Biogeosciences, 7, 1915–1926, 2010
www.biogeosciences.net/7/1915/2010/
doi:10.5194/bg-7-1915-2010

Biogeosciences

A global database of soil respiration data

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Received: 9 February 2010 – Published in Biogeosciences Discuss.: 19 February 2010
Revised: 28 May 2010 – Accepted: 1 June 2010 – Published: 15 June 2010

Abstract. Soil respiration – R_S, the flux of CO_2 from the soil to the atmosphere – is probably the least well constrained component of the terrestrial carbon cycle. Here we introduce the SRDB database, a near-universal compendium of published R_S data, and make it available to the scientific community both as a traditional static archive and as a dynamic community database that may be updated over time by interested users. The database encompasses all published studies that report one of the following data measured in the field (not laboratory): annual R_S, mean seasonal R_S, a seasonal or annual partitioning of R_S into its sources fluxes, R_S temperature response (Q_{10}), or R_S at 10 °C. Its orientation is thus to seasonal and annual fluxes, not shorter-term or chamber-specific measurements. To date, data from 818 studies have been entered into the database, constituting 3379 records. The data span the measurement years 1961–2007 and are dominated by temperate, well-drained forests. We briefly examine some aspects of the SRDB data – its climate space coverage, mean annual R_S fluxes and their correlation with other carbon fluxes, R_S variability, temperature sensitivities, and the partitioning of R_S source flux – and suggest some potential lines of research that could be explored using these data. The SRDB database is available online in a permanent archive as well as via a project-hosting repository; the latter source leverages open-source software technologies to encourage wider participation in the database's future development. Ultimately, we hope that the updating of, and corrections to, the SRDB will become a shared project, managed by the users of these data in the scientific community.

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1 Introduction

Soil respiration – R_S, the flux of carbon dioxide from the soil surface to the atmosphere – comprises the second-largest terrestrial carbon (C) flux (IPCC, 2001; Raich and Potter, 1995); at 75–100 $Pg\,C\,yr^{-1}$, it is an order of magnitude larger than anthropogenic fossil fuel combustion (Boden et al., 2009), implying that ∼10% of atmospheric CO_2 cycles through the soil annually (Reichstein and Beer, 2008). This large flux comes from a large pool: globally, soils store at least twice as much C as is in the atmosphere (Tarnocai et al., 2009; Post et al., 1982). Given that climate models predict mid- and high-latitude warming throughout this century (IPCC, 2007), a critical question is whether enhanced R_S will constitute a significant climate feedback (Jenkinson, 1991; Knorr et al., 2005; Davidson and Janssens, 2006). Such a feedback would have significant consequences for the global C cycle and rates of climate change (Jones et al., 2003; Rustad et al., 2000) and affect policy decisions based on the valuation of terrestrial C fluxes (Wise et al., 2009).

Because of its high variability, inaccessibility of the soil medium, and high cost of measurement instruments (Savage et al., 2008), R_S remains the least well constrained component of the terrestrial C cycle (Trumbore, 2006; Davidson et al., 2006). The spatial variability of R_S, and our inability to measure it remotely, remain significant constraints to regional and global evaluations of its magnitude and climate feedback potential; modeling efforts linking observations at different scales are critical to future progress in this arena (Reichstein and Beer, 2008). As the integrated result of a broad spectrum of autotrophic and heterotrophic respiratory processes operating under wildly varying environmental constraints, the temporal and spatial dynamics of R_S remain difficult to model or predict (Zobitz et al., 2008).

A better understanding of R_S flux dynamics will come from elucidating the integrated effects of environmental constraints on soil biotic and abiotic processes, based on the

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kinetic properties of soil organic compounds (Davidson and Janssens, 2006). It is also important, however, to leverage the thousands of R_S observations made over decades (Singh and Gupta, 1977; Raich and Schlesinger, 1992; Schlesinger, 1977; Chen and Tian, 2005; Hibbard et al., 2005). This is particularly important for understanding R_S, as it has been almost 20 years since the last comprehensive R_S data collection and meta-analysis was published (Raich and Schlesinger, 1992); 80% of R_S studies have appeared since that time (Fig. 1), a number large enough to deter or limit most data collection projects. Nonetheless, a global, community R_S data set would be useful both on its own and in conjunction with remote sensing, eddy covariance, soils and other databases that either exist or are being assembled, opening the possibility of identifying large-scale patterns not visible in individual studies. Such meta-analyses can result in unexpected or interesting results, even if they are sometimes subject to particular statistical issues, e.g., the "file drawer" problem (Rosenthal, 1979). For example, a database recently assembled to support a meta-analysis of C balance in relation to stand age (Luyssaert et al., 2007) led to a provocative hypothesis about the controls on forest C sequestration (Luyssaert et al., 2008). Other reviews and meta-analyses have drawn similarly broad, if tentative, inferences on ecosystem structure and function (Elser et al., 2007; LeBauer and Treseder, 2008; Lusk and Warton, 2007; Rustad et al., 2001; Wan et al., 2001; Hanson et al., 2000).

