GlobalC

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## summary

## Abbreviations

* Rroot - root respiration
* Rshoot - shoot respiration
* Rs - soil respiration
* RSG - global annual soil respiration
* Ra - autotrophic respiration (Rroot + Rshoot)
* GPP - gross primary production
* NPP - net primary production
* NEP - net ecosystem production
* Froot - Rroot / Ra (root autotrophic respiration to total autotrophic respiration fraction/ratio, calculation please see plot\_Rroot\_Ra\_ratio function)
* Fshoot - Rshoot / Ra (1-Froot)
* FsFr - (1-Froot)/Froot (FsFr = Rshoot/Rroot ratio)
* RC - (root respiration / soil respiration)
* RaGPP - (Ra/GPP) ratio

## Assumptions

* **Bottom-up approach:**

1. We collected published global soil respiration estimates (mostly is based on bottom up field Rs measurements)
2. We then partition Rs into root respiration and belowground heterotrophic resipiration
3. We also collected published NPP estimates from ITO et al. (2011)
4. From published Rroot/Ra ratios, GPP can be calculated as (NPP + Rroot + Rshoot)
5. We then compare this bottom-up GPP with published GPP in the past decades

* **Top-down approach:**

1. We first collect global GPP estimates (most are top-down from remote sensing)
2. We then estimate Ra according to published Ra/GPP ratios and GPP-NPP
3. Heterotrophic respiration was estimated as Rh = NPP - HerbComsum - Fire - Csink (NEP)
4. Rs\_topdown = Rh + Rroot
5. We then compare this with published Rs (#1 above)

## Questions and more analysis in the future

* How unlikely is it that we can reconcile current Rs and GPP estimates? E.g. what % of the distribution of each ‘allows’ us to match the central estimate of the other? (<30%)
* What is driving the differences between botton-up GPP and reported GPP and top-down Rs and reported Rs?
* How do we resolve this? Where is better/more data needed?
* These questions all resolve around influence x uncertainty = importance, right? This is basically the ‘Dietze graph’.
* Savanna and grassland more than 20% area, but sample numbers are too small for Frrot, RC, and Ra/Gpp ratio
* Ra < 0 how to resolve this (resolved)

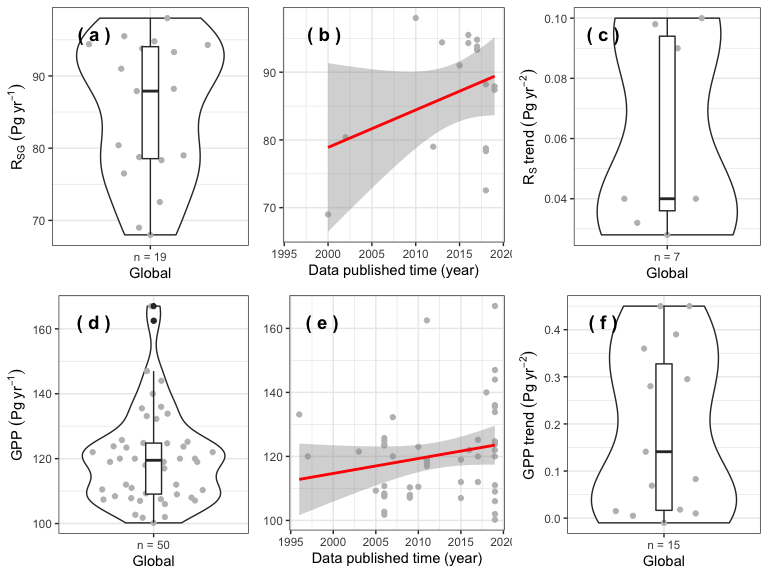
## Importance/implication/benefits

* Provide another way to estimate GPP and Rs
* Provide a method to compare bottom-up GPP (start from field Rs/Froot/RC/Rroot measurements, then modelling to estimate GPP) with remote sensing or land model GPP.
* Provide a method to compare top-down Rs (Rs separated from remote sensing land model based GPP) with filed experiment based Rs (field Rs measurement, then modeling).

