SiB4 Modeled Global 0.5-Degree Daily Carbon Fluxes and Pools, 2000-2018

Get Data

Documentation Revision Date: 2021-04-19

Dataset Version: 1

Summary

This dataset provides global daily output predicted by the Simple Biosphere Model, Version 4.2 (SiB4), at a 0.5-degree spatial resolution covering the time period 2000 through 2018. SiB4 is a mechanistic land surface model that integrates heterogeneous land cover, environmentally responsive phenology, dynamic carbon allocation, and cascading carbon pools from live biomass to surface litter to soil organic matter. Daily output includes carbon, carbonyl sulfide, and energy fluxes; solar-induced fluorescence; carbon pools; soil moisture and temperatures in the top three layers; total column soil water and plant available water; and environmental potentials used to scale photosynthesis. The SiB4 output is per plant functional type (PFT) within each 0.5-degree grid cell. SiB4 partitions variable output to 15 PFTs in each grid cell that are indexed by the "npft" dimension (01-15) in each data file. The PFT three-character abbreviations ("pft_names" variable) are listed in the same order as the "npft" dimension. To combine the PFT-specific output into grid cell totals, users must compute the area-weighted mean across the vector of PFT-specific values for each cell. Fractional areal coverages are given in the "pft_area" variable for each cell.

There are three SiB4 0.5-degree global scale datasets being released contemporaneously. They differ by frequency of model data output and aggregation–hourly, daily, and monthly. The SiB4 model runs at a 10-minute time step and outputs carbon fluxes, productivity, ecosystem respiration, solar radiation, and soil properties that are aggregated hourly. At a daily time step, carbon is allocated to pools completing the carbon cycle and providing self-consistent predicted vegetation states, soil hydrology, carbon pools, and land-atmosphere exchanges. The daily outputs are also aggregated to a monthly scale.

Estimates of carbon fluxes can be used in a variety of studies of atmospheric CO_2 concentrations. The carbonyl sulfide (COS) and solar-induced fluorescence (SIF) output can be used in studies investigating various approaches to estimate carbon uptake using these variables, and the 19-year time span of this dataset provides ample data for comparison against various satellite and in situ measurements. Finally, this output can be used in studies focused on spatial gradients as vegetation responds to shifts in climate. SiB4 can simulate these emergent ecosystem behaviors because it uses a mechanistic framework to capture vegetation responses to changes in the environment.

There are 229 data files in netCDF-4 (*.nc4) format and 3 companion files included in this dataset.

