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Reconstruction of historical pressure patterns over Japan using two-point pressure–temperature datasets since the nineteenth century

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Abstract The temperature and pressure differences between Tokyo and Nagasaki were used to reconstruct past climate conditions. January and July in each available year since the 1820s were classified into several types with characteristic sea level atmospheric pressure patterns. This results in 18 years of pre-1881 data and a continuous series thereafter. The series indicate that the warming after 1900 (after the end of the so-called Little Ice Age) and again after 1960 can at least partly be attributed to an increase in the frequency of warm circulation pattern types at the expense of cold types. The difference in nature of the shifts in circulation types that occurred in the late nineteenth century compared with that in the late twentieth centuries suggests that the mechanism behind the warming in the late nineteenth century differs from that in the late twentieth century.

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1 Introduction

Climate information from a more remote past is one of the keys to interpreting the present climate and to forecasting that of the future. The urgent need for more reliable data on pre-twentieth century climate variability has led to various attempts to reconstruct the past climate with the aid of early instrumental data, documentary data, and natural proxy indicators (e.g., Jones and Mann 2004). A primary problem associated with the early instrumental period is the poor coverage outside of Europe (e.g., Brazdil et al. 2005) in the period before the mid-nineteenth century.

Although Japan possesses a unique wealth of systematic documentary data allowing for climate reconstructions that goes centuries back (see Mikami 2008 and the references therein), no instrumental records preceding those from the official Japan Meteorological Agency (JMA) network, which was established in the 1870s, were thought to exist. In the 1990s however it turned out that pre-1878 instrumental data regarding Japanese climate were collected from 1819 onward by the Dutch at the settlement of Dejima (Nagasaki) (Können et al. 2003), with even an 1-year excursion into the eighteenth century (Demarée and Mikami 2000). These pre-JMA data, primarily kept in Dutch and German archives and libraries, cover a total of 27 years of (sub)daily temperature observations, 19 of them include pressure too. An extended search (Zaiki et al. 2006) revealed that nineteenth century instrumental

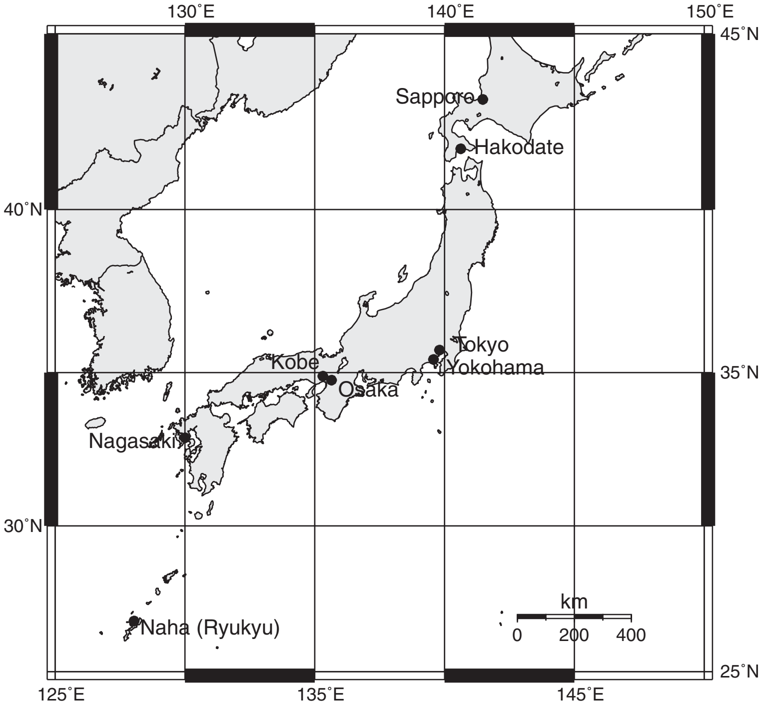

Fig. 1 Site locations of nineteenth century meteorological observations in Japan

climate data exist for a few other places in Japan, most notably Edo (Tokyo) and Osaka, as well as for Yokohama and Kobe (Fig. 1). Most of the pre-1860 data were retrieved from Japanese archives; post-1860 data were mainly found in the nineteenth century scientific journals. The pre-1878 extension of the Edo (Tokyo) series resulted in 21 years of (sub)daily observations of temperature and pressure, with a temporal coverage (Fig. 2) comparable to that of Dejima.

At the present, the recovered nineteenth century instrumental data from Dejima/ Nagasaki, Tokyo, Yokohama, Osaka, and Kobe are all available in a scientifically analyzable form (Zaiki et al. 2006). This offers a possibility for comparing with the conditions as reconstructed from historical records (Hirano and Mikami 2008). Documentary evidence suggests that a colder climate than now, the so-called Little Ice Age, which was predominant throughout Europe for about 300 years from 1550 to 1850 (Lamb 1977), did also manifest itself in Japan (Maejima and Tagami 1983; Hirano and Mikami 2008; Mikami 2008). The availability of the 1819–1878 temperature and atmospheric pressure observations taken at different locations makes it potentially possible to simultaneously analyze nineteenth century instrumental temperature and pressure time series for Japan and to reconstruct the spatial pressure patterns. However, so far there are only two locations where simultaneous data from the nineteenth century are typically available: Tokyo and Nagasaki. Therefore, the information on spatial pressure patterns over Japan is incomplete and restricted to western Japan (W-Japan) only.