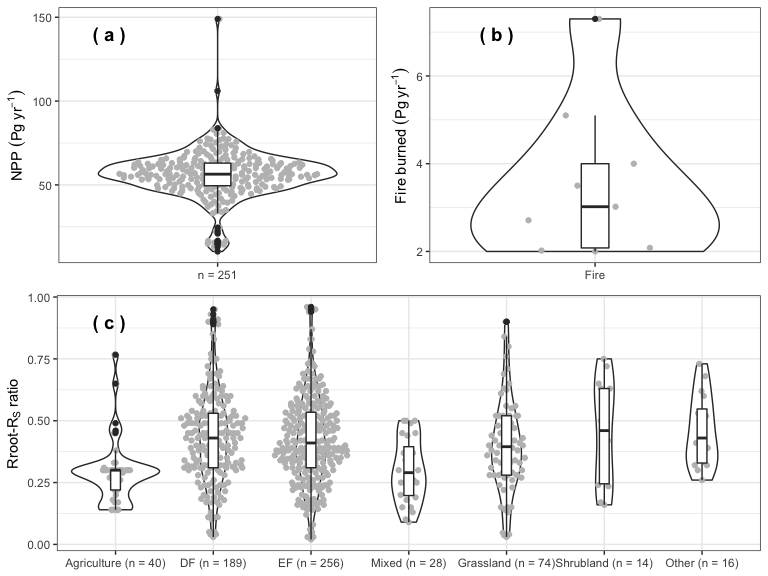
## Methods

## Ratio by vegetation types

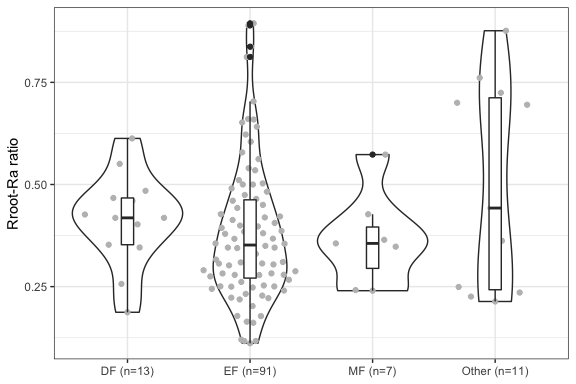
### Plot GPP



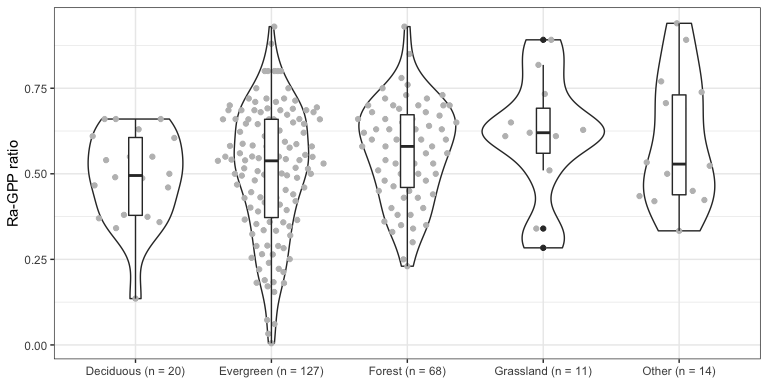
### Plot Rroot-Rs ratio



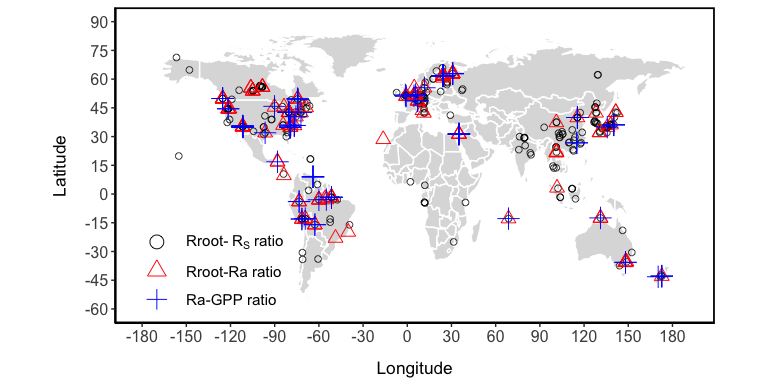
### Plot Rroot-Ra ratio



### Plot Ra to GPP ratio



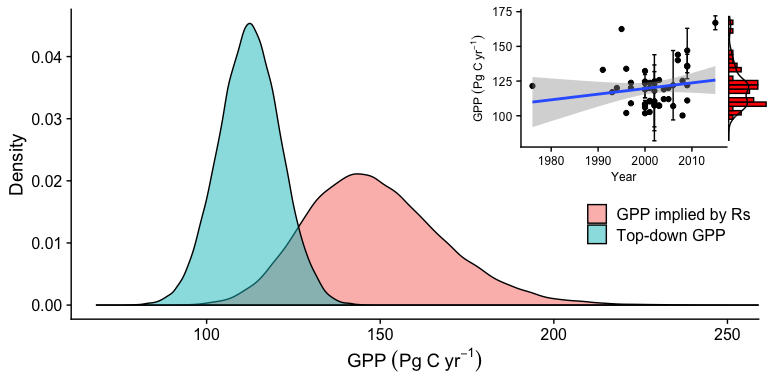
## Sites spatial distribution



## Bootstrapping GPP

## GPP results

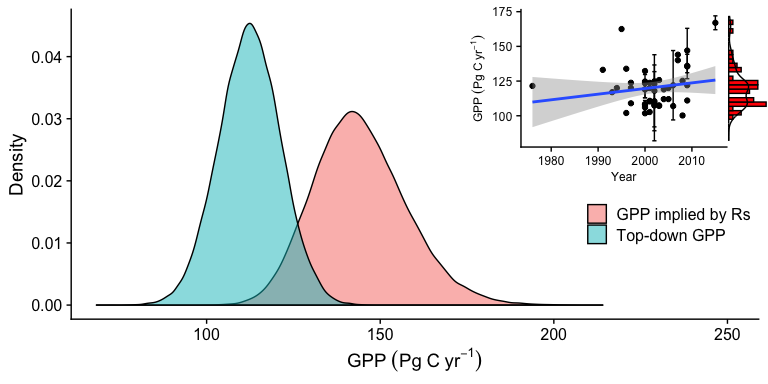
### Scenario 1 - ratio **not** weighted by ecosystem



GPP implied by Rs quantiles: 115 147 192

Top-down GPP quantiles: 95 112 130

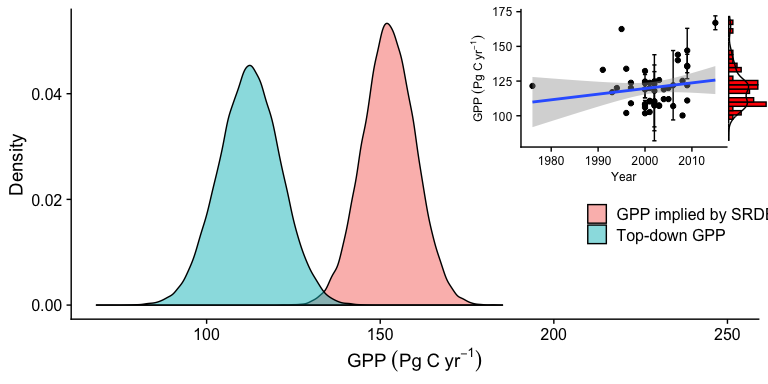
### Scenario 2 - ratio **weighted** by ecosystem



