ISAM Model Description

MSTMIP version

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Section A, Namelist reference

runname (string)

Name of current case

bgp\_bgc\_mode (1 digit)

Pick up modules for current ISAM run.

1 – run biogeophysical processes and daily scale biogeochemical processes only

2 – run weekly scale biogeochemical processes only

3 – run in fully coupled mode (biogeophysics plus biogeochemistry in all different scales)

restart (logical)

Flag to read restart file. Set ‘.true.’ when you need an automatic restart run from previous crash.

run\_type (1 digit)

Select mode of current ISAM run.

0 – run without reading a restart file, initial from zero

1 – restart run, initial from saved files

2 – disturbed run (also initial from saved files), further detail should be set for every disturb option

CN\_RATIO (integer)

Active dynamic CN ratio for model. When model mode is 1 (bgp) or 2(bgc), this value will be ignored, just set it to zero. When run model in coupled case, this can be set to 1. (Attention: Dynamic CN model may be unavailable currently)

initial\_bgp\_in\_datadir (string)

Directory path pointing to the BGP initial file that you need to run the case. See more details in source code isam\_data\_path\_module.F90.

initial\_bgc\_in\_datadir (string)

Directory path pointing to the BGC initial file that you need to run the case. See more details in source code isam\_data\_path\_module.F90.

repeat\_cycles

Number of simulation/spinup repeat cycles for current run. If you set a 50 years’ run case and set repeat\_cycle to 2, model will simulate this 50 years twice using same climate data.

start\_time (4 digits)

Start year of current case

run\_time (integer)

Time length of current case running per cycle, in year

offline\_clim\_data (string)

Climate data type. Currently we support two types of climate data: ‘NCEP\_Q’ and ‘CRU\_NCEP’. Set ‘CRU\_NCEP’ for using CRU data ranging from 1901 to 2012. Set ‘NCEP\_Q’ for using NCEP data ranging from 1979 to 2005. See dataset repository to find out details.

luc\_data (1 digit)

Determine the land cover data current case will use. 3 types of land cover data can be select till now.

1 – HYDE data

2 – SAGE (RF) data

3 – HH data

Attention: Without luc\_disturb, land cover data of which year would be used as the static land cover data should be determined in the source file isam\_data\_path\_module.F90 as variable ‘pft\_initial\_nc\_file\_yr’. (Considering putting it into namelist?)

clim\_disturb (logical)

Flag to disturb climatological data. Set ‘.true.’ for a disturbed run if you want to disturb climatological data (sequentially reading atmospheric forcing data) or ‘.false.’ for a static climatological forcing (repeat reading the atmospheric forcing data of start\_time).

co2\_disturb (logical)

Flag to disturb carbon dioxide concentration. Set ‘.true.’ for a disturbed run (reading atmospheric CO2 concentration from file every year) if you want to disturb CO2 concentration or ‘.false.’ for a non-disturbed run (atmospheric CO2 concentration keeps in 280.84 ppm, this can be changed in main.F90).

luc\_disturb (logical)

Flag to disturb land use and cover data. Set ‘.true.’ for a disturbed run (Land cover data and land conversion data will be read in every year. By the way, land conversion data are only used in calculating carbon emission) if you want to disturb land use or ‘.false.’ for a non- disturbed run (static land cover data which specified in isam\_data\_path\_module.F90).

n\_disturb (logical)

Flag to disturb atmospheric nitrogen deposition. Set ‘.true.’ for a disturbed run (reading atmospheric N deposition from file every year) if you want to disturb Nitrogen or ‘.false.’ (using deposition rate at 1860 level) for a non- disturbed run.

fna\_func (logical)

Set flag to ‘.true.’ if the case like to simulate under considering nitrogen limitation for biogeochemical processes.

region mask (1 x 11 1-digit array)

Change unwanted region to 0 when running ISAM case. If want to start a global run, set all elements to 1. See Appendix A for more details.

datadir (String)

