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A compiled soil respiration dataset at different time scales for forest ecosystems across China from 2000 to 2018

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Abstract. China's forests rank fifth in the world by area, covering a broad climatic gradient from cold-temperate to tropical zones, and play a key role in the global carbon cycle. Studies of forest soil respiration (R_s) have increased rapidly in China over the last two decades, but the resulting R_s data need to be summarized. Here, we compile a comprehensive dataset of R_s in China's undisturbed forest ecosystems from the literature published up to 31 December 2018, including monthly R_s and the concurrently measured soil temperature ($N = 8317$), mean monthly R_s ($N = 5003$), and annual R_s ($N = 634$). Detailed plot information was also recorded, such as geographical location, climate factors, stand characteristics, and measurement description. We examine some aspects of the dataset – R_s equations fitted with soil temperature, temperature sensitivity (Q_{10}), monthly variations, and annual effluxes in cold-temperate, temperate, subtropical, and tropical zones. We hope the dataset will be used by the science community to provide a better understanding of the carbon cycle in China's forest ecosystems and reduce uncertainty in evaluating of carbon budget at a large scale. The dataset is publicly available at https://doi.org/10.1594/PANGAEA.943617 (Sun et al., 2022).

1 Introduction

Soil respiration (R_s) refers to the total amount of CO_2 released by undisturbed soil, including autotrophic respiration and heterotrophic respiration, the former from plant roots and their microbial symbionts, and the latter from microorganisms decomposing litter and soil organic matter. As the second-largest terrestrial carbon flux, the recent estimations of global annual R_s (80–98 $\mathrm{Pg\,C\,yr^{-1}}$) are over 10 % of the atmospheric carbon pool (750 Pg C) (Bond-Lamberty and Thomson, 2010b; Hashimoto et al., 2015; Raich et al., 2002; Warner et al., 2019); thus, accelerating soil respiration rates with climate warming have a strong potential to influence atmospheric CO_2 levels. It is therefore important to understand better soil respiration dynamics and their response to climate changes.

Forest area in China ranks fifth in the world (FAO, 2020) and covers a broad climatic gradient, including cold-temperate, temperate, subtropical, and tropical zones. In China, most R_s measurements began only after 2001 (Chen et al., 2010), but have rapidly increased during the last 20 years (Jian et al., 2020). Several studies have summarized annual R_s in China's forest ecosystems, but with small samples (e.g., $N = 50$ in Zheng et al., 2010; $N = 62$ in Chen et al., 2008; $N = 120$ in Zhan et al., 2012; $N = 139$ in Song et al., 2014). Yu et al. (2010) established a geostatistical model with a total of 390 monthly R_s data from different ecosystems in China. With 1782 monthly R_s in forest ecosystems across China, Jian et al. (2020) analyzed the spatial patterns and temporal trends from 1961 to 2014. However, numerous R_s data are still unexploited, because they were only displayed in the form of monthly dynamics in the figures of the original papers. R_s data at a subannual timescales are important for upscaling global R_s (Jian et al., 2018), which may yield different conclusions and deserve further exploration (Huang et al., 2020).

The lack of large-scale and observation-driven R_s data is a main constraining factor in quantifying regional- to global-scale carbon budgets (Bond-Lamberty and Thomson, 2010a; Rayner et al., 2005). R_s data and concurrently measured temperature thus provide not only a solid base for understanding the critical factors influencing R_s, but also the opportunity for better simulation of R_s at a large scale. We attempted to compile a complete forest R_s dataset at different temporal scales in China, and to analyze temperature sensitivity (Q_{10}) as well as monthly and annual R_s in cold-temperate, temperate, subtropical, and tropical zones.

2 Data and methods

2.1 Data sources

The terms "soil respiration", "soil carbon (or CO_2) efflux", or "soil carbon (or CO_2) emission" were searched in publications before 2018 in the China Knowledge Resource Integrated Database (http://www.cnki.net/, last access: 27 March 2021), China Science and Technology Journal Database (http://www.cqvip.com, last access: 27 March 2021), ScienceDirect (http://www.sciencedirect.com/, last access: 8 June 2020), ISI Web of Science (http://isiknowledge.com/, last access: 8 June 2020), and Springer Link (http://link.springer.com/, last access: 8 June 2020). Means, minimums, and maximums of soil respiration during the observation periods were usually given in these published studies, and monthly patterns of soil respiration rates with the corresponding temperature were frequently shown in figures. WEBPLOTDIGITIZER, a graphic digitizing software, was used to acquire data from figures when values were not reported in the text (Burda et al., 2017).

2.2 Data collection criteria

The following criteria were used to ensure data consistency and accuracy: (i) R_s was measured in the field without obvious disturbances or manipulation experiments, e.g., fire, cutting, nitrogen addition treatments, etc. (ii) Forested swamps and commercial plantations (e.g., orchard, rubber, etc.) were not examined. (iii) R_s was measured either by static chamber and gas chromatography (GC) or by dynamic chamber and infrared gas analyzers (IRGA, model Li-6400, Li-8100, Li-8150 (LI-COR Inc., Lincoln, Nebraska, USA)), which are the most popular methods and provide methodological consistency (Sun et al., 2020; Wang et al., 2011; Yang et al., 2018; Zheng et al., 2010).