GPP implied by Rs quantiles: 121 143 173

Top-down GPP quantiles: 95 112 130

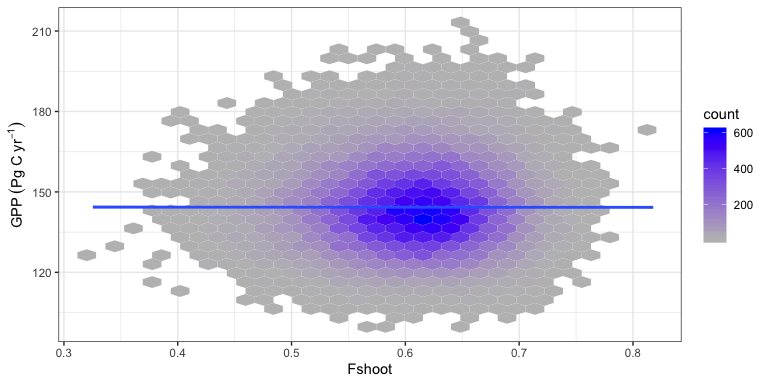
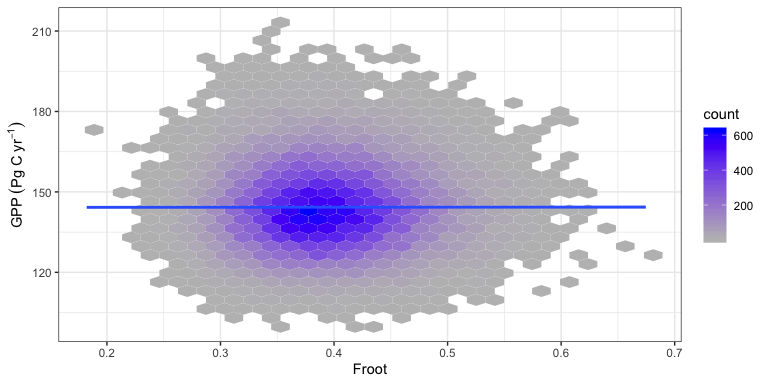
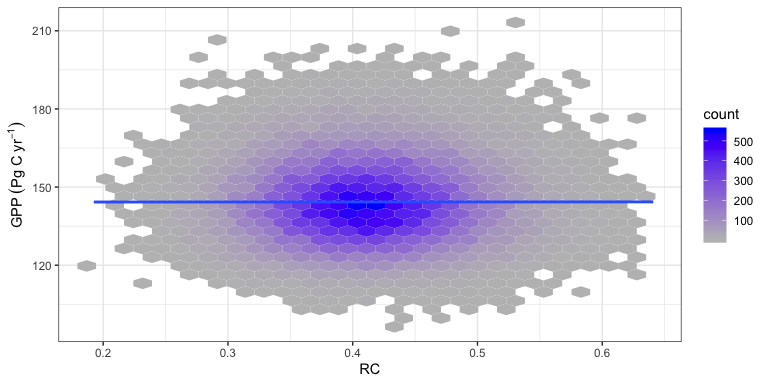
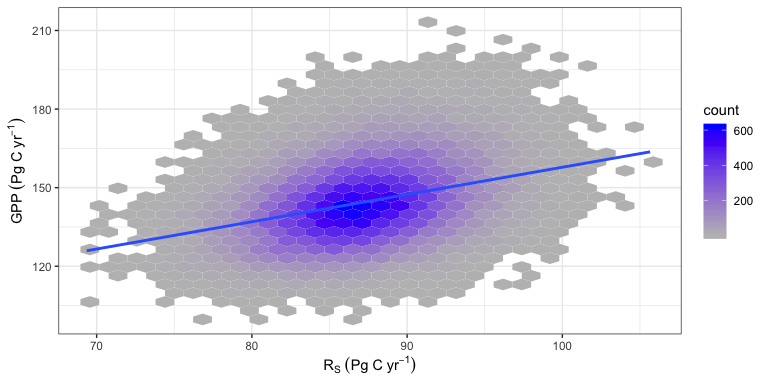
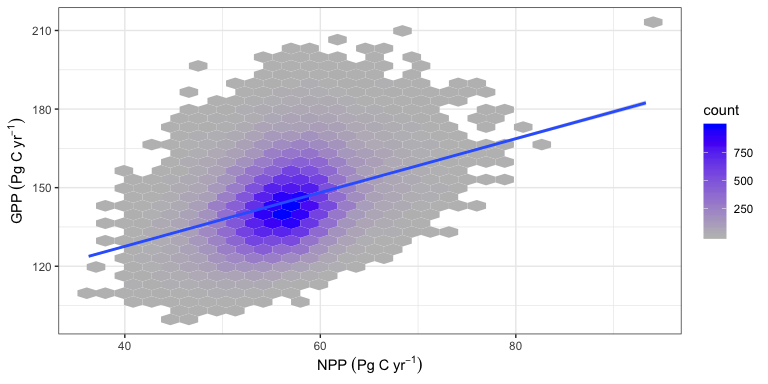
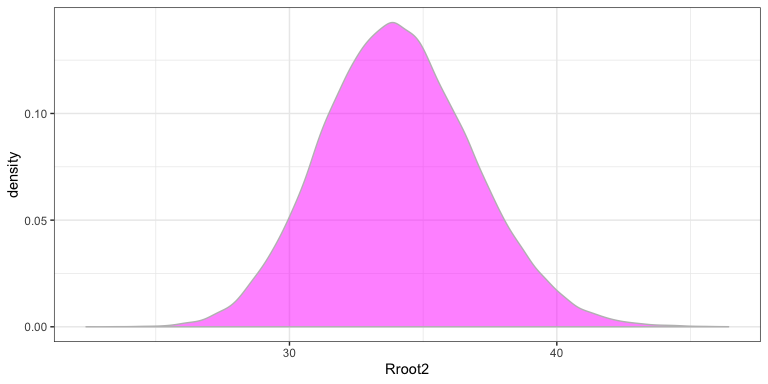
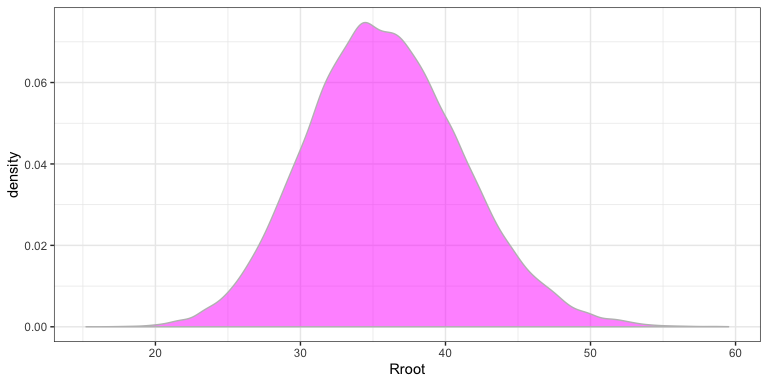
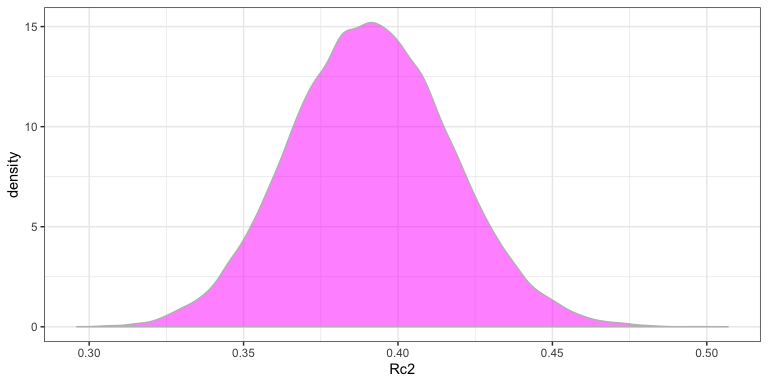
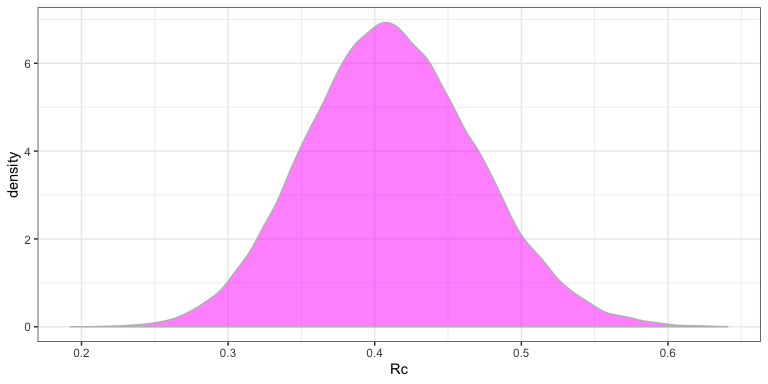
### Scenario 3 - SRDB Rs:GPP ratios