Meta-analyses are thus not new, but recent efforts to assemble large shared data sets in the earth system sciences make use of Internet-facing databases and modern computational tools, allowing for a vastly expanded pool of potential users, increased analytical power, and increased public trust (Anonymous, 2009). New data-sharing models can also be applied; in particular, technologies such as version control, developed and exploited by the open-source software movement (Raymond, 2001), enable a "living" database that is continually expanded and improved by its users. These new technologies drive the goals of this study: to assemble a near-universal database of all published R_S data and make it available to the scientific community, both as a traditional static archive and as a dynamic community database.

2 Methods

2.1 Data sources and inclusion criteria

We collected all available studies in the peer-reviewed scientific literature reporting R_S measured in the field; lab incubation studies were not included. The ISI Web of Science™ constituted the primary source of published studies; search terms used included "soil respiration," "soil CO_2 evolution," etc. Each study's title and abstract was used to decide whether to acquire it; ~40% of the almost 4700 studies were acquired and examined. To qualify for inclusion, a study had to report at least one of the following data:

- Annual R_S (as reported by the authors, or easily calculable from data; no minimum-measurement requirement was imposed)
- Mean seasonal R_S (as defined and reported by the authors)
- Annual or seasonal partitioning of R_S sources (based on field measurements; regression approaches based on other studies, e.g., Subke et al. (2006) were not allowed)
- Q_{10} and associated temperature range
- R_{10} (R_S at 10 °C)

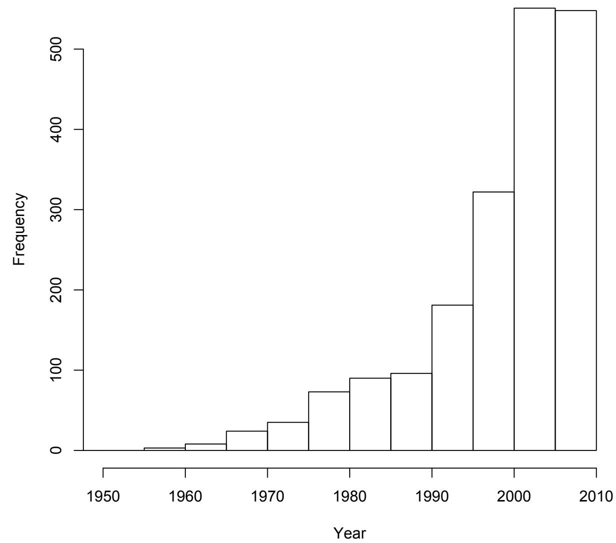

Fig. 1. Soil respiration studies over time, from the ISI Web of Science™ database.

If at least one of these data was reported, or could be calculated with few or no assumptions, e.g., straightforwardly estimated from points in a figure, the study was entered into the database. Short-term experiments (i.e., R_S measurements made over less than 1–2 weeks) were not entered unless the study authors extrapolated their results to seasonal or annual values; the database's orientation is thus to seasonal and annual fluxes, not shorter-term or chamber-specific measurements. Annual fluxes were sometimes reported by authors, and in other cases calculated from sub-annual (e.g., monthly) means. In general we did not do additional research to find older publications that might not be listed in the Web of Science.

2.2 Database structure

The database ("SRDB") is composed of two separate data files: a "studies" file, listing the publication information for all studies acquired, examined, entered or rejected, etc., and a "data" file, holding the acquired R_S data. An index number is used to map entries between the two files. The primary R_S units used were $g\,C\,m^{-2}\,yr^{-1}$ (for annual fluxes) and $\mu mol\,m^{-2}\,s^{-1}$ (for mean seasonal and R_{10} fluxes); values were converted as necessary from those given by study authors. A variety of ancillary data were also entered when reported, including site-related and experimental data, information on ecosystem structure and function, methods used, etc.; we assumed a 12:44 ratio of C to CO_2 molecular weights, and that biomass was 50%C (unless specified otherwise in the study). Temperate-response functions were categorized following table 10.1 in Luo and Zhou. (Luo and Zhou, 2006) and Reichstein et al. (2008). The primary data file includes 105 fields (Table 1). A Google Earth (http://earth.google.com/) data layer is included with the database for easy geographic visualization of the included studies.