Based on these criteria, a total of 10 288 monthly soil respiration data and 634 annual soil respiration data were assembled from 568 publications. Moreover, the related information was recorded, including geographical location (province, study site, latitude, longitude and elevation), climate (mean annual temperature and mean annual precipitation), stand description (forest type, origin, age, density, mean tree height and diameter at breast height), and measurement regime (method, time, frequency, collar area, height and numbers) (Table 1). There were 155 study sites from 28 provinces in China (18.61–52.86° N, 84.91–129.08° E, 7–4200 m) (Fig. 1). This forest region encompasses a large gradient of climate regimes, with mean annual temperature ranging from −5.4 to 23.8 °C and mean annual precipitation ranging from 105 to 3000 mm. The observation years were from 2000 to 2018.

2.3 Data verification

Soil temperature as a main influencing factor was usually concurrently measured with R_s. Monthly dynamics of R_s and soil temperature at 5 cm depth (T_5) and/or 10 cm depth (T_{10}) were shown with figures in many studies in the literature. In this study, most of the R_s data (∼ 82 %) and the concurrent T_5 and/or T_{10} were extracted with WEBPLOTDIGITIZER, while others (e.g., minimum, maximum) were given directly in the original papers. To verify the accuracy of the digital software, the means (R_s, T_5, T_{10}) averaged from the extracted data were compared with the corresponding means given in the original papers (Fig. S1 in the Supplement). The root mean square error (RMSE) of R_s, T_5, and T_{10} was 0.09 $\mu mol\,m^{-2}\,s^{-1}$, 0.35 °C, and 0.44 °C, respectively, and the coefficients of determination (R^2) were all greater than 0.99, indicating that the accuracy of WEBPLOTDIGITIZER is excellent. Moreover, the data from the same authors and different sources (e.g., master's thesis or PhD dissertation and journal article) were carefully cross-checked and supplemented.

2.4 Monthly and annual soil respiration calculation

Long-term continuous R_s could be monitored with infrared gas analyzers (e.g., Li-8100, Li-8150), but there are few published studies of such continuous data (Bond-Lamberty et al., 2020; Tu et al., 2015; Wu et al., 2014; Yu et al., 2011). The observation frequency was 1–12 d per month – high during the growing season, but low in winter. R_s was measured throughout the day (16 %) or at a representative time, e.g., 09:00–11:00 (45 %), 09:00–12:00 (22 %), etc., which was validated to be close to the diurnal mean value (Xu and Qi, 2001; Yan et al., 2006; Yang et al., 2018; Yao et al., 2011; You et al., 2013; Zheng et al., 2010). Annual soil carbon efflux was integrated with the soil respiration model (i.e., integration method) or interpolated with the average soil respiration rate between sampling dates (i.e., interpolation method) (Shi et al., 2014). Finally, monthly R_s and annual soil carbon efflux were converted to the common unit of $\mu mol\,CO_2\,m^{-2}\,s^{-1}$ and $g\,C\,m^{-2}\,yr^{-1}$, respectively (Bond-Lamberty and Thomson, 2010a).

Table 1. Variable information of soil respiration dataset in China's forest ecosystems, available at https://doi.org/10.1594/PANGAEA.943617 (Sun et al., 2022). n/a refers to values that are not applicable.

Variable	Description	Unit	Number	Range
ID	Unique identification number of each record	n/a	11 297	1–11 297
Province	Province location of study site	n/a	28	n/a
Study site	Name of study site	n/a	155	n/a
Latitude	Latitude (N) of study site	°	208	18.61–52.86
Longitude	Longitude (E) of study site	°	218	84.91–129.08
Elevation	Altitude of study site	m	329	7–4200
MAT	Mean annual temperature	°C	122	−5.4–23.8
MAP	Mean annual precipitation	mm	180	105–3000
Forest type	Forest community characterized by the dominant tree species, or the ecological similarities (e.g., life form and biotope)	n/a	180	n/a
Origin	Stand origin was classified into planted and natural (i.e., secondary, primary) forests	n/a	4	n/a
Age	Stand age, estimated from historical records or dominant tree rings in natural forest, defined since planting in planted forest	years	769	2–400
DBH	Mean diameter at breast height	cm	610	2.40–51.96
H_{tree}	Mean tree height	m	538	2.50–48.00
Density	Stem density and/or canopy coverage	trees ha^{-1}	548	209–17 000, 0.23–0.98
Instrument	Measurement instrument of R_s, i.e., gas chromatography, infrared gas analyzers (Li-6400, Li-8100, Li-8150)	n/a	4	n/a
Time	Observation time of R_s per day (Beijing time)	hour:minute	749	00:00–23:00
Frequency	Observation frequency of R_s, i.e., days per month	days	961	0.5–31
Area	Observation area of R_s, i.e., area of soil collar or base	cm^2	976	50–2500
Height	Height of soil collar or chamber	cm	828	4–50
Replication	Numbers of soil collar or chamber	n/a	968	1–768
Date	Observation month of R_s per year	month, year	10 288	Jan 2000–Mar 2018
R_s	Soil respiration rate, monthly means or a few values per month	$\mu mol\, m^{-2}\, s^{-1}$	10 288	0.01–11.84
T_5	Soil temperature at 5 cm depth concurrently measured with R_s	°C	6341	−16.51–33.58
T_{10}	Soil temperature at 10 cm depth concurrently measured with R_s	°C	2878	−16.40–33.46
Mode	Ways to obtain R_s data: (1) extracted with WEB PLOTDIGITIZER, (2) given directly in the original study	n/a	2	1–2
Period	Period of annual soil carbon efflux	month, year	631	Jan 2001–Mar 2018
Annual R_s	Annual soil carbon efflux	$g\, C\, m^{-2}\, yr^{-1}$	634	260.10–2058.00
Method	Method to calculate annual soil carbon efflux, i.e., integration method and/or interpolation method	n/a	3	n/a
Reference	Data sources	n/a	568	n/a