In this paper, we describe an empirical study to reconstruct atmospheric pressure patterns in winter and summer in W-Japan from the available nineteenth century

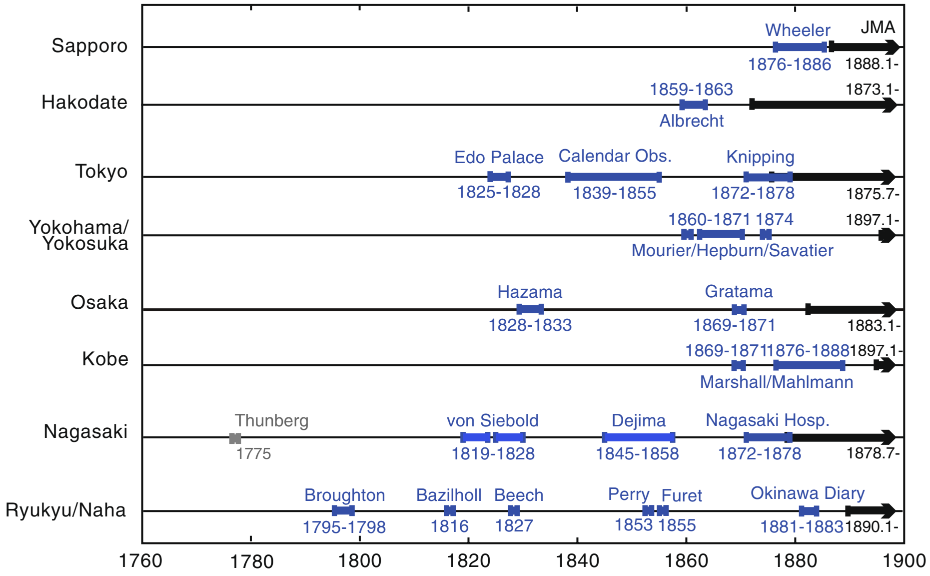

Fig. 2 The availability of pre-1900 instrumental meteorological data in Japan. *Blue* recovered data by Können et al. (2003), Zaiki et al. (2006) and thereafter. *Gray* recovered by Demarée and Mikami (2000). *Black* official meteorological stations

data. From this, we infer the weather conditions over western Japan in the nineteenth century and compare it with the twentieth century. The reconstructed circulations are analyzed to find the driving force behind the temperature changes in W-Japan occurring since the early nineteenth century.

2 Nineteenth century meteorological data in Japan

A comparison of Fig. 2 with our previous bar diagrams (Können et al. 2003; Zaiki et al. 2006) shows that the number of recovered pre-JMA nineteenth century meteorological series has steadily expanded. At present there are eight locations for which series of substantial length are known to exist. For the pre-1860 period, half of the stations were operated by Japanese observers and half by Europeans; during the period thereafter the observations were predominantly taken Europeans or Americans.

The available data were digitized; unusual units in it were deciphered and together with archaic units converted to modern units such as degrees Celsius and hPa (Können et al. 2003; Zaiki et al. 2006). The digitizing was performed on the highest available temporal resolution. (Sub)daily pressures were reduced to sea level, standard gravity, and to 0°C. In cases where barometer-attached thermometer readings were not available, the reported air temperatures were used instead to reduce the pressures to 0°C. The arithmetic means of the monthly temperature and pressure readings were transformed into real monthly averaged values by a month-depending correction factor to account for the uneven distribution of the observation hours through the day. This procedure was also applied to the JMA modern data where appropriate. A height correction for temperature was applied to outside temperature data throughout the period from the nineteenth century to the present. All outliers of daily averaged values in excess of 4 standard deviations were omitted. Finally, the monthly, seasonal and annual temperature and pressure series all went through the three location-specific statistical homogeneity tests recommended by Wijngaard et al. (2003); no major discontinuity in any of the data series was found.

For a first analysis, the temperature data from the 5 stations between Nagasaki and Tokyo were condensed into an annual and seasonal temperature time series that is representative for the W-Japan area (West Japan Temperature; WJT), running from 1820 till 2000 (Zaiki et al. 2006). This series was calculated with the same methodology as was used for the Central England temperature series by the UK Meteorological Office (Manley 1974; Parker et al. 1992). The WJT database is available for public and scientific use at the website of the Climatic Research Unit, University of East Anglia (http://www.cru.uea.ac.uk/cru/data/). The WJT series quantitatively confirmed the documentary evidence (Maejima and Tagami 1983; Hirano and Mikami 2008; Mikami 2008) about the cold nature of the nineteenth century with respect to present (Zaiki et al. 2006). Now, we take a next step in the analysis of the nineteenth century Japanese climate by linking reconstructed circulation patterns to the observed changes during the past two centuries. This is done by using the monthly temperature and pressure data from Tokyo and Nagasaki, which are the two data series that are relatively continuous and largely simultaneous throughout the period.

3 Data and methods

For modern times, monthly temperature and pressure data for Tokyo and Nagasaki from the JMA, the so-called SMP (Surface Monthly Processing) data, were used. The SMP data begins from 1876 for Tokyo, and from 1878 for Nagasaki. For the pre-JMA observation period, we used monthly temperature and pressure values for Tokyo and Nagasaki, as recovered during our previous studies (Können et al. 2003; Zaiki et al. 2006), for all months when both stations recorded data. This restricts the pre-JMA period to 16 years: 1827–1828, 1845–1848, 1852–1855, and 1873–1878. For pressure pattern reconstruction, the 1958–2002 ERA-40 (ECMWF Re-Analysis) sea level pressure (SLP: 2.5° × 2.5° grid) data were used to produce mean pressure maps as well as pressure anomaly maps. The 45-year period covered by ERA-40 (1958–2002) also acted as a reference period for temperature anomaly calculations.