2.3 Quality control

Some basic quality control has been performed on the data. Map plots were used to identify incorrectly entered location or climate information, and histograms of the primary variables of interest used to flag outliers for special attention. We have also attempted to check for basic data incompatibilities (e.g., cases where $R_S >$ total ecosystem respiration), and to identify duplicate entries. In addition, the database has fields documenting the chamber and CO_2 measurement method employed; methodological errors associated with such techniques can have important implications for field measurements (Keith and Wong, 2006; Pongracic et al., 1997; Pumpanen et al., 2004) and upscaling of fluxes (Reichstein and Beer, 2008). In spite of these efforts, many errors undoubtedly remain in the database (see Sect. 4.2 below).

Several metadata fields (field 6 in Table 1) are used to flag duplicate records, or ones with potential problems. In retrospect we wish that these metadata were even more extensive, recording, e.g., exactly how annual fluxes were calculated for each record, as such metadata constitute a critical means of filtering data and testing how assumptions affect the end data products. Certainly any use of the existing database needs to account carefully for known quality control issues along with the recorded measurement conditions (e.g., any manipulations performed, or CO_2 measurement technique used).

3 Results and discussion

In total, 1932 studies were marked for acquisition, 1853 acquired and examined, and 818 entered into the SRDB database, spanning the publication years 1963–2008 and measurement years 1961–2007. As of this writing the 818 studies resulted in 3379 records (a single study generates multiple records if, e.g., there are multiple years of data, or different sites reported, or different experimental treatments). The countries most frequently represented include USA (1404 records), Canada (308), China (273), Finland (179), Japan (162) and Germany (115); Figure 2 shows the spatial distribution of the collected data. Temperate-biome studies dominate the database (2373 records), with boreal (415) and tropical (353) also significant. While spatially clumped, the data cover the terrestrial climate space fairly completely (Fig. 3). Data from forest (2198 records), grassland (460) and agricultural (453) ecosystems are most frequently reported; upland systems (3084 records) far outnumber wetland ones. A majority of studies took place in unmanipulated ecosystems (2382 records), but data from thinned, burned, CO_2-increase, warmed and fertilized plots are represented as well.

Below we outline, rather than analyze in depth, a few characteristics of the SRDB data and suggest some lines of research that could be explored using these data.

3.1 Observed annual fluxes

Mean (± 1 s.d.) annual R_S was 109 ± 109, 383 ± 228, 745 ± 421, 813 ± 436, 776 ± 380, and 1286 ± 633 $g\,C\,m^{-2}$ for unmanipulated Arctic, boreal, temperate, Mediterranean, subtropical, and tropical ecosystems respectively. The tropical data are near-normally distributed, while boreal and temperate data are not (Fig. 4); this reflects the zero-bound of annual R_S (it is not normally negative) in ecosystems limited by low temperatures. Three variables – mean annual temperature, precipitation, and leaf area index, when combined in a simple linear regression analysis – explain ~41% of the observed variability in annual R_S, in line with previous meta-analyses of these drivers (Raich and Schlesinger, 1992; Reichstein et al., 2003). The annual data also exhibited an increasing temporal trend, driven primarily by air temperature anomaly (Bond-Lamberty and Thomson, 2010). Annual fluxes were correlated with other C fluxes (Fig. 5); such relationships have been noted in previous studies, e.g., that between litterfall and R_S (Raich and Nadelhoffer, 1989; Raich and Schlesinger, 1992; Davidson et al., 2002) or gross primary production and R_S (Hibbard et al., 2005; Janssens et al., 2001). The correlations shown in Fig. 5 (and Fig. 6 below) are relatively crude and did not vary by ecosystem type – i.e., between forests, grasslands, etc. – in spite of the significantly variation in biotic and abiotic controls that would be expected. More sophisticated analyses, e.g. machine learning or other stratified regression techniques (Jung et al., 2009), might be profitably applied to this problem.

An interesting question is how to rank the importance of various ancillary data when measuring R_S (Wayson et al., 2006). Many studies have attempted to regress R_S against a wide range of biotic and abiotic variables, but the results vary tremendously across ecosystems and biomes (Del Grosso et al., 2005; Raich and Schlesinger, 1992; Reichstein et al., 2003). These correlations also raise the possibility

Table 1. Categories of database fields and examples of data included for the soil respiration (R_S) database's main "data" file. A separate "studies" file contains bibliographic information for all studies, indexed by a study number common to both files.