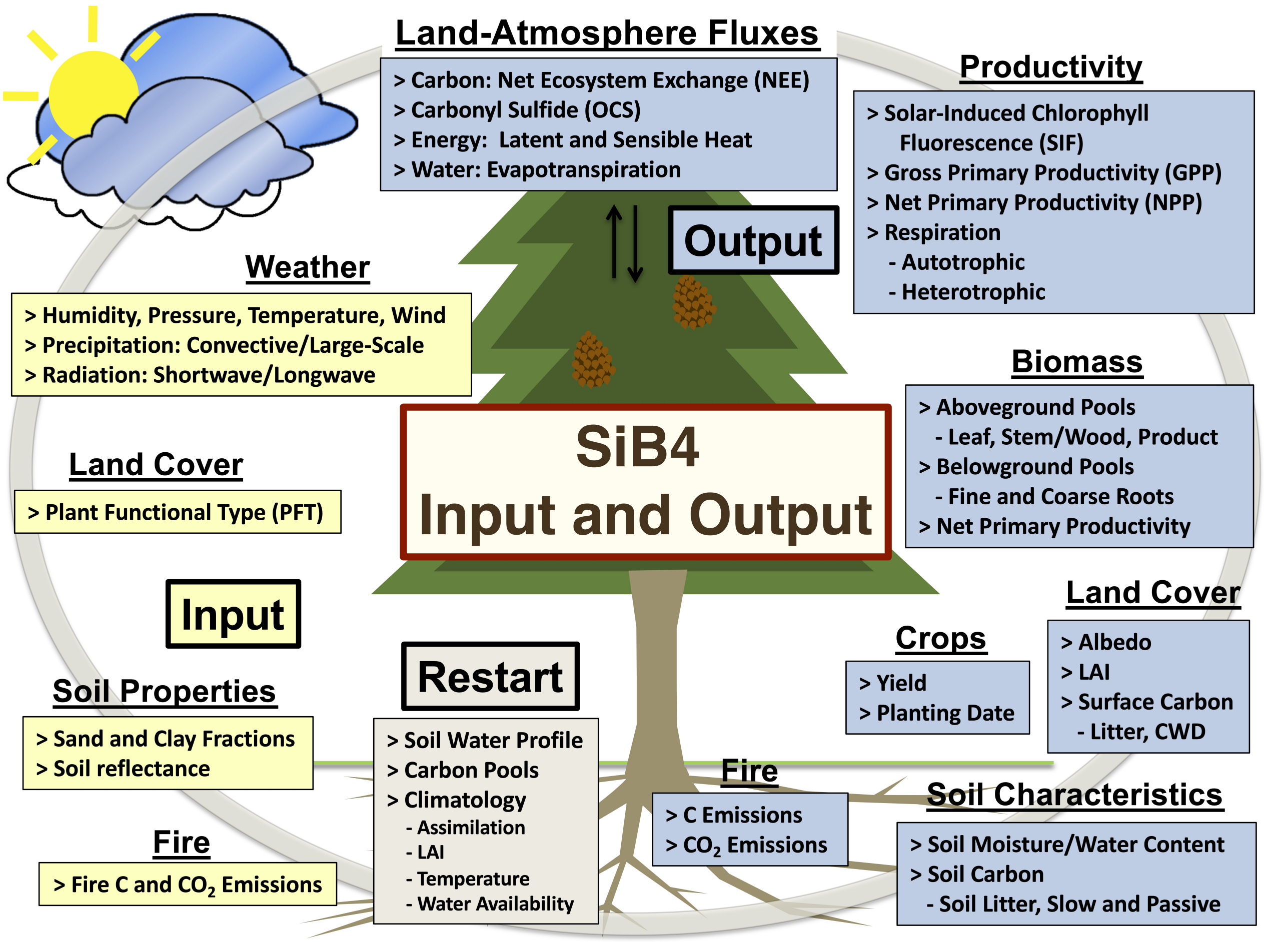

Figure 1. Overview of the Simple Biosphere Model (SiB4) that estimates carbon fluxes among the atmosphere, vegetation, and soils. Input information is shown in yellow boxes. This dataset includes a selection of the output variables (blue boxes). Source: Haynes et al. (2020)

Citation

Haynes, K.D., I.T. Baker, and A.S. Denning. 2021. SiB4 Modeled Global 0.5-Degree Daily Carbon Fluxes and Pools, 2000-2018. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1849

Table of Contents

1. Dataset Overview

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Project: Carbon Monitoring System

The NASA Carbon Monitoring System (CMS) program is designed to make significant contributions in characterizing, quantifying, understanding, and predicting the evolution of global carbon sources and sinks through improved monitoring of carbon stocks and fluxes. The System uses NASA satellite observations and modeling/analysis capabilities to establish the accuracy, quantitative uncertainties, and utility of products for supporting national and international policy, regulatory, and management activities. CMS data products are designed to inform near-term policy development and planning.

Related Publications

Haynes, K.D., I.T. Baker, A.S. Denning, R. Stöckli, K. Schaefer, E.Y. Lokupitiya, and J.M. Haynes. 2019a. Representing grasslands using dynamic prognostic phenology based on biological growth stages: 1. Implementation in the Simple Biosphere Model (SiB4 Journal of Advances in Modeling Earth Systems 11:4423–4439. https://doi.org/10.1029/2018MS001540

Haynes, K.D., I.T. Baker, A.S. Denning, S. Wolf, G. Wohlfahrt, G. Kiely, R.C. Minaya, and J.M. Haynes. 2019b. Representing grasslands using dynamic prognostic phenology based on biological growth stages: 2. Carbon Cycling. Journal of Advances in Modeling Earth Systems 11:4440–4465. https://doi.org/10.1029/2018MS001541