The method consists of four steps. First, every January and July, as representative of winter and summer, was characterized by a combination of 5 indices derived from the temperature (T) and pressure (P) values for Tokyo ($_\mathrm{T}$) and Nagasaki ($_\mathrm{N}$). All indices refer to anomalies from the reference period (1958–2002); hence they refer to values with respect to the local climatology of the station. All indices could take only one of two values:

1. $P_\mathrm{N} - P_\mathrm{T}$, the difference in pressure anomaly between Nagasaki and Tokyo. If $P_\mathrm{N} - P_\mathrm{T} > 0$, there is a positive anomaly in the N–S component of the geostrophic flow pattern and the index is given the value N(orth). If $P_\mathrm{N} - P_\mathrm{T} \leq 0$ then the value of the index is S(outh).
2. $T_\mathrm{N} - T_\mathrm{T}$, the difference in temperature anomaly between Nagasaki and Tokyo. Given the climatology of Japan, this parameter can be regarded as a substitute for the E–W component of the geostrophic flow. If $T_\mathrm{N} - T_\mathrm{T} > 0$, then the Nagasaki–Tokyo temperature gradient is increased. This situation automatically implies, for January as well for July, an increased E-W flow. If $T_\mathrm{N} - T_\mathrm{T} > 0$, then the index is assigned the value I(ncreased). If $T_\mathrm{N} - T_\mathrm{T} \leq 0$, then the index value is D(ecreased), which automatically implies a weakened E-W flow.
3. $(P_\mathrm{N} + P_\mathrm{T})/2$, the averaged pressure anomaly for Nagasaki and Tokyo. This parameter is associated with the cyclonality of the flow over W-Japan. If $P_\mathrm{N} + P_\mathrm{T} > 0$, then the index is H(igh). Otherwise, the index is L(ow).
4. T_N, the temperature anomaly for Nagasaki. If $T_\mathrm{N} > 0$, then the index is w(arm), otherwise it is c(old).
5. T_T, the temperature anomaly for Tokyo. If $T_\mathrm{T} > 0$, then the index is w(arm), otherwise it is c(old).

Each January and July of the reference period was labeled with a combination of these 5 indices. For example "NDHcc," refers to the Boolean values of the elements in the meteorological state vector ($P_\mathrm{N} - P_\mathrm{T}$, $T_\mathrm{N} - T_\mathrm{T}$, $P_\mathrm{N} + P_\mathrm{T}$, T_N, T_T). The notation is such that the elements that determine the characteristics of

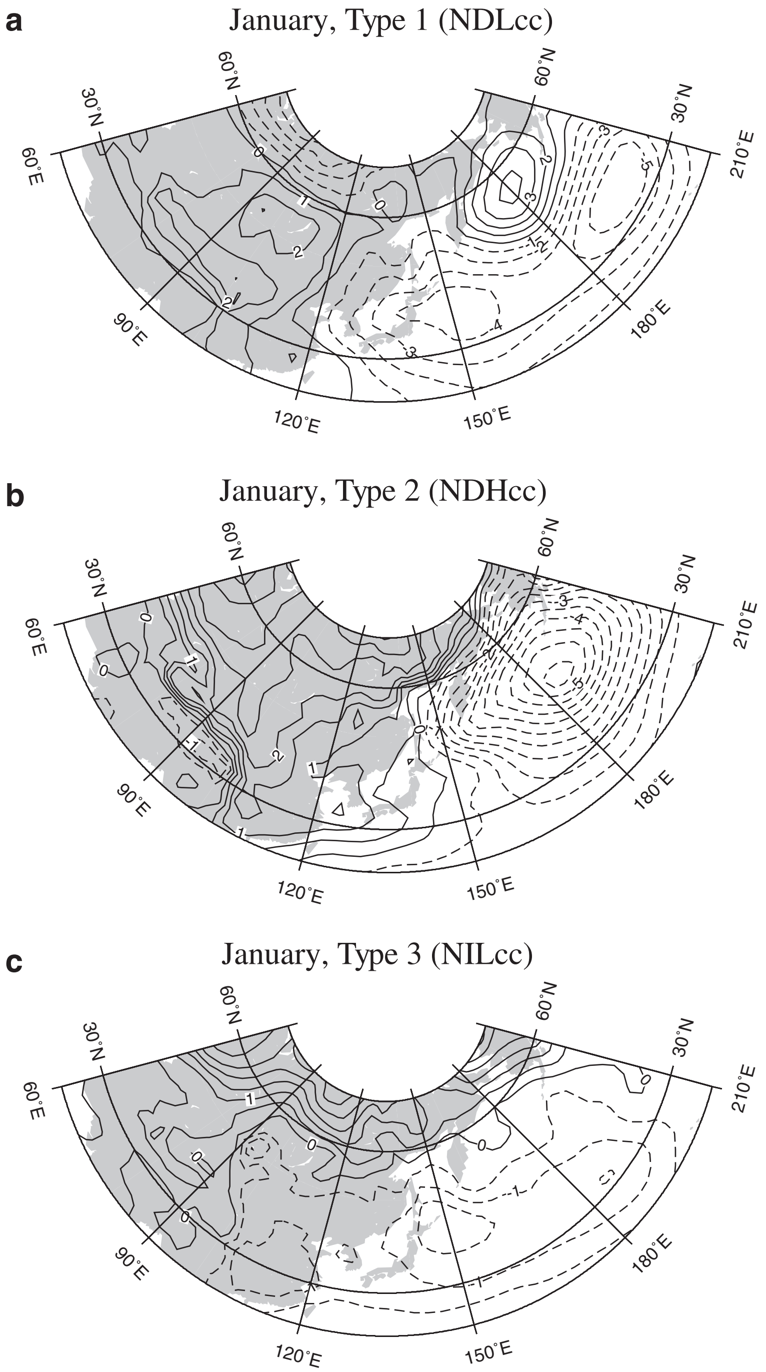

Fig. 3 Maps of mean sea level pressure (SLP) anomalies for each January weather type. Positive anomalies (in hPa) are shown by *solid lines* and negative anomalies are shown by *dashed lines*