GPP implied by Rs quantiles: 138 153 167

Top-down GPP quantiles: 95 112 130

### GPP vs components relationships



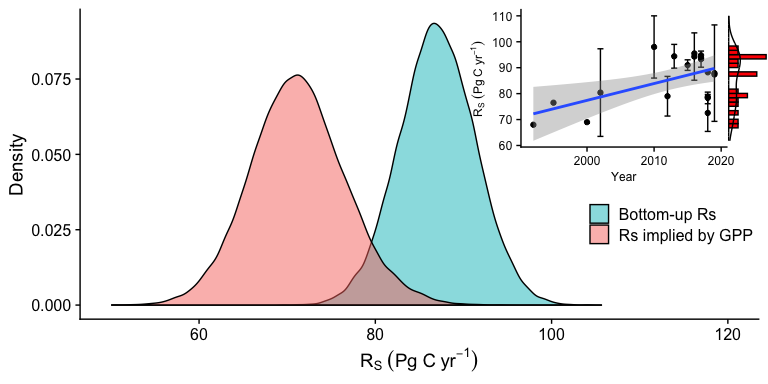
### Probability of agreement

|  |  |  |
| --- | --- | --- |
| Scenario | Agreement (quantiles) | p-value (t.test) |
| 1 (no weighting) | 16.59 % | t = -378, df = 69777, p-value = 0 |
| 2 (weighting) | 14.14 % | t = -446, df = 87306, p-value = 0 |
| 3 (global Rs:GPP) | 0.15 % | t = -768, df = 97491, p-value = 0 |