Haynes, K., I. Baker, and S. Denning. 2020. Simple Biosphere Model version 4.2 (SiB4) technical description. Mountain Scholar, Colorado State University, Fort Collins, CO, USA. https://hdl.handle.net/10217/200691

Related Dataset

Baker, I.T., A.S. Denning, L. Prihodko, K. Schaefer, J.A. Berry, G.J. Collatz, N.S. Suits, R. Stockli, A. Philpott, and O. Leonard. 2009. SiB3 Modeled Global 1-degree Hourly Biosphere-Atmosphere Carbon Flux, 1998-2006. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/909

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Haynes, K.D., I.T. Baker, and A.S. Denning. 2021. SiB4 Modeled Global 0.5-Degree Monthly Carbon Fluxes and Pools, 2000-2018. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1848

Acknowledgments

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2. Data Characteristics

Spatial Coverage: Global

Spatial Resolution: 0.5 degree

Temporal Coverage: 2000-01-01 to 2018-12-31

Temporal Resolution: Daily

Study Area: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Global	-180	180	90	-90

Data File Information

There are 229 data files in netCDF-4 (*.nc4) format and 3 companion files included in this dataset. The file naming convention is sib4_0.5x0.5_daily_YYYYmm.nc4, where YYYYmm indicates the year, and month of the estimates.

File Name	Description
Data Files	
sib4_0.5x0.5_daily_YYYYmm.nc4	Daily estimates of 36 variables (Table 1) where the year and month are indicated by YYYYmm
Betas_GPP_RESP.nc4	Carbon sink factors for gross primary production (*gpp*) and ecosystem respiration (*resp*) for each grid cell. These factors can be used to multiply carbon fluxes in the model output to estimate carbon sinks (see Section 3).
Companion Files	
SiB4_v2.tgz	Compressed archive containing Fortran code for the SiB4 model
SiB4_assessment.pdf	Evaluation of SiB4 carbon and energy flux, leaf area index, and biomass predictions
SiB4_Global_HalfDegree_Hourly.pdf	This user guide in PDF format

Data File Details

Table 1. Modeled variable descriptions.

Variable	Dimensions	Units	Description
aparkk	lon, lat, npft, time	1	Leaf to Canopy Scaling Factor
cos_assim	lon, lat, npft, time	pmole m^{-2} s^{-1}	Carbonyl Sulfide (COS) Vegetation Assimilation
cos_flux	lon, lat, npft, time	pmole m^{-2} s^{-1}	Canopy Air Space (CAS) COS Flux
cos_grnd	lon, lat, npft, time	pmole m^{-2} s^{-1}	COS Soil Uptake
fpar	lon, lat, npft, time	1	Absorbed Fraction of Photosynthetically Active Radiation
gpp	lon, lat, npft, time	μmole m^{-2} s^{-1}	Gross Primary Production in micromoles of carbon per m^2 per second
lai	lon, lat, npft, time	1	Leaf Area Index, ratio of m^2 per m^2