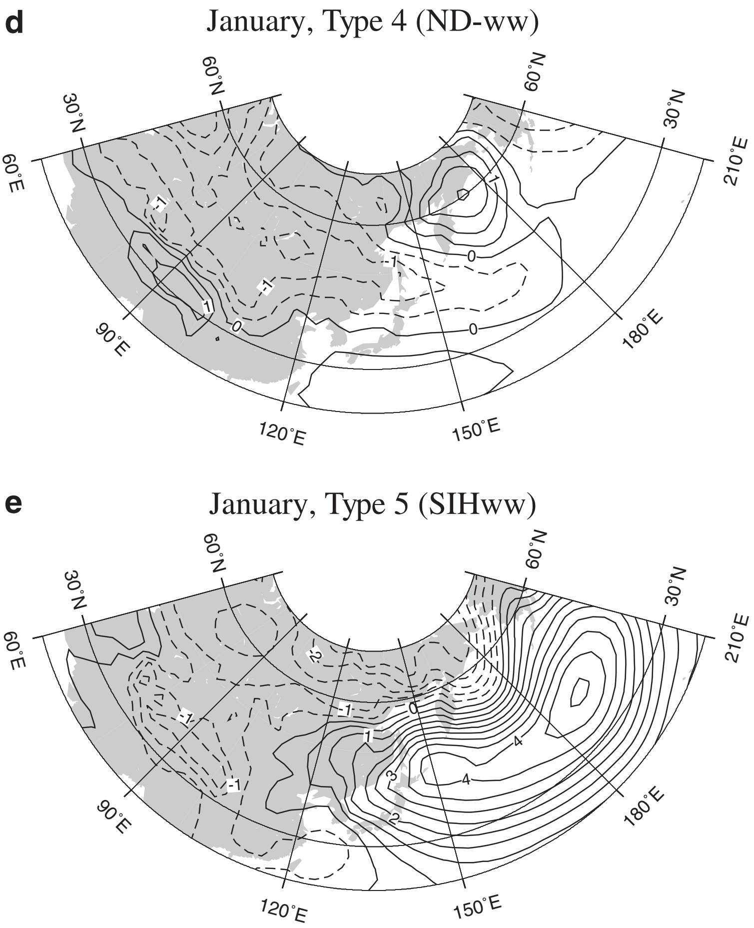

Fig. 3 (continued)

atmospheric flow (including $T_N - T_T$) are denoted by uppercase letters and those determining the temperature anomalies are in lowercase. If interpreted in terms of atmospheric circulation, a combination of "NDL" in the first three characters refers to a strengthened north flow (N), a negative anomaly in the E-W component (D), and cyclonality over W-Japan (L); a combination "SIH" indicates weakened north flow (S), a positive anomaly in the E-W component (I), and anti-cyclonality over W-Japan (H).

Second, we categorized every January and July, respectively, of the reference period years (1958–2002) into several types according to similarity of weather patterns as expressed by the 5 indices. Following the grouping of Januarys and Julys with similar 5-index weather types, each group was given an overall characterization using the 5 indices. If at least 60% of the members within groups have the same index value, then that index value was considered to be representative of the entire group; if the predominant value of the index applied to fewer than 60% of the members, then the group was considered to be too insensitive of that element to justify a splitting

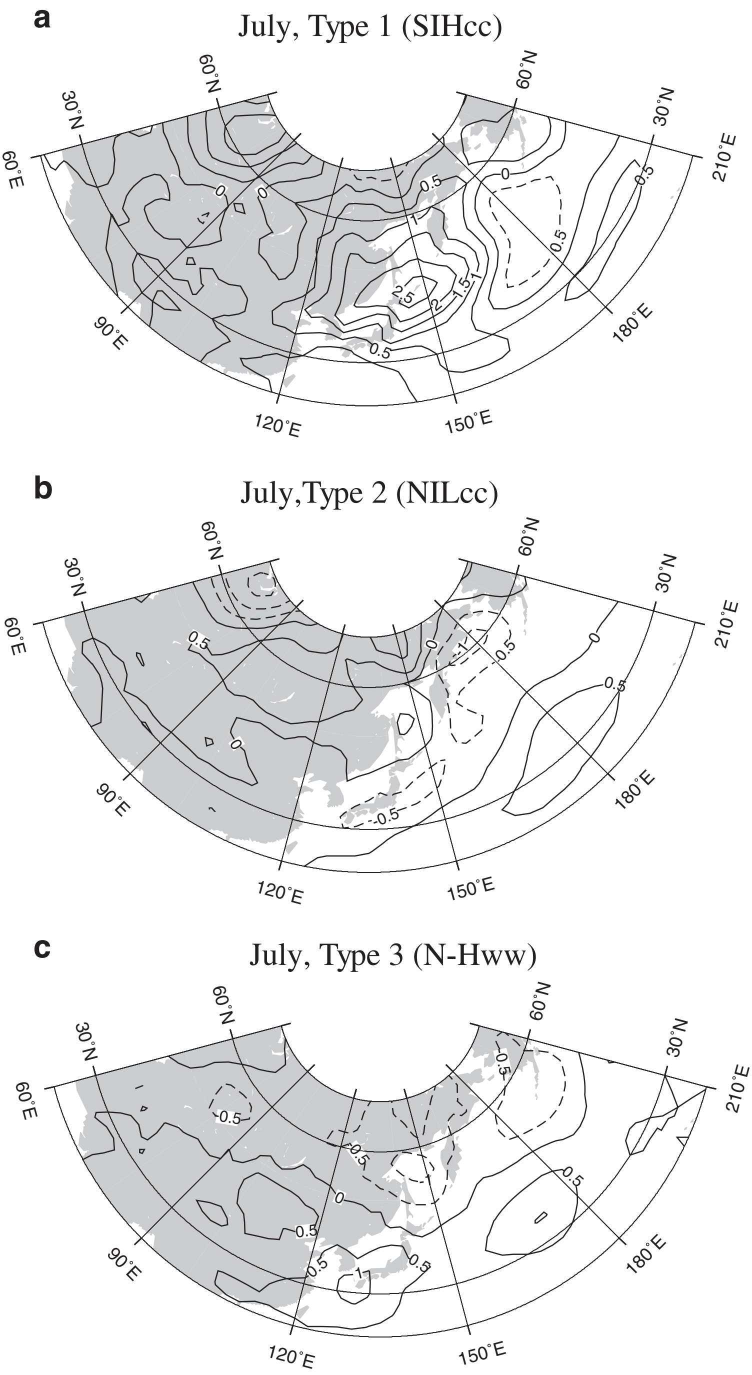

Fig. 4 Maps of mean sea level pressure (SLP) anomaly for each July weather type. Positive anomalies (in hPa) are shown by *solid lines* and negative anomalies are shown by *dashed lines*