## Bootstrapping RSG

## RSG results

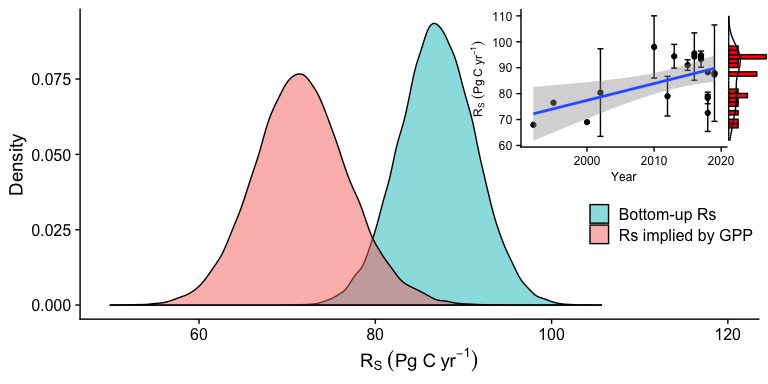
### Scenario 1 - ratio **not** weighted by ecosystem



Rs implied by GPP quantiles: 61 71 82

Bottom-up Rs quantiles: 78 87 96

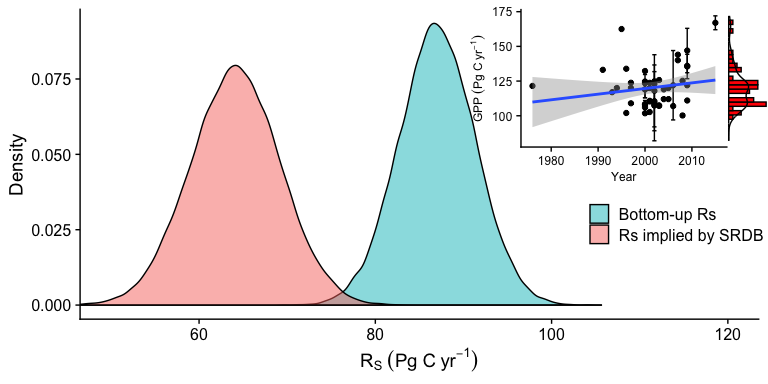
### Scenario 2 - ratio **weighted** by ecosystem



Rs implied by GPP quantiles: 61 72 83

Bottom-up Rs quantiles: 78 87 96

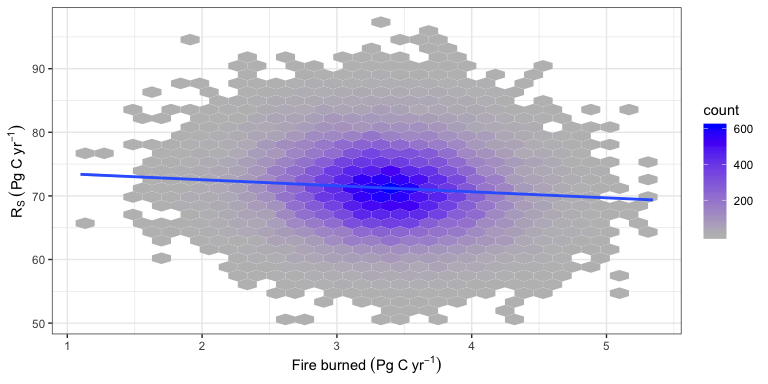
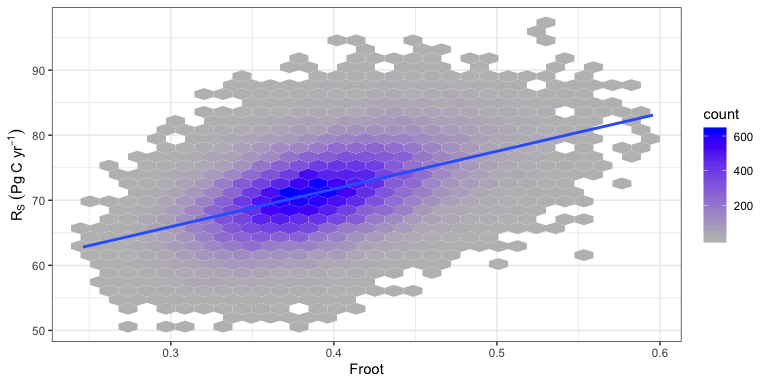
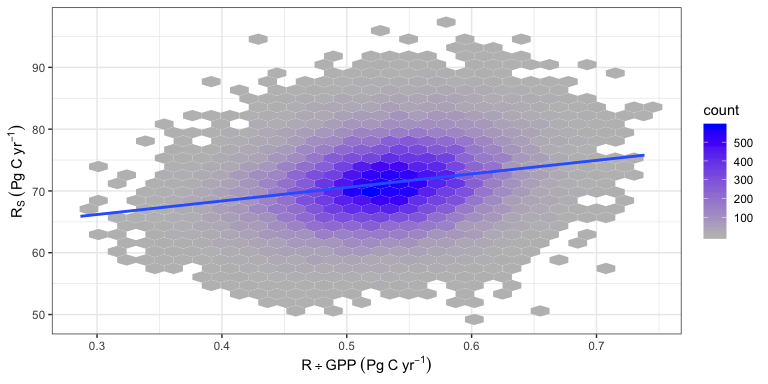
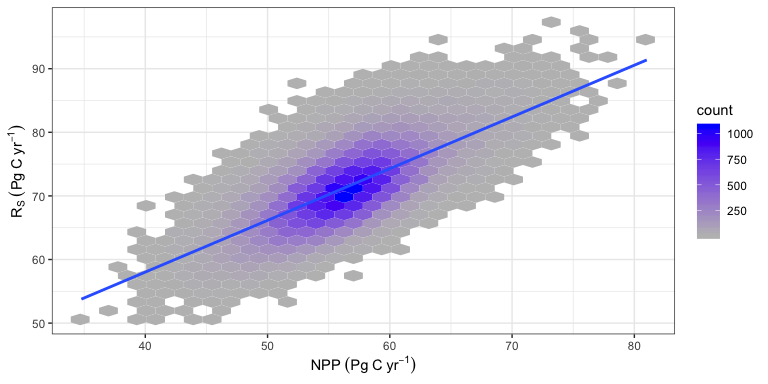
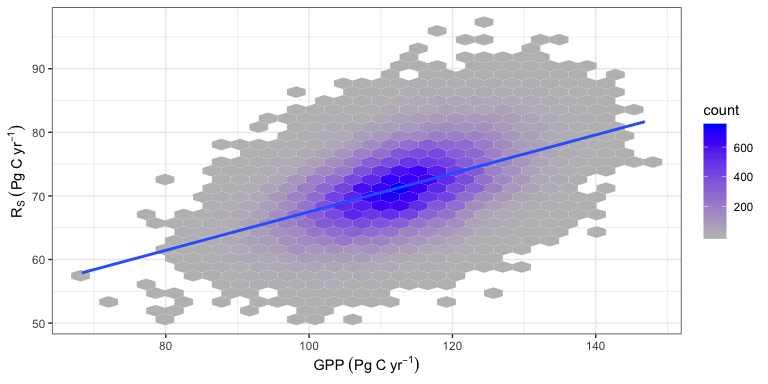
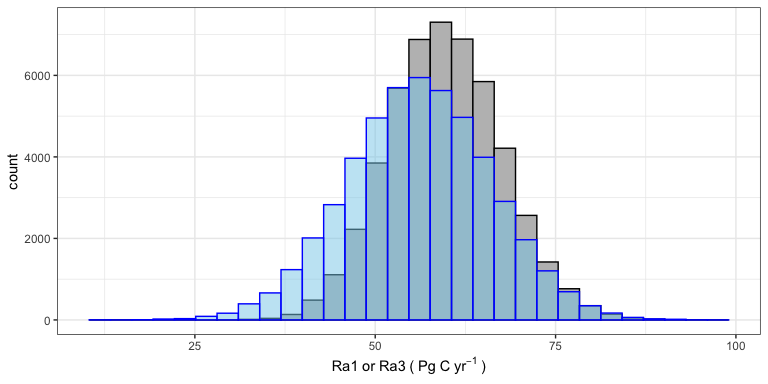
### Scenario 3 - SRDB Rs:GPP ratios