2.5 Statistical analysis

Monthly and annual R_s were averaged arithmetically in cold-temperate, temperate, subtropical, and tropical zones. Independent-samples t tests (two groups) and one-way ANOVA (≥ 3 groups) at the $P = 0.05$ significance level were used to test the differences among various forest types in the same climate zone and among the same forest type in different climate zones. Temperature sensitivity (Q_{10}) is defined as the factor by which R_s is multiplied when temperature increases by 10 °C (Davidson and Janssens, 2006; Lloyd and Taylor, 1994), which is usually calculated with the van't Hoff equation ($R_s = ae^{\beta^T}$ and $Q_{10} = e^{10^\beta}$), where R_s is soil respiration rate ($\mu mol\, m^{-2}\, s^{-1}$) and T is temperature (°C). All statistical analyses were performed with SPSS Statistics 21 (SPSS Inc., Chicago, IL, USA).

3 Results

3.1 Relationship between soil respiration rate and soil temperature

Temperature is often the main factor determining soil respiration rates. The samples of the paired R_s & T_5 and R_s & T_{10} were 6341 (69 %) and 2878 (31 %) in the dataset, respectively. There were statistically significant exponential relationships of R_s with T_5 and T_{10} in forest ecosystems across China, which could explain about 48 % and 52 % of the R_s

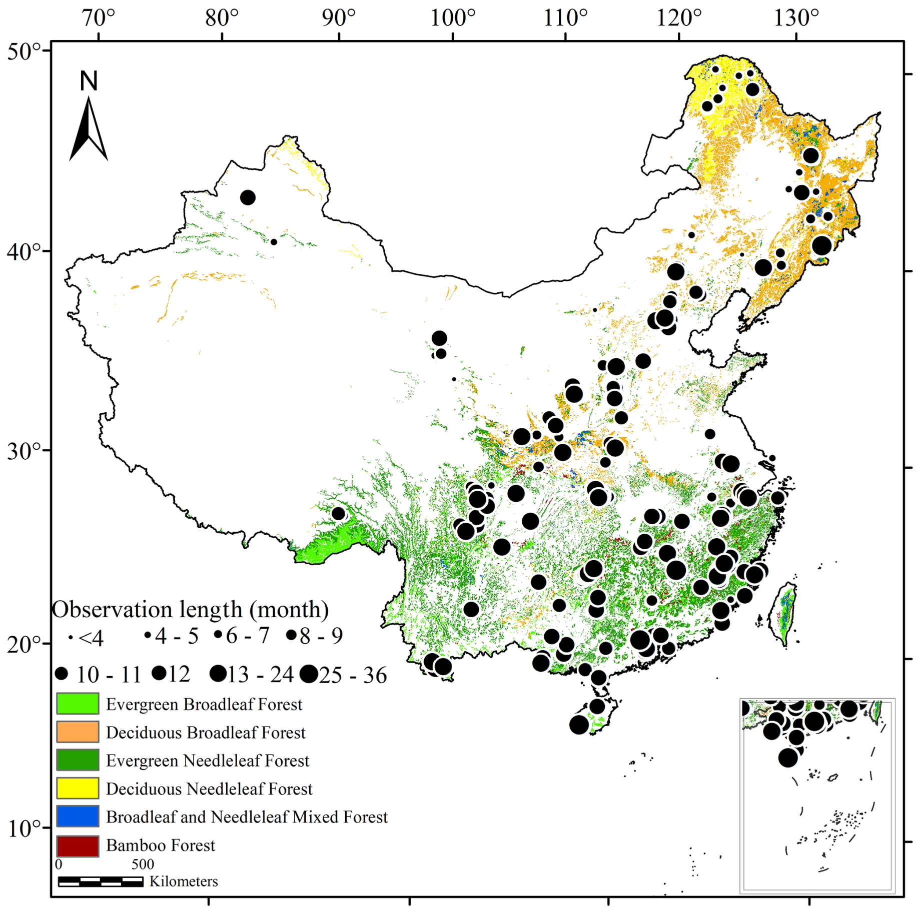

Figure 1. Distribution of study sites used to develop the forest soil respiration dataset in China.

variations, respectively (Fig. S2). The exponential correlations were all significant in four climatic zones ($R^2 = 0.23$–0.93) (Fig. 2). RMSE values in cold-temperate and temperate zones (1.52–1.67 μmol m^{-2} s^{-1}) were greater than those in subtropical and tropical zones (1.04–1.32 μmol m^{-2} s^{-1}), except for the smallest RMSE from T_{10} in the cold-temperate zone (0.42 μmol m^{-2} s^{-1}).

Q_{10} could be calculated with the exponential equations between R_s and soil temperature. At the national scale, the Q_{10} values in China's forest ecosystems from T_5 (−16.51–33.58 °C) and T_{10} (−16.40–33.46 °C) were 2.05 and 2.17, respectively. Q_{10} was the largest in the cold-temperate zone (T_5: 3.74 & T_{10}: 3.32), secondary in the temperate zone (T_5: 2.69 & T_{10}: 3.00), and the smallest in the subtropical zone (T_5: 2.15 & T_{10}: 2.20) and tropical zone (T_5: 2.28 & T_{10}: 1.63).