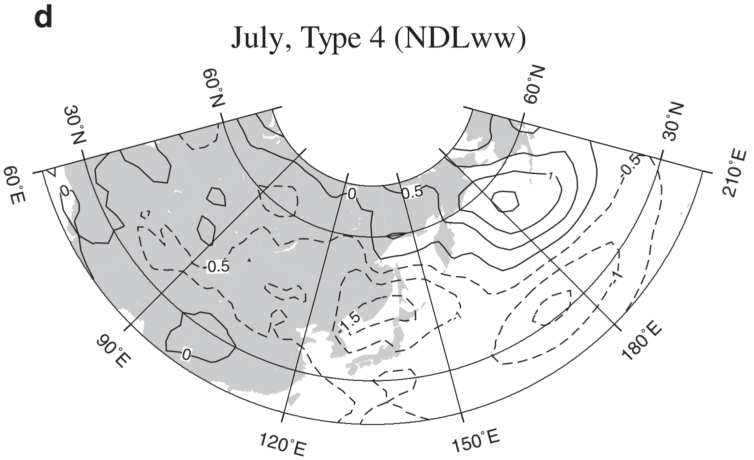

Fig. 4 (continued)

into two subgroups. In these cases, the value of that index for the group was denoted by a bar.

The strong correlations between the indices in the Japanese climate, together with the application of the 60% threshold, prevent many of the imaginable index combinations to materialize: the process identified 5 weather types for January and 4 types for July.

Third, mean anomaly maps of SLP with respect to the reference period (1958–2002) were drawn for each January (Fig. 3) and July (Fig. 4) weather type.

Fourth, all Januarys and Julys in the data set of 1827–1957 and the available years after 2002 were characterized by the values of the 5 indices. To determine the index values, the anomalies of the 1827–1957 and 2003–2007 data were calculated with respect to the 1958–2002 reference period. If the meteorological state vector of a given month corresponded to that of a certain type, then that month was assigned to that type. If the meteorological state vector of a given month did not correspond to any of the categorized types, then within-type meteorological state vectors were considered and the assignment was made if four of five indices of a given month matched with those of one of the types. In cases the latter procedure was still not decisive, then the assignment was made on basis of a match of three out of the five indices. Using this procedure, every available month in the 1827–2007 period turned out to match with one of the 9 types identified via the 1958–2002 reference dataset, and hence the weather pattern for each month could be approximated from the mean anomaly pressure patterns of SLP derived from the analyses of the years 1958–2002.

4 Results

4.1 Classifying January and July of the years

January and July in each year were classified based on combinations of 5 indices, such as “NDHcc”. The results produced five groups or types of Januarys and four types of Julys. For the reference period 1958–2002 and the available years thereafter, the following types were identified for January:

Type 1 (NDLcc, 11.1% of Januarys from 1958–2002): 1962, 1963, 1971, 1981, 1986, 2005.
Type 2 (NDHcc, 15.5%): 1961, 1967, 1970, 1976, 1977, 1984, 1985, 2003.
Type 3 (NILcc, 20.2%): 1959, 1960, 1965, 1966, 1974, 1975, 1978, 1980, 2001.
Type 4 (ND-ww, 26.7%): 1958, 1968, 1982, 1983, 1987, 1990, 1991, 1995, 1996, 1997, 1999, 2002.
Type 5 (SIHww, 26.7%): 1964, 1969, 1972, 1973, 1979, 1988, 1989, 1992, 1993, 1994, 1998, 2000, 2004, 2006, 2007.

The following types were identified for July:

Type 1 (SIHcc, 17.8% of Julys from 1958–2002): 1962, 1969, 1974, 1976, 1982, 1988, 1989, 1993, 2003.
Type 2 (NILcc, 26.7%): 1958, 1965, 1966, 1968, 1970, 1972, 1979, 1980, 1983, 1986, 1998, 1999, 2005, 2006.
Type 3 (N-Hww, 28.8%): 1960, 1963, 1964, 1973, 1975, 1977, 1978, 1981, 1990, 1992, 1995, 1996, 2001, 2004.
Type 4 (NDLww, 26.7%): 1959, 1961, 1967, 1971, 1984, 1985, 1987, 1991, 1994, 1997, 2000, 2002, 2007.

The numbering of the weather types is chosen to be in the order of ascending temperature: Type 1 is the coldest one, Type 2 the second coldest, etc. Note that no type arose for which the two temperature anomaly indices T_N and T_T are mutually different. Table 1 summarizes the climatological properties of the 9 weather types, as calculated from the reference period 1958–2002.

On the basis of these groupings, characteristic mean SLP anomaly maps were drawn for each type (Figs. 3a–e and 4a–d). The reference period for the mean SLP maps is 1958–2002. The years prior to 1958 were assigned to one of the types based on their meteorological state vector in the way described in Section 3. The result is shown in Table 2.