GPP implied by Rs quantiles: 138 153 167

Top-down GPP quantiles: 95 112 130

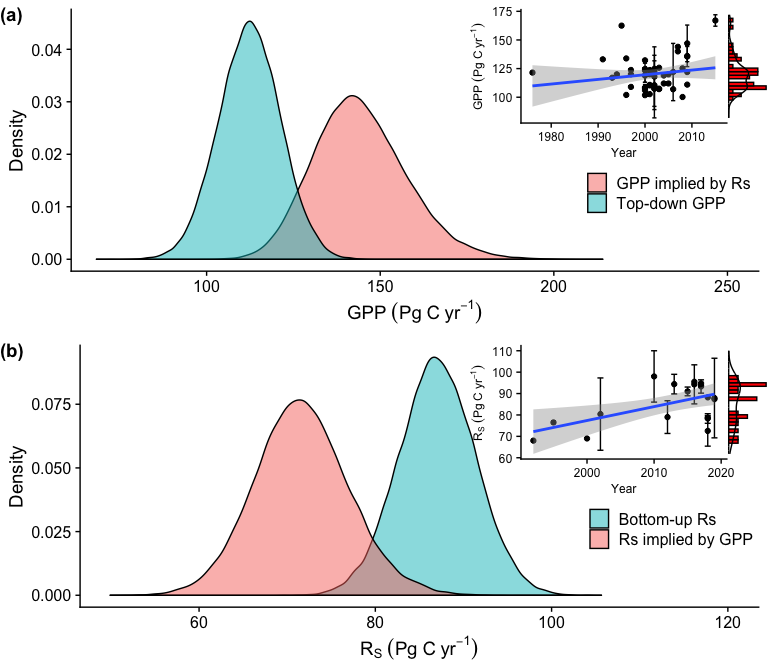
### RSG and components relationship



### RSG probability of agreement

|  |  |  |
| --- | --- | --- |
| Scenario | Agreement (quantiles) | p-value (t.test) |
| 1 (no weighting) | 10.53 % | t = 510, df = 95414, p-value = 0 |
| 2 (weighting) | 11.86 % | t = 499, df = 95727, p-value = 0 |
| 3 (simple global Rs:GPP) | 0.31 % | t = 768, df = 97491, p-value = 0 |

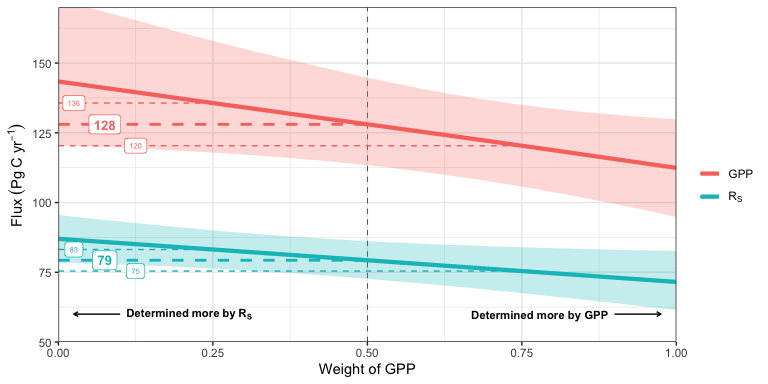
## Topdown and bottomup comparison - Figure 1



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## Combining GPP and Rs

What’s the most likely values for GPP and R[S] that are consistent with the underlying distributions?