3.2 Monthly dynamics of soil respiration

Monthly R_s appeared as a single-peak curve (Fig. 3), which derived from similar years in cold-temperate (2003–2016), temperate (2002–2018), subtropical (2000–2017), and tropical zones (2003–2015). The highest values were found in August (4.18–4.36 μmol m^{-2} s^{-1}) in cold-temperate and temperate zones, higher than the highest values in July (3.58–3.83 μmol m^{-2} s^{-1}) in subtropical and tropical zones. The lowest values occurred in January in cold-temperate (0.20 μmol m^{-2} s^{-1}), temperate (0.49 μmol m^{-2} s^{-1}), subtropical (1.10 μmol m^{-2} s^{-1}), and tropical zones (1.62 μmol m^{-2} s^{-1}). Monthly variations were largest in the cold-temperate and temperate zones, secondary in the subtropical zone, and smallest in the tropical zone.

Annual mean R_s during January–December from low to high was cold-temperate (1.63 μmol m^{-2} s^{-1}), temperate (1.93 μmol m^{-2} s^{-1}), subtropical (2.47 μmol m^{-2} s^{-1}), and tropical zones (2.57 μmol m^{-2} s^{-1}). Annual soil carbon emissions were calculated with the annual mean R_s: 621.91 g C m^{-2} yr^{-1} in the cold-temperate zone, 733.31 g C m^{-2} yr^{-1} in the temperate zone, 937.15 g C m^{-2} yr^{-1} in the subtropical zone, and 973.35 g C m^{-2} yr^{-1} in the tropical zone. Soil carbon emissions in the growing season (May–October) and in winter (November–April) accounted for 85 % and 15 % of emissions in the cold-temperate zone, 80 % and 20 % in the temperate zone, 69 % and 31 % in the subtropical zone, and 61 % and 39 % in the tropical zone. Subtropical and