Num	Field name	Description
Metadata		
1	Record_number	Record number
2	Entry_date	Entry date
3	Study_number	Study number; index into the studies database
4	Author	Name of first author
5	Duplicate_record	Is record a known duplicate? (Study number)
6	Quality_flag	Quality control. Quality control flags include Q0 (default/none), Q01 (estimated from figure), Q02 (data from another study), Q03 (data estimated-other), Q04 (potentially useful future data), Q_{10} (potential problem with data), Q11 (suspected problem with data), Q12 (known problem with data), Q13 (duplicate?), Q14 (inconsistency). Further details can generally be found in the notes field (#105 below)
7	Contributor	Data contributor
Site and measurement data		
8	Country	Country
9	Region	State/province/region
10	Site_name	Name of study site
11	Study_midyear	Year study was performed (middle year if multiple years)
12	YearsOfData	Years of data; always ≥ 1
13	Latitude	Latitude, decimal; positive=north, negative=south
14	Longitude	Longitude, decimal; positive=east, negative=west
15	Elevation	Elevation, m
16	Manipulation	Manipulation performed (CO_2, fertilization, etc.)
17	Manipulation_level	Degree of manipulation performed
18	Age_ecosystem	Time since ecosystem established, years. This is used when, e.g., the time of conversion of forest to agriculture is known
19	Age_disturbance	Time since disturbance, years
20	Species	Dominant species
21	Biome	Biome (boreal, temperate, etc). Subjective
22	Ecosystem_type	Ecosystem type (grassland, forest, etc). Subjective
23	Ecosystem_state	Ecosystem state (managed, unmanaged, natural). Subjective. "Unmanaged" means human management or disturbance in the past, but not currently.
24	Leaf_habit	Dominant leaf habit (deciduous, evergreen)
25	Stage	Developmental stage (aggrading, mature). Subjective
26	Soil_type	Soil description (classification and texture)
27	Soil_drainage	Soil drainage (dry, wet). Subjective. "Dry" means well-drained uplands; "wet" peatlands, swamps, etc.
28	Soil_BD	Soil bulk density, $g\,cm^{-3}$
29	Soil_CN	Soil C:N ratio
30	Soil_sandsiltclay	Soil sand:silt:clay ratio
31	MAT	Reported mean annual temperature, °C
32	MAP	Reported mean annual precipitation, mm
33	PET	Reported potential evapotranspiration, mm
34	Study_temp	Annual temperature in year of study, °C
35	Study_precip	Annual precipitation in year study of study, mm
36	Chamber_method	Chamber method
37	CO2_method	CO_2 measurement method
38	Partition_method	Method used to partition R_S source fluxes, following Bond-Lamberty et al. (2004)

Table 1. Continued.

Annual and seasonal R_S fluxes		
39	Rs_annual	Annual C flux from soil respiration, g C m^{-2}. This can either be reported directly by the study, calculated from reported mean fluxes, or estimated from a figure (in which case a quality control note is made, field 6)
40	Rs_annual_err	Error (typically plot-to-plot) for Rs_annual, g C m^{-2}
41	Rs_interann_err	Interannual error reported for Rs_annual, g C m^{-2}. This is occasionally reported by authors, or defined as the standard deviation between year i and year i+1 (N=2)
42	Rs_max	Maximum R_S flux, µmol m^{-2} s^{-1}
43	Rs_maxday	Maximum R_S flux day of year
44	Rs_min	Minimum R_S flux, µmol m^{-2} s^{-1}
45	Rs_minday	Minimum R_S flux day of year
46	Rlitter_annual	Annual R_S flux from litter, g C m^{-2}
47	Ra_annual	Annual autotrophic R_S flux, g C m^{-2}
48	Rh_annual	Annual heterotrophic R_S flux, g C m^{-2}
49	RC_annual	Root contribution to Rs_annual, annual fraction
50	Rs_spring	Mean spring R_S flux, µmol m^{-2} s^{-1}. Seasons are defined by authors
51	Rs_summer	Mean summer R_S flux, µmol m^{-2} s^{-1}
52	Rs_autumn	Mean autumn R_S flux, µmol m^{-2} s^{-1}
53	Rs_winter	Mean winter R_S flux, µmol m^{-2} s^{-1}
54	Rs_growingseason	Mean growing R_S flux, µmol m^{-2} s^{-1}
55	Rs_wet	Mean wet season R_S flux, µmol m^{-2} s^{-1}
56	Rs_dry	Mean dry season R_S flux, µmol m^{-2} s^{-1}
57	RC_seasonal	Root contribution to seasonal R_S, fraction
58	RC_season	Season of RC_seasonal
Response of R_S to temperature and moisture		
59	Model_type	Type of temperature-response model used
60	Temp_effect	Temperature effect on R_S (none, positive, negative)
61	Model_output_units	Temperature-response model output units
62	Model_temp_range	Soil temperature range over which model fitted
63	Model_N	Model N
64	Model_R2	Model r-squared
65	T_depth	Depth at which soil temperature recorded, cm. A value of −200 (i.e., 2 m above ground) is used for air temperature
66–70	Model_paramA...	Model parameters (A–E)
71	WC_effect	Soil water effect on R_S
72	R10	R_S at 10 °C, µmol m^{-2} s^{-1}
73–80	Q_{10}...	Q_{10} temperature responses, for 0–10, 5–15, 10–20, 0–20 °C, as well as custom ranges. Q_{10} values are either reported by authors, calculated from reported R_S-temperature regressions, or occasionally estimated from figures (in which case a quality control note is made, field 6)

of estimating R_S, with an associated error range, from airborne and satellite observations; the lack of such large-scale, observation-driven R_S estimates is a major problem in constraining regional- to global-scale C fluxes (Qi et al., 2002; Rayner et al., 2005; Jones et al., 2003).

