–	–	–
1874	–	–	–	–	–	–	–	–	–	–	–	–
1875	–	–	–	–	–	–	–	–	–	–	–	–
1876	20.3	18.6	16.9	14.1	12.6	10.3	11.3	12.6	10.5	17.3	14.8	20.8
1877	–	–	–	–	–	–	12.9	9.0	12.9	15.1	19.6	19.6
1878	18.5	21.3	19.4	16.3	11.4	8.4	10.2	9.6	10.1	17.5	21.0	18.8
1879	22.8	21.1	17.2	18.7	10.6	7.6	12.7	9.1	12.0	21.5	–	–
1880	22.1	21.7	21.0	17.6	12.3	11.1	6.3	7.0	13.7	16.1	17.7	19.3
1881	16.2	18.9	20.1	14.9	13.1	9.3	8.7	9.0	11.8	15.2	–	–
1882	–	–	20.1	15.5	11.6	8.4	10.9	11.2	14.7	18.1	23.1	23.5
1883	22.0	23.4	18.7	18.3	16.9	14.0	9.5	13.4	14.8	18.3	21.8	18.2
1884	22.7	18.5	17.7	17.7	12.6	13.6	13.7	10.8	13.2	21.4	20.2	22.9
1885	23.8	21.9	21.1	18.5	15.4	11.8	12.1	12.0	13.1	14.8	17.2	22.0
1886	19.2	18.1	18.4	16.3	13.4	10.8	14.3	12.2	9.8	17.2	20.1	18.8
1887	19.7	–	17.0	13.4	13.7	6.7	14.6	–	–	–	–	–
1888	–	–	–	–	–	–	4.8	7.4	8.2	18.4	18.2	–

Appendix B1. Monthly mean temperatures in 1825–1878 for Tokyo. The data are adjusted to a height of 5.8 m (the station height of Tokyo observatory II). Uncertain values are italicized and the years are marked with an asterisk

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1825*	*13.8*	*13.5*	*15.4*	*18.9*	*20.7*	*22.6*	*25.1*	*24.4*	*23.0*	*20.8*	*17.5*	*14.4*
1826*	–	*13.8*	*18.7*	*19.1*	*21.7*	*24.9*	*27.1*	*26.3*	23.3	*20.0*	*17.8*	*14.7*
1827*	*13.6*	–	–	–	–	–	–	–	24.2	*20.4*	*17.0*	*15.0*
1828*	*13.9*	*13.4*	*15.5*	*18.2*	*21.1*	*22.7*	*25.1*	–	–	–	–	–
1839	2.8	3.3	6.3	12.4	18.1	21.3	27.6	27.1	22.5	16.2	10.6	5.3
1840	2.3	3.2	6.1	14.0	18.0	20.9	23.5	25.4	22.5	16.1	12.6	4.8
1841	1.2	1.3	6.1	12.8	17.0	20.0	26.6	24.8	21.0	15.7	9.5	3.4
1842	0.7	3.3	7.6	–	–	–	–	–	–	–	–	–
1843	–	–	–	–	–	–	–	–	–	–	–	–
1844	–	–	–	–	18.3	20.8	25.2	27.3	22.6	17.1	12.7	8.1
1845	6.3	5.6	9.4	14.0	18.6	21.7	25.6	23.5	21.5	16.9	11.2	4.7
1846	4.5	5.0	7.9	14.0	17.6	22.2	24.9	26.5	25.7	18.4	10.4	7.6
1847	5.2	5.1	8.3	15.6	18.5	20.5	25.8	26.3	22.9	17.2	12.9	8.6
1848	4.8	6.1	10.2	15.0	19.0	21.1	27.1	28.2	24.6	17.8	11.9	8.3
1849	5.5	6.9	9.5	–	18.2	21.7	24.8	26.2	25.3	18.2	11.6	9.4
1850	4.6	5.4	10.2	14.6	19.8	22.0	26.0	25.6	25.7	18.1	12.6	7.1
1851	5.9	5.0	8.2	13.9	17.5	22.0	25.8	28.0	24.4	16.9	11.6	6.9
1852	5.0	4.1	6.8	12.8	18.5	22.5	25.2	27.9	22.4	18.0	12.2	6.1
1853	4.5	4.3	8.9	15.1	18.0	22.1	27.1	28.6	24.7	17.5	12.5	6.6
1854	7.0	6.1	8.9	13.7	18.4	22.2	26.9	27.0	23.0	18.6	12.4	7.2
1855	5.0	6.6	–	–	–	–	–	–	–	–	–	–
1872	–	–	–	–	–	–	–	–	20.6	15.9	9.9	5.3
1873	2.0	2.3	5.7	13.3	17.6	19.3	25.0	26.3	21.6	15.3	8.4	5.3
1874	3.0	4.1	7.0	12.0	16.2	21.7	23.6	25.7	20.8	14.3	8.6	5.1
1875	2.0	1.8	8.7	11.8	16.7	20.6	25.4	24.7	21.0	14.6	8.7	3.8
1876	1.1	3.0	11.2	12.1	16.9	18.3	24.1	26.7	22.4	14.1	8.2	4.1
1877	2.0	2.7	5.6	13.3	16.1	21.8	26.1	25.3	20.6	14.9	8.7	5.1
1878	1.4	1.6	6.3	11.0	17.7	19.8	25.8	24.2	22.3	15.2	9.1	4.3