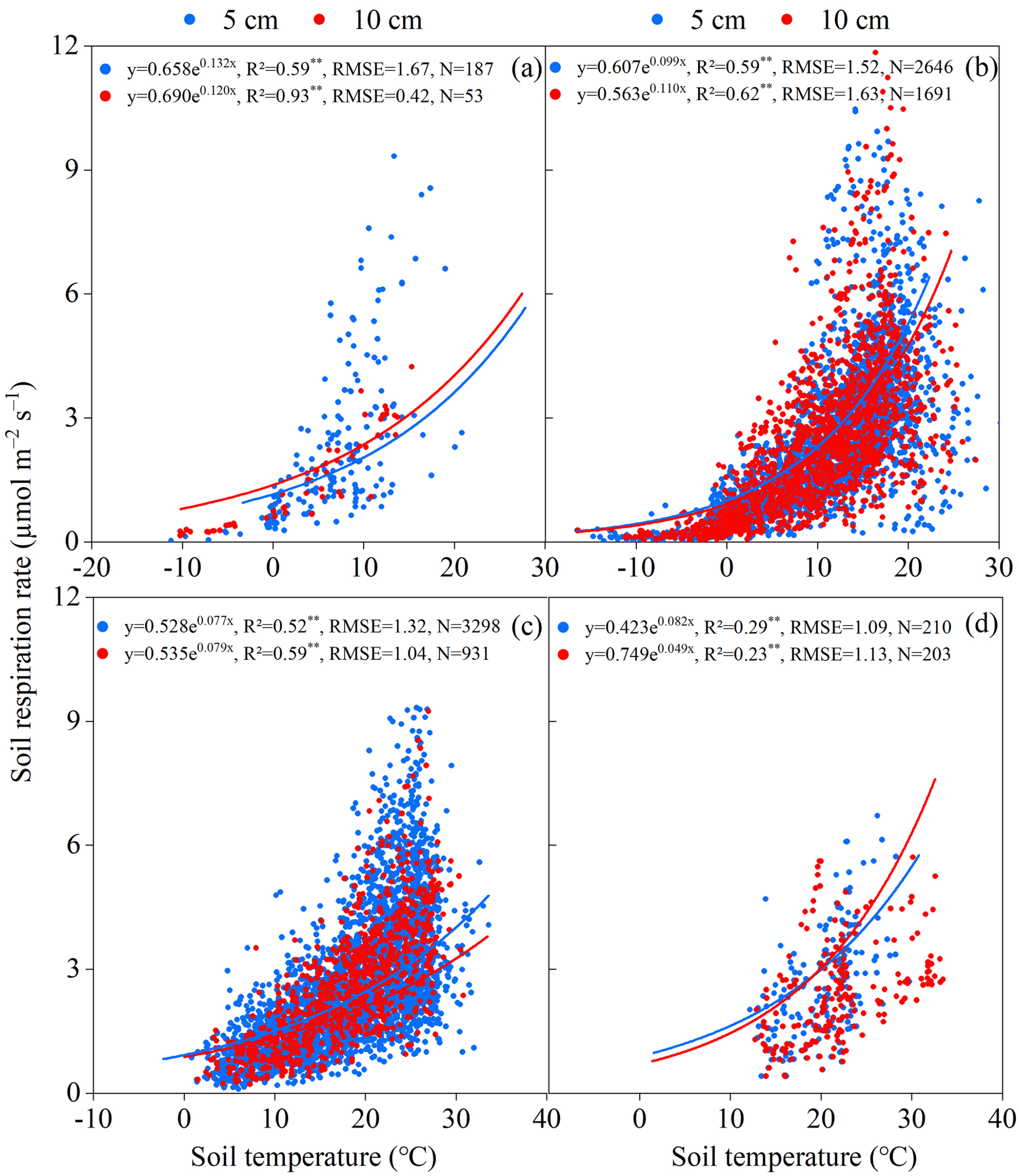

Figure 2. Exponential relationships of forest soil respiration rates with soil temperature at 5 and 10 cm depth in cold-temperate **(a)**, temperate **(b)**, subtropical **(c)**, and tropical zones **(d)**. ** $P < 0.01$.

tropical zones maintained high soil respiration rates during November–April, which is the main source of their higher annual soil carbon emissions.

3.3 Annual soil carbon effluxes

There were 634 annual soil carbon effluxes, and most of the observations were conducted in the subtropical zone (61 %) and temperate zone (32 %) (Fig. 4). The observations spanned the period 2003–2014 in the cold-temperate zone, 2000–2018 in the temperate zone, 2002–2017 in the subtropical zone, and 2003–2017 in the tropical zone. The annual soil carbon effluxes ranged from 260.10 to 2058.00 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ in China's forest ecosystems, and the mean was $851.88 \pm 12.75\ \mathrm{g\,C\,m^{-2}\,yr^{-1}}$. The annual soil carbon effluxes increased with the increase in mean annual temperature and precipitation at the national scale (Fig. S3). The mean annual soil carbon emissions in the tropical, subtropical, temperate, and cold-temperate zones were 1042.01 ± 68.55, 928.91 ± 16.68, 697.85 ± 16.39, and $684.29 \pm 61.81\ \mathrm{g\,C\,m^{-2}\,yr^{-1}}$, respectively. The first two were significantly higher than the last two, but the differences were not significant between the tropical and subtropical zones, and between the temperate and cold-temperate zones. The

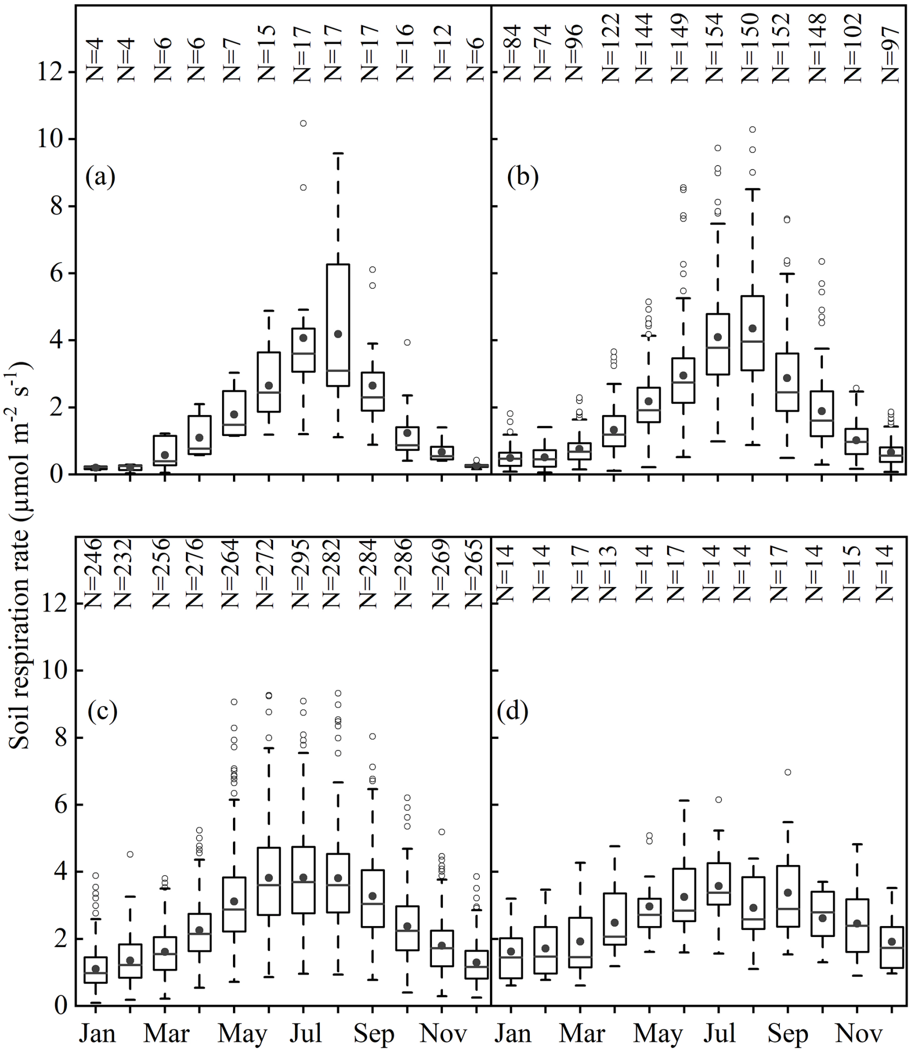

Figure 3. Monthly patterns of forest soil respiration rates in cold-temperate **(a)**, temperate **(b)**, subtropical **(c)**, and tropical zones **(d)**. Solid circle: mean value; solid horizontal line: median; box: 25th to 75th percentiles; whisker: 1.5 times interquartile range; open circle: data points beyond the whiskers. The samples per month are listed in the upper part of the figure.