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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| which | q025 | q500 | q975 | w |
| GPP | 113.4 | 128.0 | 144.8 | 0.5 |
| Rs | 72.6 | 79.3 | 86.2 | 0.5 |

## Site-specific ratios of GPP to Rs

Presumably, as a matter of mathematics, the ratio of global Rs to global GPP should be the linear combination (sum) of all terrestrial points Neither SRDB nor FLUXNET is an unbiased sample of the land surface, but it may be instructive to look at the Rs:GPP for three data sources:

* Global GPP estimates, comparing them against the mean Rs estimate (~85 Pg C);
* the SRDB itself, for sites at which both GPP and Rs were measured;
* and FLUXNET2015 Tier 1, using Rs data measured very close to the towers.

Source

Ratio

SRDB (N = 171)

0.542

FLUXNET (N = 1043)

0.535

CMIP6 (N = 0)

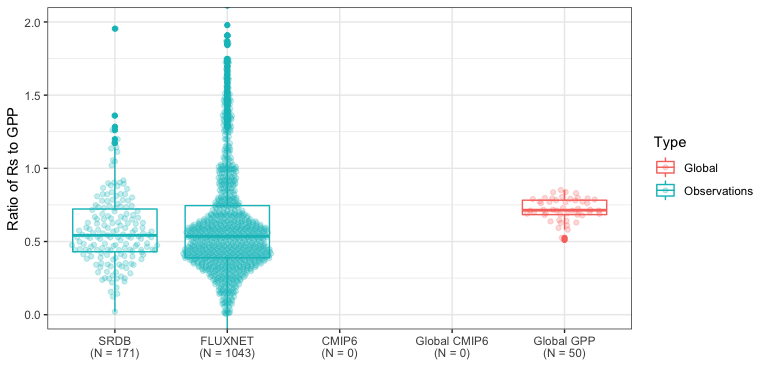
NA

Global CMIP6 (N = 0)

NA

Global GPP (N = 50)

0.714



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Note that the arithmetic mean of Rs:GPP in SRDB is 0.559 (median 0.509), while the weighted (by area of ecosystem types globally) is 0.57. This close agreement implies that SRDB is in fact a pretty good representation of the land surface (and/or that Rs:GPP doesn’t vary much).

## Other diagnoses

### Abstract

Top-down global GPP: (72±5 Pg C yr^{-1})

Bottom-up global R[S]: (x ± y).

### Text for methods / supplemental information

We conducted an analysis of global terrestrial carbon cycling to compare and explore the consistency of top-down and bottom-up global gross primary production (GPP) and soil respiration (R[S]) estimates. Soil respiration, the soil-to-atmosphere CO2 flux measured worldwide, is the sum of root respiration (Rroot) and heterotrophic respiration (Rh). These source fluxes both consume carbon fixed by plants at some point in the past via photosynthesis or GPP. Plant autotrophic respiration (including leaf respiration and stem respiration, Rshoot, and root respiration, Rroot) consumes part of GPP, and the remainder is termed net primary productivity (NPP). Part of NPP is in turn consumed by heterotrophic respiration (Rh), another part is consumed by herbivores or burned in fires, with the remainder comprising long term carbon storage (the terrestrial carbon sink). Theoretically, if we know how GPP is partitioned at each step, we can estimate mean annual soil respiration at site or global scales, producing a top-down estimate of R[S]; similarly, we can estimate GPP via a bottom-up approach that starts with R[S]. To make this comparison, we evaluated two approaches to partitioning the global carbon cycle from known estimates of the various fluxes and calculated the unknowns (Figure S1–S5 and Table S1–S4).

#### GPP implied by RSG

In the past decades, many estimates of global RS (bottom-up global RS estimates, n=19) have been made and are summarized in **Figure S1**. Most of these estimates were based on the field measured RS data. RS consists of heterotrophic respiration (Rh) and root respiration (Rroot), and some studies have separated RS into these source fluxes; the resulting Rroot-to-RS ratios (RC) have been compiled into the SRDB-V4 (**Figure S2**). We used all RC values from SRDB-V4 ≥0 and ≤1, in total 617 separate RC values RC values. These covered 9 vegetation types, but the majority were from forest, grassland, agriculture, and shrubland; all other vegetation types had only 16 samples (**Figure S2c**).

In addition, root respiration is only part of autotrophic respiration, and the rest is shoot respiration. Many studies have separated Ra into Rroot and Rshoot, and thus Rroot-to-Ra ratio, Rroot-to-Rshoot ratio can be calculated. According to the bottom-up Global RS estimates, Root-to-RS ratio (RC), and Rroot-to-Rshoot ratio (data come from SRDB), Rroot and Rshoot, GPP can be calculated (bottom-up GPP, **Figure S1** and **Equations 1-3**).

