Interannual variability in soil respiration from terrestrial ecosystems in China and its response to climate change

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Soil respiration is an important process in terrestrial carbon cycle. Concerning terrestrial ecosystems in China, quantifying the spatiotemporal pattern of soil respiration at the regional scale is critical in providing a theoretical basis for evaluating carbon budget. In this study, we used an empirically based, semi-mechanistic model including climate and soil properties to estimate annual soil respiration from terrestrial ecosystems in China from 1970 to 2009. We further analyzed the relationship between interannual variability in soil respiration and climatic factors (air temperature and precipitation). Results indicated that the distribution of annual soil respiration showed clear spatial patterns. The highest and lowest annual soil respiration rates appeared in southeastern China and northwestern China, respectively, which was in accordance with the spatial patterns of mean annual air temperature and annual precipitation. Although the mean annual air temperature in northwestern China was higher than that in some regions of northeastern china, a greater topsoil organic carbon storage in northeastern China might result in the higher annual soil respiration in this region. By contrast, lower temperature, less precipitation and smaller topsoil organic carbon pool incurred the lowest annual soil respiration in northwestern China. Annual soil respiration from terrestrial ecosystems in China varied from 4.58 to 5.19 Pg C a⁻¹ between 1970 and 2009. During this time period, on average, annual soil respiration was estimated to be 4.83 Pg C a⁻¹. Annual soil respiration in China accounted for 4.93%–6.01% of the global annual soil CO₂ emission. The interannual variability in soil respiration depended on the interannual variability in precipitation and mean air temperature. In order to reduce the uncertainty in estimating annual soil respiration at regional scale, more in situ measurements of soil respiration and relevant factors (e.g. climate, soil and vegetation) should be made simultaneously and historical soil property data sets should also be established.

China, soil respiration, temporal variability, climate

critical to provide a theoretical basis for evaluating carbon
budget. There are two main approaches available for esti-
mating soil respiration at regional scale. One is using pro-
cess-based model; the other is using empirically based, geo-
statistical model. Cao et al. [6, 7] reported that averaged
annual soil respiration in China from 1980 to 2000 was 4.82
Pg C a\(^{-1}\) using a process-based model CEVSA. Ji et al. [8]
estimated that averaged annual soil respiration in China
from 1981 to 2000 was 4.43 Pg C a\(^{-1}\) using a process-based
AVIM2 model. Yu et al. [7] indicated a lower value of soil
respiration in China using a region-scale geostatistical mod-
el, with the averaged annual soil respiration of 3.84 Pg C a\(^{-1}\)
from 1995 to 2004. Great uncertainty remains in the annual
soil respiration estimation for terrestrial ecosystems in Chi-
na, with differences of 1 Pg C a\(^{-1}\) between the highest and
lowest values. Moreover, few studies focused on the rela-
tion between interannual variability in soil respiration and
climatic factors.

Increasing field measurement data covering various plant
functional types and biomes provide not only the solid base
to model soil respiration, but the opportunity to better esti-
mate regional amount of soil respiration [9]. In this study,
we used an empirically based, semi-mechanistic model in-
cluding climate and soil properties to estimate annual soil
respiration from terrestrial ecosystems in China from 1970
to 2009. We further analyzed the relationship between in-
terannual variability in soil respiration and climatic factors
(air temperature and precipitation).

1 Materials and methods

1.1 Data sets

The data sets used in estimating soil respiration include
climate (mean annual air temperature and precipitation) data
sets from 1970 to 2009 and topsoil (0–20 cm) properties
data sets obtained from the 2nd State Soil Survey. Data on
the annual precipitation at ~670 weather stations from 1970
to 2009 were derived from the National Meteorological In-
formation Center, China Meteorological Administration;
these stations cover most of ecosystem types and climate
zones in China, except for few measurements data in Tibet-
an Plateau and deserts [10]. The meteorological data sets are
the most inclusive and accurate data sets available for Chi-
nese terrestrial ecosystems.

1.2 Estimation method

An empirically based, semi-mechanistic model including
climate and soil properties was used to estimate annual soil
respiration [9]. We tabulated 657 published estimates of
annual soil respiration from 147 sites globally. We also rec-
ordered the annual precipitation and mean temperature, and
the soil physiochemical parameters such as surface (0–20
cm) topsoil organic carbon storage. Most soil properties
were compiled directly from the original literatures. If the
data of soil organic carbon storage and soil total nitrogen
storage at 0–20 cm were not available in the original litera-
tures, they were estimated by using the equation similar to
that used by Schwager and Mikhailova [11] and Pan et al.
[12]:

\[ \text{SOC} = C_s \times \gamma \times H \times (1 - \delta_{\text{ssoil}}/100) \times 10^{-1}, \]

where SOC and C\(_s\) are the 0–20 cm topsoil organic carbon
storage (t ha\(^{-1}\)) and content (g kg\(^{-1}\)), respectively, \(\gamma\) is the
bulk density (g cm\(^{-3}\)), \(H\) is the soil thickness (20 cm), and
\(\delta_{\text{ssoil}}\) is the <2 mm fraction (%) of soil. In cases where bulk
density was not available in the literature, it was estimated
from the relationship between bulk density and SOC [9, 11].

Based on the in situ measurements, the global soil respi-
ration data sets were compiled. The data sets include mea-
ured annual soil respiration from China and other countries,
covering the most terrestrial ecosystem types. Approximate
88% annual soil respiration rates are within the range of
0.1–1.5 kg C m\(^{-2}\) a\(^{-1}\) (Figure 1). In the data sets, there are 97
annual soil respiration samples measured in China,
occupying 20.5% of global data sets. These samples in
farmlands, grasslands and forests ecosystems contribute
28.9%, 25.8% and 45.4%, respectively, to the whole
samples in terrestrial ecosystems of China. These samples
from China are within the latitude range of 20°N–60°N,
corresponding to the latitude zone where 85% global soil
respiration data (mainly from USA, Europe and China) are
measured. Additionally, annual soil respiration rates vary
within the range of 0.1–1.6 kg C m\(^{-2}\) a\(^{-1}\); the range is
similar to that of global soil respiration. To describe the
dependence of annual soil respiration on mean air tempera-
ture and annual precipitation, we established a T&P&C-
model using mean annual air temperature, annual precipita-
tion sum and soil organic carbon storage as predictors for annual soil respiration:

\[ R_s = R_o e^{(T - \theta)Q} \times \frac{P}{P + K} \times \frac{SOC}{SOC + M}, \]

where \(R_s\) (kg C m\(^{-2}\) a\(^{-1}\)) represents annual soil respiration, \(T\)
(°C) is mean annual air temperature, \(P\) (m) is annual precipi-
tation, and SOC (kg C m\(^{-2}\)) is topsoil organic carbon stor-
age. \(Q\) (°C\(^{-1}\)) determines the exponential relationship be-
tween soil respiration and temperature, \(K\) (m) is the
half-saturation constant of the hyperbolic relationship of
soil respiration with annual precipitation, and \(M\) (kg C m\(^{-2}\))
is the half-saturation constant of the hyperbolic relationship
of soil respiration with soil organic carbon storage. The
model was parameterized by calculating a nonlinear least
squares fit of the parameters \((R_o, Q, K)\) to our data sets [13,
14].

The model was established and validated by using a
\(k\)-fold cross-validation method. The whole data sets were
randomly split into \(k\) \((k=6)\) roughly equal subsets called a