differences were not significant for evergreen broadleaf forest (EBF), evergreen needleleaf forest (ENF), and deciduous needleleaf forest (DNF) among different climate zones. The values for deciduous broadleaf forest (DBF) in the temperate ($748.59 \pm 25.18\,g\,C\,m^{-2}\,yr^{-1}$) and subtropical zones ($755.41 \pm 58.26\,g\,C\,m^{-2}\,yr^{-1}$) were similar, both of which were greater than that in the cold-temperate zone ($284.20 \pm 21.36\,g\,C\,m^{-2}\,yr^{-1}$). Broadleaf and needleleaf mixed forest in the subtropical zone ($977.35 \pm 43.56\,g\,C\,m^{-2}\,yr^{-1}$) had significantly higher emissions than in the temperate zone ($733.44 \pm 45.29\,g\,C\,m^{-2}\,yr^{-1}$).

Emissions in evergreen forests were usually higher than in deciduous forests in the same climatic zone, e.g., ENF ($866.98 \pm 63.74\,g\,C\,m^{-2}\,yr^{-1}$) and DNF ($734.56 \pm 83.67\,g\,C\,m^{-2}\,yr^{-1}$) in the cold-temperate zone, ENF ($699.96 \pm 32.77\,g\,C\,m^{-2}\,yr^{-1}$) and DNF ($555.15 \pm 24.19\,g\,C\,m^{-2}\,yr^{-1}$) in the temperate zone, EBF ($1073.50 \pm 26.44\,g\,C\,m^{-2}\,yr^{-1}$) and DBF ($755.41 \pm 58.26\,g\,C\,m^{-2}\,yr^{-1}$) in the subtropical zone. Broadleaf forests showed significantly larger annual fluxes than coniferous forests in the temperate zone (DBF: $748.59 \pm 25.18\,g\,C\,m^{-2}\,yr^{-1}$ vs. DNF: $555.15 \pm 24.19\,g\,C\,m^{-2}\,yr^{-1}$) and subtropical zone (EBF: $1073.50 \pm 26.44\,g\,C\,m^{-2}\,yr^{-1}$ vs. ENF: $717.50 \pm 17.61\,g\,C\,m^{-2}\,yr^{-1}$). However, DNF fluxes ($734.56 \pm 83.67\,g\,C\,m^{-2}\,yr^{-1}$) were larger compared with DBF ($284.20 \pm 21.36\,g\,C\,m^{-2}\,yr^{-1}$) in the cold-temperate zone, which was from the high-latitude Great Xing'an Mountains ($\sim 51°$ N) and high-altitude Mount Gongga (2800–2950 m). Additionally, bamboo is a special type in subtropical areas, exhibiting the highest soil carbon emissions ($1133.55 \pm 42.74\,g\,C\,m^{-2}\,yr^{-1}$).