Appendix B2. Monthly mean temperatures in 1859–1874 for Yokohama/Yokosuka. The data are adjusted to a height of 38.3 m (the station height of Yokohama observatory II). The values for December 1862–November 1863, December 1865–November 1869 and April 1871–November 1873 are derived from the monthly-averaged values, so are the same for each of the months in question

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1859	–	–	–	–	–	–	–	–	–	–	–	6.2
1860	3.2	3.9	7.2	13.2	17.0	21.5	25.3	26.6	23.9	17.1	10.4	–
1861	–	–	–	–	–	–	–	–	–	–	–	–
1862	–	–	–	–	–	–	–	–	–	–	–	5.6
1863	4.5	4.5	8.2	12.1	16.8	19.9	23.6	24.9	20.8	15.8	10.4	6.6
1864	2.2	3.0	5.9	13.7	17.4	20.1	24.6	26.3	20.8	16.8	10.8	6.2
1865	4.4	6.5	7.7	14.2	17.9	20.9	22.0	26.4	21.9	15.3	10.1	5.6
1866	4.5	4.5	8.2	12.1	16.8	19.9	23.6	24.9	20.8	15.8	10.4	5.6
1867	4.5	4.5	8.2	12.1	16.8	19.9	23.6	24.9	20.8	15.8	10.4	5.6
1868	4.5	4.5	8.2	12.1	16.8	19.9	23.6	24.9	20.8	15.8	10.4	5.6
1869	4.5	4.5	8.2	12.1	16.8	19.9	23.6	24.9	20.8	15.8	10.4	5.5
1870	2.9	4.4	9.0	13.4	16.8	20.9	21.4	25.4	23.8	17.8	11.8	7.3
1871	3.7	3.2	7.5	14.2	18.6	21.3	25.4	26.8	22.5	18.2	13.0	7.9
1872	4.8	5.3	9.2	14.2	18.6	21.3	25.4	26.8	22.5	18.2	13.0	7.9
1873	4.8	5.3	9.2	14.2	18.6	21.3	25.4	26.8	22.5	18.2	13.0	3.1
1874	2.0	3.0	6.3	11.5	16.5	21.8	24.0	25.8	20.3	13.2	7.0	–

Appendix B3. Monthly mean temperatures in 1828–1833 and in 1869–1871 for Osaka. The data are adjusted to a height of 23.0 m (the station height of Osaka observatory IV). Uncertain values are italicized and the years are marked with an asterisk

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1828*	–	–	–	–	–	–	–	*27.2*	–	–	–	–
1829*	–	–	–	–	–	*20.9*	*25.9*	*26.6*	–	–	–	–
1830*	–	–	–	–	–	–	–	–	*22.0*	–	*10.3*	*5.4*
1831*	–	–	–	–	–	–	–	*26.6*	*25.1*	*19.0*	*12.5*	*7.3*
1832*	*6.4*	*6.9*	*8.9*	*14.9*	*18.8*	*22.6*	*26.9*	*28.8*	*24.1*	*18.8*	*13.3*	*10.4*
1833*	*5.3*	*5.7*	*8.8*	–	–	–	–	–	–	–	–	–
1869	–	–	–	–	–	–	–	24.8	22.9	17.8	12.1	7.9
1870	4.1	6.5	9.5	13.6	17.2	22.4	25.7	26.9	24.2	18.9	13.5	7.9
1871	4.1	–	–	–	–	–	–	–	–	–	–	–

Appendix B4. Monthly mean temperatures in 1869–1888 for Kobe. The data are adjusted to a height of 58.3 m (the station height of Kobe observatory)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1869	–	–	–	–	–	–	–	–	–	18.3	12.8	–
1870	4.1	4.4	8.7	14.3	16.6	21.5	26.4	26.6	23.7	–	14.3	10.5
1871	6.9	5.5	9.8	15.0	18.6	24.8	27.4	27.4	24.3	18.6	11.2	8.5
1872	–	–	–	–	–	–	–	–	–	–	–	–
1873	–	–	–	–	–	–	–	–	–	–	–	–
1874	–	–	–	–	–	–	–	–	–	–	–	–
1875	–	–	–	–	–	–	–	–	–	–	–	–
1876	4.6	5.5	8.2	12.9	18.5	20.4	26.5	28.6	23.5	16.8	10.3	6.6
1877	–	–	–	–	–	–	27.4	26.8	23.1	16.1	11.0	7.1
1878	3.8	4.0	7.6	13.7	18.1	22.6	26.1	27.6	25.1	18.3	11.7	6.4
1879	5.2	6.5	8.2	12.9	19.2	22.7	27.3	29.0	23.6	–	–	–
1880	3.7	7.2	8.4	12.7	18.0	21.1	26.5	26.4	23.7	17.4	10.4	4.7
1881	1.0	3.4	6.2	12.8	18.6	22.8	26.2	28.0	24.4	17.1	–	–
1882	–	–	–	12.9	17.4	20.4	25.2	25.5	22.2	17.4	10.8	4.8
1883	3.5	4.1	6.5	12.1	16.7	22.2	26.7	26.9	24.0	18.2	10.7	5.2
1884	3.5	3.3	6.3	12.2	16.5	21.7	25.0	25.4	23.5	16.2	8.5	4.2
1885	2.4	3.4	5.7	13.3	16.8	21.4	24.7	27.3	24.1	17.9	11.4	6.9
1886	3.1	2.3	8.1	13.5	17.3	22.0	26.5	27.1	24.3	18.8	11.9	6.2
1887	5.3	–	7.1	14.2	17.4	21.6	–	–	–	–	–	–
1888	–	–	–	–	–	–	27.1	28.1	23.6	17.4	13.9	–

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