lh	lon, lat, npft, time	W m^{-2}	Canopy Air Space (CAS) to Mixed Layer Latent Heat Flux
pawfrw	lon, lat, npft, time	1	Root-Weighted Plant Available Water Fraction
pawftop	lon, lat, npft, time	1	Mean Plant Available Water Fraction in the top three Soil Layers
pool_arm	lon, lat, npft, time	Mg ha^{-1}	Armored (Passive) Soil Carbon Pool in Mg carbon per hectare
pool_cdb	lon, lat, npft, time	Mg ha^{-1}	Coarse Dead Biomass Carbon Pool in Mg carbon per hectare
pool_croot	lon, lat, npft, time	Mg ha^{-1}	Coarse Root Carbon Pool in Mg carbon per hectare
pool_froot	lon, lat, npft, time	Mg ha^{-1}	Fine Root Carbon Pool in Mg carbon per hectare
pool_leaf	lon, lat, npft, time	Mg ha^{-1}	Leaf Carbon Pool in Mg carbon per hectare
pool_lmet	lon, lat, npft, time	Mg ha^{-1}	Metabolic Litter Carbon Pool in Mg carbon per hectare
pool_lstr	lon, lat, npft, time	Mg ha^{-1}	Structural Litter Carbon Pool in Mg carbon per hectare
pool_prod	lon, lat, npft, time	Mg ha^{-1}	Product Carbon Pool (includes flowers/seeds for non-crops) in Mg carbon per hectare
pool_slit	lon, lat, npft, time	Mg ha^{-1}	Soil Carbon Litter (Dead Roots) in Mg carbon per hectare
pool_slow	lon, lat, npft, time	Mg ha^{-1}	Slow Soil Carbon Pool in Mg carbon per hectare
pool_wood	lon, lat, npft, time	Mg ha^{-1}	Wood Carbon Pool in Mg carbon per hectare
resp	lon, lat, npft, time	µmole m^{-2} s^{-1}	Ecosystem respiration in micromoles of carbon per m^2 per second (does not include fire emissions). Total ecosystem respiration = *resp* + *resp_fireco2*.
resp_fireco2	lon, lat, time	µmole m^{-2} s^{-1}	Fire CO_2 emissions in micromoles of carbon per m^2 per second from the Global Fire Emissions Database (van der Werf et al. 2017). **NOTE:** This value is total per grid cell and not partitioned among plant functional types.
rstfac1	lon, lat, npft, time	1	Leaf Surface Relative Humidity Potential
rstfac2	lon, lat, npft, time	1	Rootzone Water Potential
rstfac3	lon, lat, npft, time	1	Temperature Potential
rstfac4	lon, lat, npft, time	1	Environmental Photosynthetic Potential, the product of leaf surface relative humidity (*rstfac1*), rootzone water (*rstfac2*), and temperature (*rstfac3*) potentials.
sh	lon, lat, npft, time	W m^{-2}	Canopy Air Space (CAS) to Mixed Layer Sensible Heat Flux
sif	lon, lat, npft, time	W m^{-2} nm^{-1} sr^{-1}	Solar Induced Fluorescence (SIF)
tc	lon, lat, npft, time	K	Canopy Temperature
td1	lon, lat, npft, time	K	Soil Temperature, Layer 1
td2	lon, lat, npft, time	K	Soil Temperature, Layer 2
td3	lon, lat, npft, time	K	Soil Temperature, Layer 3
www_liq1	lon, lat, npft, time	kg m^{-2}	Soil Liquid, Layer 1
www_liq2	lon, lat, npft, time	kg m^{-2}	Soil Liquid, Layer 2
www_liq3	lon, lat, npft, time	kg m^{-2}	Soil Liquid, Layer 3
www_tot	lon, lat, npft, time	kg m^{-2}	Total Soil Column Water and Ice

Table 2. Input variable descriptions.

Variable	Dimensions	Units	Description
crs			The Coordinate Reference System, WGS84 (EPSG:4326)
lat	lat	degrees_north	Latitude
lon	lon	degrees_east	Longitude
pft_area	lon, lat, npft	1	Fractional areal coverage of PFT in each grid cell
pft_names	npft, clen		Names of 15 plant functional types (PFT); three-character string abbreviations (*clen*) defined in Table 3. Output variables are partitioned by PFT and indexed by the *npft* dimension, except for fire carbon-dioxide emissions (*resp_fireco2*).
time	time	d	Timestep in days since 2000-01-01 00:00:00
time_bnds	time	d	Timestep in days since 2000-01-01 00:00:00

Table 3. Plant functional types (PFT) from Haynes et al. (2020). *npft* and *clen* are the dimensions of variable *pft_names*.