3.2 Experimental error and R_S variability

The high variability of R_S constitutes a major reason why its measurement and modeling remain so difficult, as it responds to a suite of drivers including temperature, moisture, and vegetation productivity, all at different spatial and temporal scales (Reichstein et al., 2003; Rochette et al., 1991; Rodeghiero and Cescatti, 2008; Saiz et al., 2006; Vincent et al., 2006; Webster et al., 2008). Two measures of variability (fields 40–41 in Table 1) are defined in the SRDB: interannual variability (the standard deviation of a series of annual R_S values, all measured at one place) and error of the annual flux (typically plot-to-plot error, i.e., the standard deviation of a group of concurrently-measured values); few studies report both (Kabwe et al., 2005). The former is either

Table 1. Continued.

Ancillary pools and fluxes		
81	GPP	Annual gross primary production at site, $g\,C\,m^{-2}$
82	ER	Annual ecosystem respiration at site, $g\,C\,m^{-2}$
83	NEP	Annual net ecosystem production at site, $g\,C\,m^{-2}$
84	NPP	Annual net primary production at site, $g\,C\,m^{-2}$
85	ANPP	Annual aboveground NPP at site, $g\,C\,m^{-2}$
86	BNPP	Annual belowground NPP at site, $g\,C\,m^{-2}$
87	NPP_FR	Annual fine root NPP at site, $g\,C\,m^{-2}$
88	TBCA	Total belowground carbon allocation at site, $g\,C\,m^{-2}$
89	Litter_flux	Annual aboveground litter flux, $g\,C\,m^{-2}$. This is reported very inconsistently (leaf only, leaf and fine woody material, all material, etc). Generally this should not include large woody material
90	Rootlitter_flux	Annual belowground litter flux, $g\,C\,m^{-2}$
91	TotDet_flux	Annual total litter flux, $g\,C\,m^{-2}$. This should be the sum of Litter_flux and Rootlitter_flux
92	Ndep	Annual nitrogen deposition, $g\,N\,m^{-2}$
93	CH4_flux	Annual methane flux, $g\,C\,m^{-2}$
94	N2O_flux	Annual nitrous oxide flux, $g\,N\,m^{-2}$
95	LAI	Leaf area index at site, $m^2\,m^{-2}$. Hemispheric (one-sided) if possible
96	BA	Basal area at site, $m^2\,ha^{-1}$
97	C_veg_total	Total carbon in vegetation, $g\,C\,m^{-2}$. This should be the sum of C_AG and C_BG. For this and all "C_" fields, biomass is converted to carbon using a ratio of 0.5 unless study-specific values are available
98	C_AG	Total carbon in aboveground vegetation, $g\,C\,m^{-2}$
99	C_BG	Total carbon in belowground vegetation, $g\,C\,m^{-2}$
100	C_CR	Total carbon in coarse roots, $g\,C\,m^{-2}$
101	C_FR	Total carbon in fine roots, $g\,C\,m^{-2}$
102	C_litter	Total carbon in standing litter, $g\,C\,m^{-2}$
103	C_soil	Total carbon in soil organic matter, $g\,C\,m^{-2}$
104	C_soildepth	Depth to which soil C recorded, cm
Other		
105	Notes	Notes

reported by study authors or calculated within the database from individual year data. The mean coefficient of variability (standard deviation divided by the mean) in the SRDB is 15–16% for both variables. Ecosystem variability does not scale linearly to regional or global variability, and estimates of the interannual variability of large-scale R_S fluxes are much smaller than these means (Potter and Klooster, 1998; Raich et al., 2002; Bond-Lamberty and Thomson, 2010).

3.3 Temperature sensitivity

Ambient temperature constitutes the dominant – but not only – short-term control on R_S in most boreal and temperate ecosystems, at most points in time (Chen and Tian, 2005); temperate deserts and other dry areas constitute only one of many exceptions to this generalization (Parker et al., 1983; Zhou et al., 2009; Sponseller and Fisher, 2008; Tang et al., 2005). Our understanding of R_S and ecosystem respiration generally (Trumbore, 2006) is less advanced than that of photosynthesis, and most biogeochemical models still use simple, constant-Q_{10} models (originating from van't Hoff, 1898) that – among other problems – have been shown to overestimate low-temperature R_S (Lloyd and Taylor, 1994).