Table 1 Climatological characteristics of the January and July sea level pressure (SLP) patterns, as derived for the 1958–2002 reference period

January					July				
	Boolean notation	Nature	Temperature anomaly			Boolean notation	Nature	Temperature anomaly	
			Nagasaki	Tokyo				Nagasaki	Tokyo
Type 1	NDLcc	cold	−1.81	−1.11	Type 1	SIHcc	cold	−0.93	−1.61
Type 2	NDHcc	cold	−1.68	−0.93	Type 2	NILcc	cold	−0.32	−0.57
Type 3	NILcc	cold	−0.22	−0.49	Type 3	N-Hww	warm	0.68	0.92
Type 4	ND-ww	warm	0.43	0.86	Type 4	NDLww	warm	0.71	1.56
Type 5	SIHww	warm	1.51	1.22					

Table 2 Types of SLP patterns in January and July for 1827–1957, which is the period that precedes the reference period

	January	July
1827	3	–
1828	5	1
1845	5	3
1846	2	1
1847	2	1
1848	2	3
1852	3	3
1853	3	3
1854	2	4
1855	1	–
1873	3	1
1874	5	1
1875	3	4
1876	5	1
1877	5	1
1878	2	3
1879	5	3
1880	5	2
1881	3	1
1882	5	1
1883	5	1
1884	5	1
1885	5	1
1886	3	3
1887	5	1
1888	3	1
1889	2	1
1890	5	1
1891	3	2
1892	5	3
1893	3	3
1894	3	3
1895	2	2
1896	3	2
1897	5	1
1898	5	3
1899	2	2
1900	5	2
1901	5	2
1902	5	2
1903	5	3
1904	2	1
1905	3	1
1906	5	2
1907	5	2
1908	5	2
1909	5	1
1910	3	2
1911	5	3
1912	2	2
1913	5	2

Table 2 (continued)

	January	July
1914	5	4
1915	5	1
1916	5	1
1917	3	3
1918	3	2
1919	5	1
1920	3	3
1921	5	1
1922	5	1
1923	5	3
1924	5	3
1925	3	1
1926	2	1
1927	2	3
1928	2	1
1929	2	3
1930	5	4
1931	5	2
1932	5	3
1933	2	3
1934	2	3
1935	3	1
1936	1	3
1937	5	1
1938	2	1
1939	2	3
1940	3	3
1941	3	2
1942	3	3
1943	2	1
1944	5	3
1945	3	2
1946	5	4
1947	5	3
1948	5	3
1949	3	1
1950	3	2
1951	5	1
1952	5	2
1953	3	1
1954	5	2
1955	2	4
1956	1	3
1957	5	2

See Section 4.2 and Table 1 for an explanation of each SLP type. Mean SLP anomaly maps for these types are presented in Figs. 3 and 4

4.2 Characteristics of January and July weather types

4.2.1 January types

Type 1 (NDLcc) The January Type 1 SLP anomaly map shows an enhanced positive-negative pressure contrast between Siberia and the North Pacific region (Fig. 3a). The accompanying southward advancement of the Aleutian Low results in the development of a cold trough over Japan. This pattern leads to very cold and snowy winters. Virtually all Type-1 winters are documented as abnormally severe. The winter of 1963 was a very snowy, in particular in the Hokuriku region (along the Sea of Japan), because of a stagnation of deep low-pressure troughs over Japan (Japan Meteorological Agency 2008; Yoshino and Fukuoka 2003). The year 1981 was reported as the coldest and snowiest winter in the whole country since the year 1963 (Aoki 1989; Japan Meteorological Agency 2008). The year 2005 saw the deepest snow depth on record in the region adjacent to the Sea of Japan (Japan Meteorological Agency 2008). The Type-1 winters are throughout cold (Table 1) and are characterized by heavy snowfall.

Type 2 (NDHcc) The January Type 2 SLP anomaly map (Fig. 3b) shows a positive pressure anomaly over Siberia and a negative one over the Aleutian Islands. This indicates a typical strong winter pressure pattern, with a strongly developed Siberian High and Aleutian Low. The strengthened pressure gradient generates a strong winter monsoon. The Type-2 winters are about as cold as those of Type 1 (Table 1), but do not share its snowy characteristics.

Type 3 (NILcc) The January Type 3 SLP anomaly map (Fig. 3c) shows a negative pressure anomaly extending from mid-Siberia to the centre of the North Pacific. The negative anomaly over Japan implies that the Aleutian Low develops stronger and more south-westward than the normal. On the other hand the negative anomaly over Siberia implies a weaker Siberian High. The Type-3 winters tend to be colder than normal (Table 1) and are characterized by normal amounts of precipitation.

Type 4 (ND-ww) The January Type 4 anomaly SLP map (Fig. 3d) shows a negative pressure anomaly over Siberia and a positive one over the Aleutian Islands. This implies a weakening of the Siberian High and a stronger Aleutian Low than normal. This results in a weakened winter pattern with a smaller atmospheric pressure gradient over Japan. The Type-4 winters tend to be warmer than normal (Table 1) and are in the region adjacent on the Sea of Japan characterized by less snow than normal.

Type 5 (SIHww) The January Type 5 SLP anomaly map (Fig. 3e) shows a positive pressure anomaly over the North Pacific including Aleutian Islands and a negative one over Siberia. This is basically the reversion of the Type-1 anomaly pattern. The Type-5 winters tend to be very mild (Table 1) and are in the region adjacent on the Sea of Japan characterized by little snow.

4.2.2 July types

Type 1 (SIHcc) The July Type 1 SLP anomaly map (Fig. 4a) shows a strong positive pressure anomaly centered over northern Japan. This points to a strongly developed and persistent Okhotsk High. The presence of the Okhotsk High causes cold air to flow from the Arctic to Japan. The Type-1 summers are cool (Table 1) and are characterized by a prolonged rainy season.

Type 2 (NILcc) The July Type 2 SLP anomaly map (Fig. 4b) shows a saddle northeast of Japan with its negative pressure anomaly branch extending over Japan.