We collected 19 published RSG estimates from articles, with approximately half of studies reported RSG standard deviation (SD, n=10, **Table S1**) and change rate during a period (n=7, **Table S1**). The reported RSG range from 68 to 98 Pg C yr-1, with an average RSG of 85.32 Pg C yr-1. The RSG were published from 1992 to 2019, and the RSG estimate showed a clear increase trend from the earlier years to the modern year (increase rate = 0.65 Pg C yr-2, Figure S1 b). However, this rate is much higher than the average increase rate reported by previous studies (mean = 0.06 Pg C yr-2, n=7, Figure S1 c).

Then Rshoot can be calculated based on the Rroot and Rroot-to-Rshoot ratio, finally, bottom-up GPP can be calculated (**Figure S1**). We then compare the bottom-up GPP with GPP from publication in the past decades (top-down GPP) to determine the consistency between the bottom-up and top-down GPP. The following equations were used to calculate GPP from RSG:

**Equations (1 to 3)**  
Rroot = Rs × Rroot-Rs ratio (i.e., RC in SRDB) (1)  
Rshoot = Rroot × Rroot-Rshoot ratio (2)  
GPP = NPP + Rroot + Rshoot (3)

#### RSG implied by GPP

Many efforts have been made to estimate GPP based on both remote sensing and FLUXNET data in the past decades (n=50, Figure S1). We collected 50 GPP estimates from published articles, with only 11 of estimates reported corresponding SD, and 15 estimates reported corresponding trend during a period (Table S2). The reported GPP estimates were from 1996 to 2019, ranged from 100.21 to 167 Pg, and with an average of 120.28 Pg C yr-1. There is a clear positive relationship between GPP and estimate-year, with an increase rate of 0.47 Pg C yr-2, Figure S1 e), which is bigger than the mean of reported increase rates (0.19 Pg C yr-2, Figure S1 f). Furthermore, the extreme high (167 Pg) and low (100.21 Pg) GPP estimates does not affect the overall mean GPP, as the average does not change when both extreme high and low GPP values were excluded.

GPP can be further separated into NPP, carbon consumed by herbivore, carbon burned by fire, carbon going to terrestrial as carbon sink, and carbon consumed by autotrophic respiration (Ra). Global NPP estimates were directly from a previous meta-analysis (Table S3 and Figure S2 a). Based on 251estimates (Table S2), global annual mean NPP from 1862 to 2011 was 56.25 Pg C yr-1 (±14.3, SD). In order to estimate Rh, we collected published estimates on NPP going to the terrestrial (Csink), NPP components burned by fire, and NPP components consumed by herbivores (Table S3). When substract carbon consumed by herbivores, fire, and land sink from NPP, global Rh between 1961 and 2014 can be estimated (Rh = NPP - Herbivores - Csink – Fire, Figure S1 and Table S1-S3).

The difference between GPP and NPP is autotrophic respiration (Ra), Ra is a major component of the terrestrial carbon cycling and it consumes a major part of plants sequestrated carbon by photosynthesis (GPP). Ra-to-GPP-ratio is required to estimate Ra based on GPP. Ra-to-GPP-ratio used in this study were from two sources: (1) We conducted a literature search and collected 123 Ra-to-GPP-ratio estimates (Table S5); (2) We obtained additional 117 Ra-to-PP-ratio estimates from SRDB-V4. Ra-to-GPP-ratio used in this study covered 9 vegetation types, but mainly from forest and grassland, all the other vegetation types only have 14 samples (Figure S4).

Autotrophic respiration (Ra) consists of root respiration (Rroot) and shoot respiration (Rshoot), Rroot-to-Ra ratio is required to separate Ra into Rroot and Rshoot. Rroot-to-Ra ratio used in this study were from two sources: (1) We collected 35 Rroot-to-Ra ratio estimates from 28 studies (Table S4); (2) We obtained additional 87 Rroot-to-Ra ratio estimates from SRDB-V4 (Table S4). Rroot-to-Ra ratio covered 7 vegetation types (Figure S3), but mainly from forest, all other vegetation types only have 11 samples.

Finally, according to the top-down GPP, NPP, Ra-to-GPP ratio, Rroot-to-Ra ratio, and Rshoot-to-Ra ratio, GPP can be separated into Rh, Rshoot, and Rroot, and thus, global RS can be calculated (Up-panel in Figure S1 and equations 4-10). We then compare the top-down RSG with RSG from publication in the past decades (bottom-up RSG) to determine the consistency between the bottom-up and top-down RSG.

**Equations (4 to 10)**  
Ra = GPP – NPP (4)  
Ra = ecosystem-respiration – heterotrophic-respiration (5)  
Ra = GPP × Ra-GPP ratio (6)  
Rh = NPP - Fire\_C - Herb\_C (7)  
Rroot = Ra × Rroot-Ra ratio (8)  
Rshoot = Ra × Rshoot-Ra ratio (9)  
Rs = Ra + Rh (10)

***Bootstrap resampling***

We used a bootstrap resampling approach to get the best estimate for each component in the bottom-up and top-down process. Sample size of each component in the bottom-up and top-down approach is different, and many of them do not following normal distribution (Figure S1-S4). We thus used a boosting resampling approach to regenerate the samples for each component (details please see the Github repository). For the Rroot-to-RS-ratio (RC), Rroot-to-Ra-ratio, and Ra-to-GPP ratio, we further separated them by ecosystem types, and weighted by their area (area of each ecosystem were from the IGBP ecosystem land classification, <https://climatedataguide.ucar.edu/climate-data/ceres-igbp-land-classification>).

We evaluated X different resampling methods, which differed in how they treated the presence and absence of errors associated with each flux estimate. … We used the most conservative approach, i.e. that resulted in the widest distributions of GPP and R[S].

***Statistical analysis***

Summarize stats and software used.

***Components important analysis***