An interesting question to which the SRDB could be applied is how R_S temperature sensitivity changes with temperature, and whether a general temperature-dependent model exists for R_S; if this is the case, most large-scale R_S models, which use a constant Q_{10} response, could be shown to be considerably biased, (Chen and Tian, 2005; Tjoelker et al., 2001). The SRDB records the temperature-response model used by individual studies as well as Q_{10} values (the relative R_S change over 10 °C) for a variety of temperature ranges, as this parameter is reported so frequently in the R_S literature. Mean Q_{10} values in the database are 3.3 ± 1.5 for 0–10 °C, 2.9 ± 1.2 for 5–15 °C, 2.6 ± 1.1 for 10–20 °C, and 3.0 ± 1.1 over the entire 0–20 °C range; these means exclude a few extreme ($Q_{10} \geq 10$, ~1% of the data) reported values. These values must be treated with caution: these values

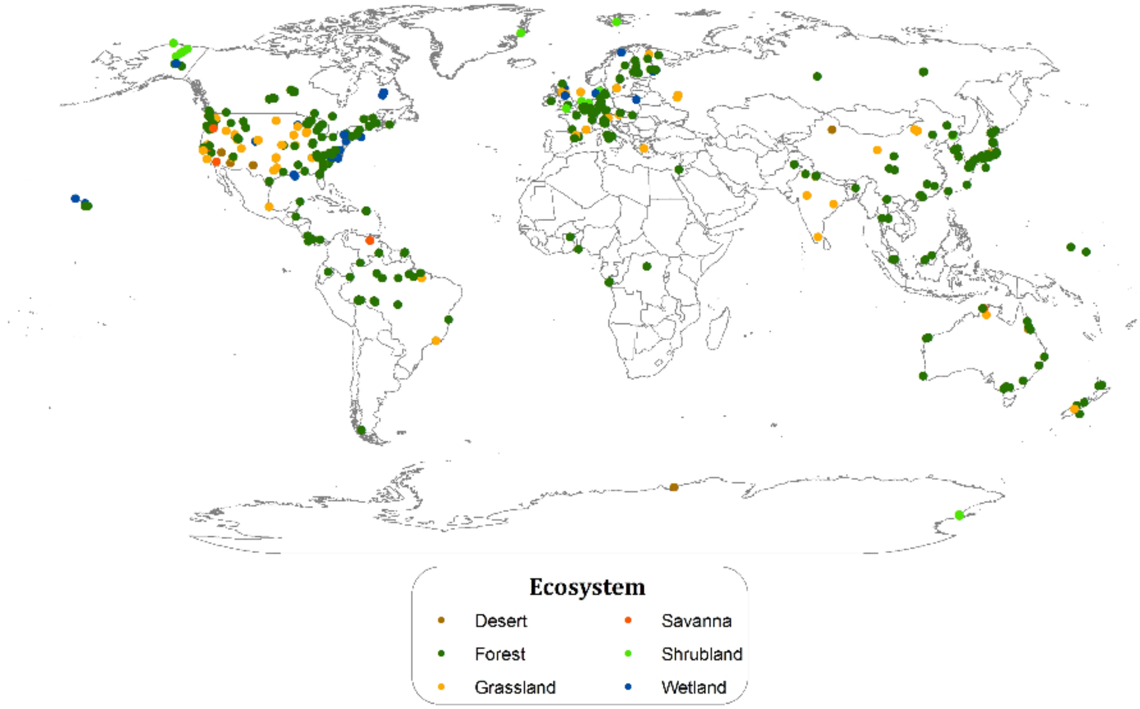

Fig. 2. Location of SRDB database observations (dots), by ecosystem type. A Google Earth™ data layer is included with the database for more detailed spatial views.

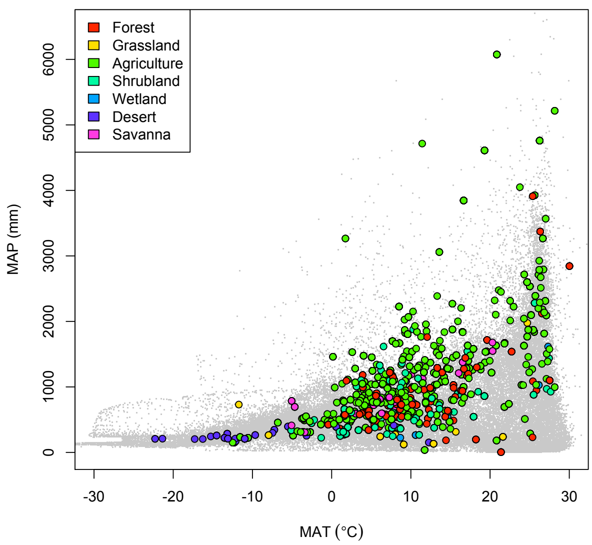

Fig. 3. SRDB data distribution across global mean annual temperature (MAT) and mean annual precipitation (MAP) climate space, by ecosystem type. Background dots show climate distribution of terrestrial surface (0.5° cells).