npft	clen	PFT

1	DBG	Desert and Bare Ground
2	ENF	Evergreen Needleleaf Forest
3	DNF	Deciduous Needleleaf Forest
4	EBF	Evergreen Broadleaf Forest
5	DBF	Deciduous Broadleaf Forest
6	SHB	Shrubs (Non-Tundra)
7	SHA	Tundra Shrubs
8	C3A	Tundra Grassland
9	C3G	C3 Grassland
10	C4G	C4 Grassland
11	C3C	C3 Generic Crop
12	C4C	C4 Generic Crop
13	MZE	Maize
14	SOY	Soybeans
15	WWT	Winter Wheat

Companion File Details

The file SiB4_v2.tgz contains the SiB4 (Version 4.2) code and sample data required to perform a sample simulation. The folder, SiB4_v2, contains:

- A file named LICENSE describing the BSD 3-Clause license.
- A file named README.txt containing a basic description of the contents in this folder, along with how to compile SiB4 and references.
- The subfolder *code*, which contains the SiB4 code for use in Fortran F90.
- The subfolder *sample*, which contains all the data required to run a sample site. The file README_sample.txt details how to run SiB4.

3. Application and Derivation

The Simple Biosphere Model (SiB4) is a mechanistic land surface model that integrates land cover, phenology, dynamic carbon allocation, and cascading carbon pools from live biomass to surface litter to soil organic matter. By combining biogeochemical, biophysical, and phenological processes, SiB4 predicts vegetation and soil moisture states, land surface energy and water budgets, and the terrestrial carbon cycle. SiB4 fully simulates the terrestrial carbon cycle by using the carbon fluxes to determine the above- and belowground biomass, which in turn feeds back to impact carbon assimilation and respiration. At every 10-minute time step, SiB4 computes the albedo, radiation budget, hydrological cycle, layered temperatures, and soil moisture, as well as the resulting energy exchanges, moisture fluxes, carbon fluxes, and carbon pool transfers. Photosynthesis depends directly on environmental factors (i.e., humidity, moisture, and temperature) and aboveground biomass; and carbon uptake is determined using enzyme kinetics and stomatal physiology. Carbon release and pool transfers depend on assimilation rate, day length, moisture, phenology, temperature, and pool size. At daily time steps, the net assimilated carbon is allocated to the live pools depending on phenology, soil moisture, and temperature; all live and dead pools are updated, including any necessary carbon transfers between pools; and the land surface state and related properties are revised. The new leaf area index and pools are then used for sub-hourly assimilation and respiration, completing the carbon cycle and providing self-consistent predicted vegetation states, soil hydrology, carbon pools, and land-atmosphere exchanges.

Estimates of carbon fluxes can be used in a variety of studies of atmospheric CO_2 concentrations. The carbonyl sulfide (COS) and solar-induced fluorescence (SIF) output can be used in studies investigating various approaches to estimate carbon uptake using these variables, and the 19-year time span provides ample data for comparison against various satellite and in situ measurements. Finally, this output can be used in studies focused on spatial gradients as vegetation responds to shifts in climate. SiB4 can simulate these emergent ecosystem behaviors because it uses a mechanistic framework to capture vegetation responses to changes in the environment.

Carbon Sinks in Simulated SiB4 Output

The companion file Betas_GPP_RESP.nc4 provides the multipliers of carbon fluxes to produce carbon sinks in simulated SiB4 output.

Since the equations in land surface models are by definition balanced, all long-term sources and sinks of carbon must be prescribed. This monthly global dataset includes biomass burning, crop harvest, and grazing disturbances; however, these processes do not fully capture the magnitude of the sink of carbon seen in observations. Supplemental sinks of carbon per PFT and per grid cell as multipliers on the carbon fluxes are provided. These photosynthesis and respiration multipliers will create sinks matching the observed carbon sink. The four processes used to create these sinks are CO_2 fertilization, North American nitrogen fertilization, European nitrogen fertilization, and boreal forest warming. To use these fluxes, multiply the SiB4 gross primary production (*gpp*) by the *beta_gpp* and the respiration (*resp*) by the *beta_resp*.