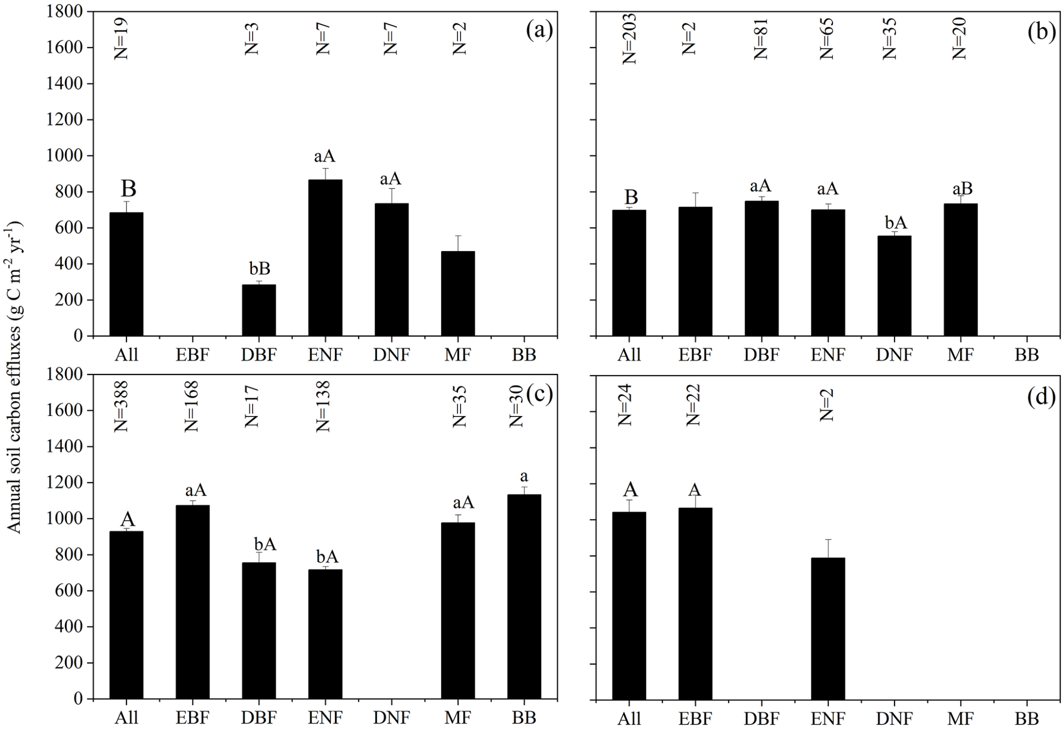

Figure 4. Comparisons of annual soil carbon effluxes (mean ± standard error) among different forest types across China in cold-temperate **(a)**, temperate **(b)**, subtropical **(c)**, and tropical zones **(d)**. Lowercase letters indicate comparisons of different forest types in each climatic zone, while uppercase letters are comparisons of the same forest type in different climatic zones. The samples are listed in the upper part of the figure, and samples larger than 3 were compared. EBF: evergreen broadleaf forest, DBF: deciduous broadleaf forest, ENF: evergreen needleleaf forest, DNF: deciduous needleleaf forest, MF: broadleaf and needleleaf mixed forest and BB: bamboo forest.

4 Discussion

4.1 Temperature sensitivity (Q_{10}) of soil respiration

Q_{10} is a key parameter in modeling the effects of climate warming on soil carbon release. The Q_{10} values calculated with the exponential equations of T_5 and T_{10} were 2.05 and 2.17, respectively, at the national scale (Fig. S2), which were lower than the averaged Q_{10} from different studies in the syntheses of China's forest ecosystems (T_5: 2.28–2.51 and T_{10}: 2.74–3.00, Peng et al., 2009; Song et al., 2014; Xu et al., 2015; Zheng et al., 2009) and global forest ecosystems (T_5: 2.55–2.70 and T_{10}: 3.01–3.31, W. Wang et al., 2010; X. Wang et al., 2010). Our results were close to the Q_{10} of 2, which is commonly used in many biogeochemical models (e.g., Cox et al., 2000; Sampson et al., 2007), and the mean Q_{10} of 2.11 estimated with inverse modeling in forest soils across China (Zhou et al., 2009).

Temperature was the most important limiting factor for soil microbial activity and root growth in cold regions; thus, R_s was more sensitive to temperature changes (Lloyd and Taylor, 1994; Peng et al., 2009; Zheng et al., 2009, 2020). The Q_{10} increased from the tropical zone to the cold-temperate zone in this study, and varied from 1.63 to 3.74. Soil temperature at the depth of 5 and 10 cm could only explain 29 % and 23 % of the R_s variations and RMSEs were 1.09 and 1.13 μmol m^{-2} s^{-1} in the tropical zone, respectively (Fig. 2d). The difference of the mean R_s between tropical moist forests (1260 g C m^{-2} yr^{-1}) and tropical dry forests (673 g C m^{-2} yr^{-1}) was about 2-fold (Raich and Schlesinger, 1992), indicating that soil moisture might play more important roles.

4.2 Comparisons of monthly and annual soil carbon effluxes

The lowest monthly R_s occurred in January, and the highest values occurred in August in the cold-temperate and temperate zones and in July in the subtropical and tropical zones (Fig. 3). Similarly, monthly R_s values of global terrestrial ecosystems reached their minima in February and peaked in July and August (Hashimoto et al., 2015; Raich et al., 2002). Due to the limitation of low temperature, winter observations of R_s were relatively fewer in the cold-temperate and temperate zones. The R_s in winter (November–April) was usually assumed to account for 20 % of the total annual R_s (Geng et al., 2017; Yang and Wang, 2005), which was in agreement with the proportion in the temperate zone, but greater than 15 % in the cold-temperate zone.

Annual soil carbon emissions were synthesized for forest ecosystems across China, and the mean was 745.34 g C m^{-2} yr^{-1} (Zheng et al., 2010), 764.11 g C m^{-2} yr^{-1} (Zhan et al., 2012), 917.73 g C m^{-2} yr^{-1} (Song et al., 2014) and 975.50 g C m^{-2} yr^{-1} (Chen et al., 2008); the mean of 851.88 g C m^{-2} yr^{-1} in the present study was in the mid-range. The mean annual R_s in China's forest ecosystems was slightly lower than the mean R_s of 990.00 g C m^{-2} yr^{-1} in global forest ecosystems (Chen et al., 2010). Warner et al. (2019) modeled global R_s and found that the lowest and highest annual soil carbon emissions were in deciduous needleleaf forests (mean = 344.10 g C m^{-2} yr^{-1}) and evergreen broadleaf forests (mean = 1310.47 g C m^{-2} yr^{-1}), respectively. Compared with the predicted annual R_s, deciduous needleleaf forests in the cold-temperate (mean = 734.56 g C m^{-2} yr^{-1}) and temperate zones (mean = 555.15 g C m^{-2} yr^{-1}) had higher values, but those of evergreen broadleaf forests in subtropical (mean = 1073.50 g C m^{-2} yr^{-1}) and tropical zones (mean = 1065.09 g C m^{-2} yr^{-1}) were lower (Fig. 4).