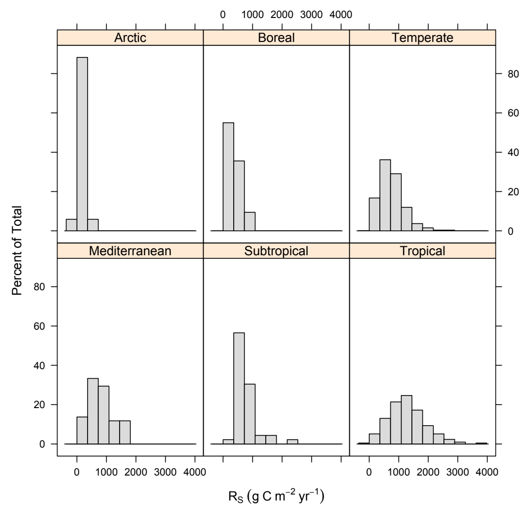

Fig. 4. Annual soil respiration (R_S) fluxes observed in the field, unmanipulated plots only, by biome. Relative histograms are shown; total observations are $N = 17$, 180, 1053, 51, 46, and 215 for Arctic, boreal, temperate, Mediterranean, subtropical, and tropical respectively.

are "apparent" (Davidson and Janssens, 2006) temperature sensitivities, as they are observed in the field and thus constrained by ambient environmental conditions (Zhou et al., 2009), rather than "intrinsic" or theoretical sensitivities; in addition, they are not based on a statistically random sample. Nonetheless these data should be of use for further explorations of how soil and air temperatures affect on Q_{10} variability (Chen and Tian, 2005).

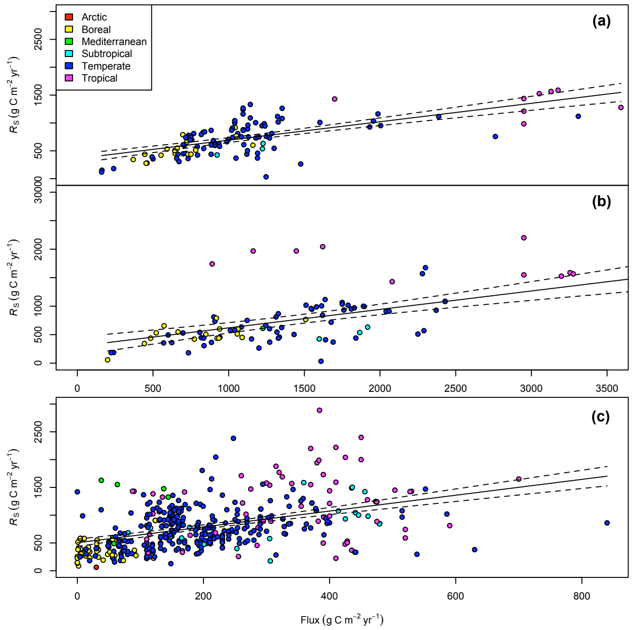

Fig. 5. Correlation between annual soil respiration (R_S) and other carbon fluxes: **(a)** annual ecosystem respiration, **(b)** annual gross primary production, and **(c)** annual aboveground litter flux, by biome. Solid lines show linear regression fit; dashed lines are 95% confidence intervals. Regressions shown are (a) $y = 361 + 0.33x$, $N = 116$, $R^2 = 0.48$; (b) $y = 296 + 0.32x$, $N = 92$, $R^2 = 0.33$; (c) $y = 502 + 1.43x$, $N = 421$, $R^2 = 0.21$.

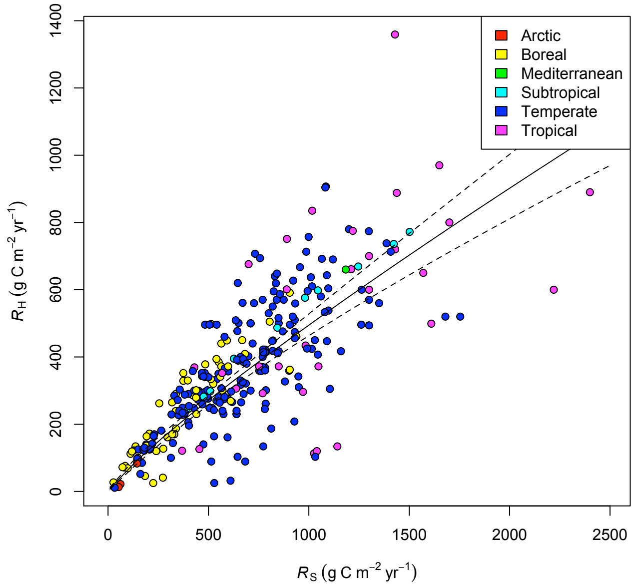

Fig. 6. Relationship between soil respiration (R_S) and heterotrophic soil respiration (R_H) in the database, by biome, following Bond-Lamberty et al. (2004). Fitted model shown (solid line) is $\ln(R_H)=0.22+0.87\ln(R_S)$, $R^2 = 0.64$, $P < 0.001$; dashed lines show 95% confidence interval. Two studies (Grier and Logan, 1977; Thierron and Laudelout, 1996) in the database were excluded from this figure based on a Cook's influential outlier test (R Development Core Team, 2009).