4. Quality Assessment

SiB4 has been evaluated around the globe using a variety of metrics:

- Atmospheric CO_2 concentrations produced from the SiB4 carbon fluxes have been evaluated against satellite data (OCO-2) (Philip et al., 2019).
- Carbon and energy fluxes for grasslands have been compared against Fluxnet data and satellite (MODIS) leaf area index (LAI) (Haynes et al., 2019b).
- Gross primary productivity (GPP), total ecosystem respiration (TER), and the resulting net ecosystem exchange (NEE) response to drought over Europe in 2018 have been evaluated using the Integrated Carbon Observation System (ICOS) ecosystem/atmospheric observations and satellite SIF (GOME-2B) (Smith et al., 2020).
- Soil moisture and SIF have been analyzed against satellite data (i.e., SMAP, OCO-2) to evaluate the timing of spring green-up in SiB4 (Smith et al., 2018).
- Solar-induced fluorescence (SIF) has been evaluated against remotely-sensed SIF (OCO-2) (Cheeseman 2018).

The companion file SiB4_assessment.pdf provides a thorough evaluation of SiB4 carbon and energy fluxes, LAI, and biomass.

5. Data Acquisition, Materials, and Methods

This dataset is output from a SiB4 simulation. SiB4 methodology is reported in Haynes et al. (2019a) and Haynes et al. (2020).

For weather, the simulation uses hourly data (i.e., surface incident shortwave and longwave radiation, surface pressure, mixed-layer temperature, water vapor mixing ratio, wind speed, and convective and large-scale precipitation) from the Modern-Era Retrospective Analysis for Research and Applications (MERRA), gridded at 0.5 degree by 0.625 degree (Rienecker et al., 2011). Following Baker et al. (2010), to ensure realistic rainfall, each hourly convective and large-scale precipitation value is scaled equally such that the monthly total rainfall matches the monthly precipitation in the Global Precipitation Climatology Project (GPCP) Version 1.2 product (Huffman et al., 2001). The soil characteristics, including soil texture and reflectance, are specified from the International Geosphere-Biosphere Programme (IGBP) (Global Soil Data Task, 2014).

SiB4 predicts land cover heterogeneity by utilizing patches, with up to 10 different plant functional types (PFT) allowed per grid cell. The PFTs are derived from 0.1-degree MODIS data as described by Lawrence and Chase (2007).

Carbon pools were initialized in an equilibrium state using the procedure outlined in Haynes et al. (2019b; 2020). Initializing with steady-state conditions implies mature ecosystems with no disturbances wherein growth balances decay (NEE ~ 0), and such initial conditions are typical for biogeochemical models. Equilibrium pools are estimated during spin-up simulations when, after each iteration, the steady-state pool sizes are determined analytically. These simulations continue until beginning, ending, and steady-state pools are within 1% of each other. Using this approach, carbon pools reflect the effects of climate and other forcing variables rather than arbitrary settings chosen by researchers.

SiB4 can incorporate fire emissions and the vegetation response by including data from the Global Fire Emissions Database (GFED, Version 4.1; van der Werf et al., 2017). Beginning in 2003, the burned carbon is removed from the carbon pools, and the carbon emissions from fire are included separate from the ecosystem respiration.

The SiB4 output is per PFT. SiB4 has 15 PFTs listed in each of the files. The output for each PFT is in the matching position as the name in the PFT list and is indexed by the *npft* dimension. To combine the PFT-specific output into grid cell totals, compute the area-weighted mean across the vector of PFT-specific values for each cell. Fractional areas are given in the *pft_area* variable for each cell.

SiB4 can incorporate fire emissions and the vegetation response by including fire emissions data. Fire emissions here are from the Global Fire Emissions Database, version 4.1 (van der Werf 2017). The carbon pools are depleted by the total amount of carbon burned (see methodology in Haynes et al. 2020). Since the fire emissions are per grid cell, the ecosystem respiration variable per PFT (resp) does not include the fire emissions. Total ecosystem respiration can be obtained by adding CO2 emissions from fires (resp_fireco2) with the PFT-area-weighted sum of resp.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

SiB4 Modeled Global 0.5-Degree Daily Carbon Fluxes and Pools, 2000-2018

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

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