The mean annual soil carbon emissions from 634 annual R_s and 5003 mean monthly R_s were 684.29 and 621.91 g C m^{-2} yr^{-1}, respectively, in the cold-temperate zone, 697.85 and 733.31 g C m^{-2} yr^{-1} in the temperate zone, 928.91 and 937.15 g C m^{-2} yr^{-1} in the subtropical zone, and 1042.01 and 973.35 g C m^{-2} yr^{-1} in the tropical zone (Figs. 4 and 3). The differences between the directly averaged annual R_s and the accumulative mean monthly R_s were smallest in the tropical zone (−8.24 g C m^{-2} yr^{-1}), secondary in the temperate zone (−35.46 g C m^{-2} yr^{-1}), and largest in the cold-temperate and tropical zones (62.38–68.66 g C m^{-2} yr^{-1}). From Fig. 4 we can also see that the standard errors in the tropical and temperate zones (∼ 16 g C m^{-2} yr^{-1}) were smaller than those in the cold-temperate and tropical zones (∼ 65 g C m^{-2} yr^{-1}). Mean annual soil carbon emissions in the temperate, subtropical, and tropical ecosystems were 745, 776, and 1286 g C m^{-2} yr^{-1} at the global scale, respectively (Bond-Lamberty and Thomson, 2010a), which were comparable to our results.

4.3 Improvements of the dataset

R_s measurements were mainly from Li-8100 (47 %) and Li-6400 (33 %), secondary from gas chromatography (18 %), and Li-8150 only accounted for 2 %. The differences of the four common measurement methods were proved to be small (∼ 10 %) (Wang et al., 2011; Yang et al., 2018; Zheng et al., 2010). The sample sizes of annual R_s were 50–139 (Chen et al., 2008; Song et al., 2014; Zhan et al., 2012; Zheng et al., 2010) and 634 in the current study, and increased more than 4-fold. The global soil respiration database (SRDB-V5) collected 523 undisturbed annual R_s in China's forest ecosystems (Jian et al., 2021), but all methods were included, e.g., alkali absorption, gas chromatography, and various infrared gas analyzers. The alkali absorption method could underestimate R_s (Chen et al., 2008; Jian et al., 2020). The total samples of mean monthly R_s were 5003, which was much larger than the other dataset monthly samples of 1782 in China's forest ecosystems (Jian et al., 2020; Steele and Jian, 2018). Additionally, we extended the dataset with the digital software (WEBPLOTDIGITIZER) from the monthly dynamics figures of the original papers, including the paired R_s & T_5 ($N = 6341$) and R_s & T_{10} ($N = 2878$). Predicting soil respiration from soil temperature has gained extensive acceptance (Shi et al., 2014; Song et al., 2014; Sun et al., 2020). These data could be used to establish a large-scale soil respiration equation and acquire the key parameters of the carbon cycle. Compared with the aforementioned monthly or annual databases, this study collected all available R_s data at different time scales. Figure S4 showed the length of the individual time series from the different sites; the high frequencies were 12 months (38 %), 6–7 months (20 %), and 13–24 months (15 %). Bamboo forests were seldom considered in the previous databases (Chen et al., 2008; Steele and Jian, 2018; Zhan et al., 2012; Zheng et al, 2010), which exhibited the highest soil carbon emissions (Mean = 1133.55 g C m^{-2} yr^{-1}, Fig. 4). With the area increasing at a high rate of 3.1 % per year (Song et al., 2017), bamboo forests would play an important role in the regional and even national carbon cycle. It is worth noting that the R_s studies were fewer in the regions of latitude greater than 48° (∼ 2 %) or elevation higher than 3000 m (∼ 4 %). The potentially under-represented forest types might affect the evaluation of the temperature sensitivity of soil respiration and of annual soil carbon emissions at the regional and national scales.

5 Data availability

The soil respiration dataset in China's forest ecosystems used to produce the results in this study is free to the public for scientific purposes and can be downloaded at https://doi.org/10.1594/PANGAEA.943617 (Sun et al., 2022).

6 Conclusions

In this study, we reviewed the R_s-related literature and collected in situ R_s measurements with common infrared gas analyzers (i.e., Li-6400, Li-8100, Li-8150) or gas chromatography to assemble a comprehensive and uniform dataset of China's forest ecosystems at different time scales. Besides the R_s data reported directly in the original papers, the monthly patterns of R_s and the concurrently measured soil temperature at 5 and/or 10 cm depth in the figures were digitized. Moreover, we made a preliminary analysis of the data. The results showed that soil temperature could explain 22.5 %–93.4 % of the R_s variations. Temperature sensitivity (Q_{10}) was about 2.05–2.17 at the national scale, increasing from 1.63 in the tropical zone to 3.74 in the cold-temperate zone. Monthly R_s showed a single-peak curve, and the highest values occurred in August (4.18–4.36 $\mu mol\,m^{-2}\,s^{-1}$) in the cold-temperate and temperate zones, higher than the highest values in July (3.58–3.83 $\mu mol\,m^{-2}\,s^{-1}$) in the subtropical and tropical zones. Mean annual soil carbon emissions decreased from tropical (1042.01 $g\,C\,m^{-2}\,yr^{-1}$), subtropical (928.91 $g\,C\,m^{-2}\,yr^{-1}$), temperate (697.85 $g\,C\,m^{-2}\,yr^{-1}$) to cold-temperate zones (684.29 $g\,C\,m^{-2}\,yr^{-1}$). This study provides basic data and a scientific basis for the quantitative evaluation of soil carbon emissions from forest ecosystems in China.

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Author contributions. BJ designed the soil respiration dataset and searched the papers published until 2018. HS and BJ collected and digitized soil respiration data and compiled the associated information. HS and BJ prepared the manuscript. ZX provided many useful suggestions and reviewed the paper.

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