This negative anomaly implies that the North Pacific High does not developed westward where Japan locates. This indicates a stagnation of the advection of hot and humid air by a south-easterly or southerly airflow. The Type 2 summers are cool (Table 1) with a normal rainy season.

Type 3 (N-Hww) The July Type 3 SLP anomaly map (Fig. 4c) shows a belt of negative pressure anomaly north of Japan and a belt of positive anomaly south of it with a maximum over SW-Japan (Kyushu). This implies a westward extension of the North Pacific High that mainly affects W-Japan. The hot air flow generated by this development reaches into W-Japan, but not to Hokkaido (N-Japan). This pressure pattern is often called "South-High, North-Low" which generates a distinct South-North pressure/temperature contrast in Japan (Kimura 2004). The Type-3 summers tend for W-Japan to be warm (Table 1) and are characterized by a shortened rainy season.

Type 4 (NDLww) The July Type 4 SLP anomaly map (Fig. 4d) shows an area of negative pressure anomaly that extends over entire Japan. This feature implies a weakened Okhotsk High. In that situation cold air from the Arctic region is prevented to flow to Japan. The Type-4 summers tend to be warm (Table 1) and are characterized by a shortened rainy season.

5 Discussion

5.1 Time series of weather types

Figure 5 shows the frequency distributions of the January and July types as a function of time. The six post-1880 bars in the figure cover intervals of 20 years each. The first bar however, covering 1827–1880, consists of only 18 years spread over a 54-year interval; these years have its centre point at 1859. The figure is constructed to observe any evolving patterns in the frequency distributions. Three main periods distinguished in Fig. 5 are: the nineteenth century (I), the twentieth century up to 1960 (II), and the period of warming thereafter (III).

In the frequency distribution of January types, the most striking feature is the complete absence of Type 4 before 1940. This type emerges late in Period II and Period III, and is accompanied by a vanishing frequency of Type 3. A potential explanation for this change in circulation type may be the accelerated urbanization of Tokyo, which leads to a tendency for the second index value to change from 'I' to 'D', hence negating its correlation with the E-W flow, and to a tendency for the fourth index to change from 'c' to 'w'. Therefore, the recent warming can be at least in part be attributed to the change in circulation involving the disappearance of the cold Type 3 and the appearance of a "new" Type 4, which is a warm January type whose weather characteristics resembles that of the cold Type 2.

Comparing January weather types during Periods I and II, when a transition from negative to positive temperature trends occurred (Zaiki et al. 2006), the cold Types 1, 2, and 3 decrease in frequency, and the warm Type 5 increases in frequency during Period I, and then this pattern reverses during Period II until the appearance of Type 4 at the end of Period II.

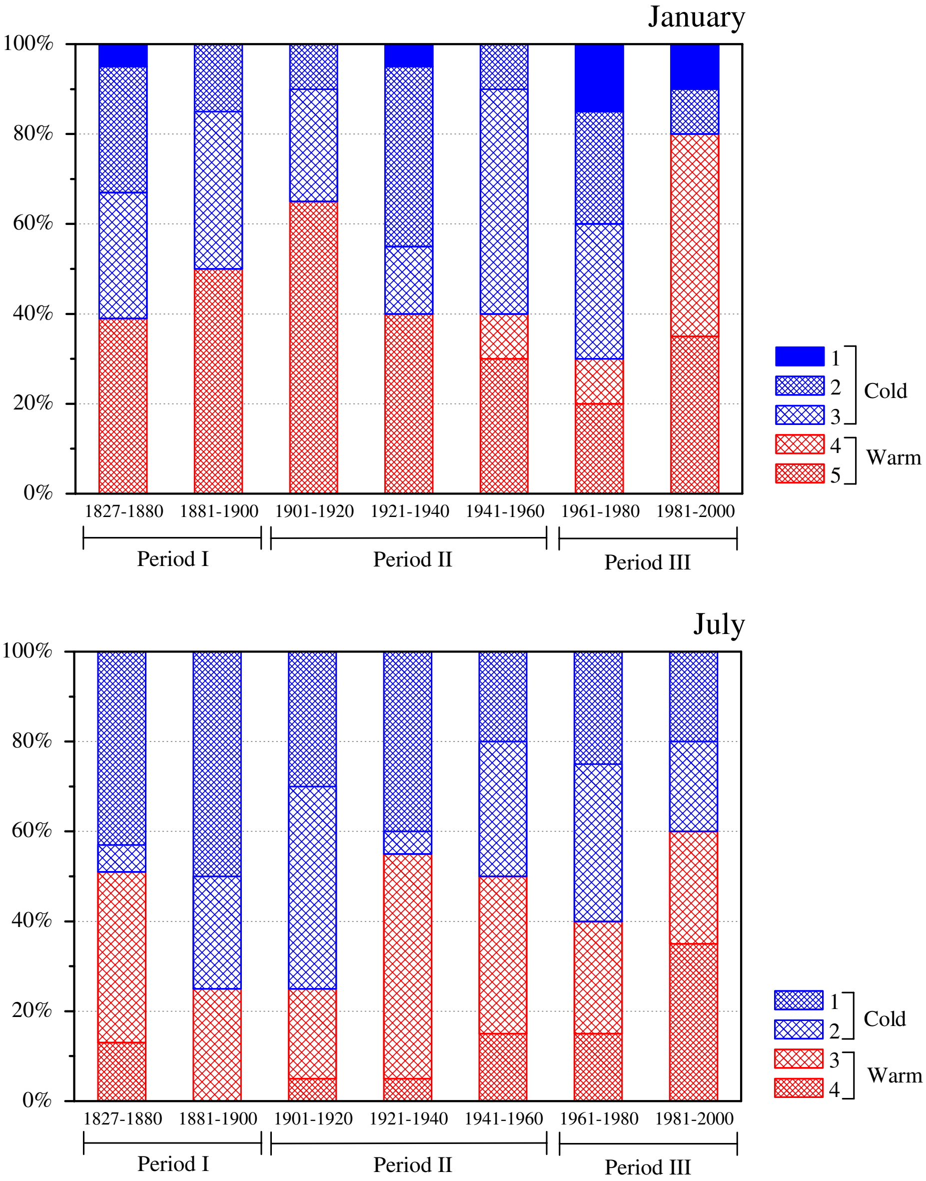

Fig. 5 Time series of relative frequencies of the January (*above*) and July (*below*) SLP patterns 1827–2000. The periods distinguish: the nineteenth century (I); pre-1960 in the twentieth century (II); the period of warming thereafter (III). The warm circulations (*red*) are Types 4, 5 for January and Types 3, 4 for July; the cold circulations (*blue*) are Types 1–3 for January and Types 3, 4 for July. See Table 1 for a climatological summary of the Types