Path of data directory using in current ISAM case. Attention: initial file will be saved in the data directory so please make sure you have the write access to this path before starting your case.

outputdir (String)

Path of output directory using in current ISAM case. User should make sure having the write permission under this path.

single\_point (logical)

Set to ‘.true.’ when running single point case for experiment or site validation. Current model only supports serial single site case so compile model under serial mode if you need single site simulation.

single\_x (integer)

Longitude column number of single point, valid only in single point mode. Set -999 for regional or global case. Start from 1 standing for 0E to 720 standing for 0W. (Current model resolution is fixed to 0.5 degree)

single\_y (integer)

Latitude row number of single point, valid only in single point mode. Set -999 for regional or global case. Start from 1 standing for 90S to 360 standing for 90N. (Current model resolution is fixed to 0.5 degree)

generate\_site\_met\_nc\_from\_global (logical)

Set this option to ‘.true.’ to extract site met data from global dataset. When turn this option to ‘.true.’, model only extract site data without proceeding land surface processes so model is used as a extractor to get single site meteorological data. This option is only useful under single point case.

fixed\_harvest (logical)

Set ‘.true.’ to use fixed harvest. (Crop model)

fixed\_planttime (logical)

Set .true. to use fixed planting time. (Crop model)

crop\_mode (string)

Two types of crop mode are available. Set ‘generic’ starting generic crop process and ‘dynamic’ triggering dynamic component. (Crop model)

offline\_clim\_data (string)

Offline climate forcing datasets. Two types of global atmospheric forcing data are available. Set ‘CRU\_NCEP’ for using CRU data ranging from 1901 to 2012. Set ‘NCEP\_Q’ for using NCEP data ranging from 1979 to 2005.

hist\_freq\_yr (integer)

The frequency for model to write historical output into ‘outputdir’. Unit is year.

save\_hist\_yr (logical)

Set to ‘.true.’ to save yearly history file

save\_hist\_mon (logical)

Set to ‘.true.’ when you need to save monthly history file

save\_hist\_bgp\_to\_bgc (logical)

Set ‘.true.’ to save bgp to bgc initial file. These files are needed in mode 2 (BGC mode).

restart\_freq\_yr (integer)

The frequency for model to generate restart (initial) file. Unit is year.

isam\_deltim (integer)

The time step of ISAM case. Current model only support 1800, 3600, 5400, 7200, 9000 and 10800.Unit is in second.

Section B. Model I/O (input and output file) Description

Four types of data are used to drive the offline version ISAM model: Climate data, Land cover data, initial data and disturbance data.

Climate data provide ISAM model the upper layer conditions to drive the model. Current model version support two types of climate data: CRU\_NECP and NCEPQ. CRU\_NECP climate data is a 0.5 degree times 0.5 degree, 6-hourly global climate data containing 8 meteorological factors (bottom air temperature, bottom air zonal wind speed, bottom air meridional wind speed, bottom air moisture, 6 hour total precipitation, land surface air pressure, 6 hourly average downward shortwave radiation and 6 hourly average downward longwave radiation) which cover from 1901 to 2009. NCEPQ covers a relatively shorter time series (1970 to 2004) and only contains 6 climate factors (bottom air temperature, bottom air wind speed, bottom air moisture, 6 hour total precipitation, bottom air pressure and 6 hourly average downward shortwave radiation), and NCEPQ data has a nicer temporal resolution of 3 hours and a coarser spatial resolution (1.875 degree).

Land cover data represent the heterogeneity of global land surface. Current ISAM model provide user three types of land cover dataset: Historical Database of the Global Environment (HYDE), data based on Ramankutty and Foley (RF) and regional estimates based on Houghton (HH). Three datasets are modified to adapt the working environment of ISAM model.

Land cover dataset also provide the region mask and dominant land cover type for every gridcell. It directly give the area of every gridcell and the percentage of each biome type occupying the gridcell.