Reported Q_{10} values for R_S depend strongly on the depth at which the temperature measurement is made (Reichstein and Beer, 2008; Graf et al., 2008), as well as the observed temperature range. The current database structure includes a field for recording this depth datum, and is flexible enough to accommodate multiple depths of measurement. If a study reported a variety of Q_{10} values across multiple depths, these are not always all measured, as we focused on typical measurement depths (0–20 cm). This is an obvious area for future improvement.

3.4 Source fluxes of soil respiration

Partitioning R_S into its autotrophic (R_A) and heterotrophic (R_H) source fluxes is important for assessing plant physiology, C allocation, ecosystem C balance, and the climate feedback potential of changes in R_S. The relative responses of R_A and R_H will strongly affect the terrestrial climate feedback under future conditions, at scales from the ecosystem to the globe (Burton et al., 2008; Boone et al., 1998; Curiel Yuste et al., 2007; Lavigne et al., 2003). Broad means have been computed for the relative contribution of R_S source fluxes (Hanson et al., 2000); in addition, Bond-Lamberty et al. (2004) noted a highly significant ($R^2 = 0.8$, $P < 0.001$) relationship between R_S and R_H, permitting the estimation of the latter from annual estimates of the former. The much larger data set collected here allows us to re-examine this relationship (Fig. 6); it remains fundamentally the same as that found in Bond-Lamberty et al. (2004), although these data show considerably more scatter. We also note that a few studies examine mycorrhizal (Moyano et al., 2007; Heinemeyer et al., 2007) and geological (Andrews and Schlesinger, 2001) contributions to R_S, although these sources are not broken out in the current database.

4 SRDB access and future development

The SRDB database described here is being released to the scientific community and other interested users, and is available immediately online.

4.1 Database access and updates

A static version of these data is permanently archived at the Oak Ridge National Laboratory's Distributed Active Archive Center (ORNL-DAAC, http://daac.ornl.gov), with a digital object identifier (DOI) of 10.3334/ORNLDAAC/984. There is also a dynamic version of the database, hosted as of this writing on Google Code (http://code.google.com/p/srdb/). This latter archive uses version control software (Subversion, http://subversion.tigris.org/), so that researchers can use (check out) current as well as previous versions of the database. It also features online wiki documentation, a mailing list, and other aspects typical of any open-source project.

Both archives include the database itself, metadata, and usage notes. Initially the two repositories will hold identical copies, but we anticipate that the dynamic version will be expanded and change with time. (In fact it has been updated, as of mid-May 2010, with studies published in 2009.) Thus we recommend that citations to this database always include a version number, download date, and relevant URL. For the immediate future, we anticipate biannual updates to the database; ultimately the scientific community will determine how, and if, this database is used and updated.

4.2 Weaknesses of the current database

This database should be viewed as a "1.0" release. First, there are inevitable data entry mistakes – in unit conversion, language translation, etc. – that will be discovered and corrected. Second, data can be added: new studies appear frequently (91 studies published in 2008 alone were entered, and a similar number were published in 2009), and missed older ones found. In particular, we suspect that there is substantial data in the Russian- and Chinese-language scientific literatures not currently in SRDB. Finally, there are undoubtedly better ways to structure the existing data, and new fields or calculations could be added (for example, meta-information could be improved, as noted above; the R_S soil moisture response is only cursorily treated in the current database; no error terms are included for Q_{10} and R_{10} estimates; R_S partitioning is limited to a crude autotrophic and heterotrophic separation; Q_{10} estimates are not recorded separately by source flux; etc). For all these reasons, we intend to update the dynamic version of this database, and hope that such updating and corrections will ultimately become a shared project driven by interested users of these data; this will make it a true community database that over time could be linked with other, similar projects.

5 Conclusions

The SRDB is designed to capture and make available for analysis the large number of R_S studies published over the last four decades. It will also, we hope, be one of the first such databases in the earth sciences to leverage open-source software technologies, resulting in a dynamic, shared, and more powerful data resource for interested users. The science community will determine how, and if, it changes in the future, and the uses to which these data will be put.

Acknowledgements. This research was supported by the U.S. Department of Energy Office of Science and the Laboratory Directed Research and Development program of the Pacific Northwest National Laboratory. It would not have been possible without the thousands of researchers worldwide who measured, analyzed, and published the data collected here.

Edited by: M. Bahn

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