In July, the most striking feature is the shift in frequency between Types 1 and 4 before and after the period 1941–1960, which represents the transitional years between Periods II and III. Type 1, which is cool, frequently occurred during Period

I and until 1940 in Period II, but became less frequent from 1941 onward. On the other hand, the frequency of Type 4 Julys, which are warm, increased in Period III. As suggested for January, the change in circulation types might partly reflect the accelerated urbanization of Tokyo, leading to a change of the second index from I to D, hence negating its correlation with the E-W flow. However, a shift from Type 1 (SIHcc) to Type 4 (NDLww) cannot be fully explained by an urbanization-forced change of index I in D and of index c in w. Therefore, the recent warming suggests a change in circulation patterns, with a decreased frequency of the cool Type 1 and an increased frequency of the warm Type 4.

During 1827–1880, as well as during 1901–2000, the occurrence of the cool Types 1 and 2 is balanced by the occurrence of the warm Types 3 and 4. Only during the transition from Periods I to II, the cool types appear with a frequency greater than 70%. During Period II, the warm types increase in frequency reaching the level of Period III. This warming again is attributable at least in part to a change in circulation patterns.

The instrument-based WJT series (Zaiki et al. 2006) shows that the warming in the late nineteenth century/early twentieth century (Period I to II) as well as the warming in the late twentieth century (Period III) originated more from winters than from summers Fig. 5 shows that for both seasons the circulation change between Periods I and II differs from that observed in Period III, most strikingly in winter. This suggests that the mechanisms causing these warmings are different.

5.2 Comparison of reconstructed patterns with historical documents

We compared the nineteenth century climate conditions estimated by the procedure described herein with the conditions as reconstructed from historical records. Documentary evidence suggests a colder climate than now prevailed until 1850, not only in Europe (Lamb 1977) but also in Japan (Maejima and Tagami 1983; Hirano and Mikami 2008; Mikami 2008).

Focusing on the 1827–1880 period in Fig. 5, which consists of the first 18 years for which SPL patterns could be reconstructed, one observes that the cold types (Type 1, 2 and 3) were predominant in January (61%), whereas July types were evenly divided between warm and cold. This finding agrees with the results of Maejima and Tagami (1983), which is based on historical records and report very cold winter conditions from 1821–1880. It is also consistent with the instrumental WJT series (Zaiki et al. 2006), which indicate lower winter temperatures and the occurrence of very severe winters in that period. Moreover, our 1827–1880 reconstructions includes the exceptionally severe (Maejima and Tagami 1983; Können et al. 2003; Zaiki et al. 2006) winter of 1855, which is by our reconstruction indeed characterized as having a Type 1 January (Table 2). In contrast to the cold winters, summers during this period were not unusual, although cool summers may have occurred intermittently.

Mizukoshi (1993) reports that there were frequent severe winters near the beginning of the nineteenth century according to historical records. Hirano and Mikami (2008) reaches the same conclusion. Maejima and Tagami (1986) provides results that there were continuous cold winters in the first half of nineteenth century and relatively equal occurrences of each summer type (warmer and cooler) throughout the nineteenth century. In the second 20 years of Period I (1881–1900), cool July types (Types 1 and 2) were predominant (frequency >70%) and Januarys were evenly divided between warm and cool types.

Our reconstruction of weather conditions over W-Japan indicate that the frequencies of cold winter types were high during the period from 1827–1880, and those of cool summer types were relatively high from 1881–1900. We emphasize that our 1827–1880 data set consists of 18 years only, which need not to be representative for the entire 54-year period. Nevertheless, this finding is consistent with the results from other sources, as these weather features are also evident in reconstructions based on historical records.

6 Conclusions

This study represents an application of limited and fragmented meteorological time series data from the nineteenth century when no other meteorological measurements were believed to be available. It is a follow-up work to the construction of a database of instrumental meteorological data from the nineteenth century and to our subsequent condensation of the recovered temperature data 1820–present in a single series representative for West Japan, the so-called WJT series.

The temperature and pressure differences between Tokyo and Nagasaki were used to reconstruct past climate conditions. January and July for each available year since the 1820s were categorized into several types on the basis of characteristic sea level pressure patterns. This results in 18 years in the period 1827–1880 with reconstructed pressure patterns; after 1872 the series is uninterrupted. Our findings indicate that the warming after 1900 (after the end of the so-called Little Ice Age) and again after 1960 were at least partly attributable to an increase in the frequency of warm circulation types at the expense of cold types. The most striking shift occurs for the winter, were in the second half of the twentieth century a warm circulation type emerges that did not had manifested itself before. Such an effect was not observed during the warming in the late nineteenth century. The different nature of the shift in circulation types in the late nineteenth and twentieth centuries, respectively, suggests that the mechanisms behind these warmings differ.

It is likely that there are more historical meteorological data to be recovered in Japan and in other East Asian countries. If more supporting instrumental data from the pre-nineteenth century are found, they will provide information about the past climate over East Asia with higher resolution and more reliability.

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