Land cover conversion data (to be continue)

Initial dataset will be needed when start a restart case and the running case will write initial files with the frequency the namelist assigned. For each case of ISAM model (bgp-only case, bgc-only case and bgp-bgc coupled case), different initial file need to be settled before a restart run.

Current model version set 41 variables (12 two-dimensional variables, 22 three-dimensional variables and 7 four-dimensional variables) in BGP initial file. Details on all variables are listed in tables below.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Units | Description |
| c\_coszen | (longitude, latitude) | None | Cosine of the solar zenith angle |
| c\_fmax | (longitude, latitude) | % | Maximum saturated fraction for a gridcell |
| c\_sag | (longitude, latitude) | None | Non dimensional snow age |
| c\_scv | (longitude, latitude) | Kg/m2 | Snow mass |
| c\_scv\_lak | (longitude, latitude) | Kg/m2 | Lake snow mass |
| c\_snowdp | (longitude, latitude) | m | Snow depth |
| c\_snowdp\_lak | (longitude, latitude) | m | Lake snow depth |
| c\_tg | (longitude, latitude) | k | Ground surface temperature |
| c\_tg\_lak | (longitude, latitude) | k | Lake surface temperature |
| c\_w\_a | (longitude, latitude) | mm | Water in the unconfined aquifer |
| c\_w\_t | (longitude, latitude) | mm | Total water storage (unsaturated soil water + groundwater) |
| c\_z\_wt | (longitude, latitude) | m | Water table depth |

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Units | Description |
| c\_alb\_lak | (longitude, latitude, bin) | None | Lake albedo |
| c\_extkb | (longitude, latitude, numpft) | None | Direct solar extinction coefficient |
| c\_extkd | (longitude, latitude, numpft) | none | Diffuse and scattered diffuse PAR extinction coefficient |
| c\_fsno | (longitude, latitude, numpft) | none | Fraction of snow cover |
| c\_fveg | (longitude, latitude, numpft) | none | Fraction of vegetation cover |
| c\_green | (longitude, latitude, numpft) | None | Greenness |
| c\_lai | (longitude, latitude, numpft) | m2/m2 | Leaf area index |
| c\_ldew | (longitude, latitude, numpft) | Kg/m2/s | Depth of water on foliage |
| c\_sai | (longitude, latitude, numpft) | m2/m2 | Stem area index |
| c\_sigf | (longitude, latitude, numpft) | none | Fraction of vegetation cover, excluding snow-covered vegetation |
| c\_thermk | (longitude, latitude, numpft) | None | Canopy gap fraction for thermal infrared radiation |
| c\_tlsha | (longitude, latitude, numpft) | K | Shaded leaf temperature |
| c\_tlsun | (longitude, latitude, numpft) | K | Sunlit leaf temperature |
| c\_tss | (longitude, latitude, levsoi) | K | Soil plus snow layer temperature |
| c\_tss\_lak | (longitude, latitude, nlevlak) | K | Lake temperature |
| c\_wice | (longitude, latitude, levsoi) | Kg/m2 | Ice lens (?) |
| c\_wice\_lak | (longitude, latitude, nlevlak) | Kg/m3 | Lake ice |
| c\_wliq | (longitude, latitude, levsoi) | Kg/m2 | Liquid water |
| c\_wliq\_lak | (longitude, latitude, nlevlak) | Kg/m3 | Lake water |
| dzsoi | (longitude, latitude, levsoi) | m | Soil layer thickness |
| zisoi | (longitude, latitude, levsoi2)\*levsoi2 = levsoi + 1 | m | Soil layer interface |
| zsoil | (longitude, latitude, levsoi) | M | Soil layer depth |

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Unit | Description |
| c\_alb | (longitude, latitude, pft, layer)\*layer = 4 | None | Averaged albedo |
| c\_albg | (longitude, latitude, pft, layer) | None | Ground albedo |
| c\_albv | (longitude, latitude, pft, layer) | None | Vegetation albedo |
| c\_carbon | (longitude, latitude, pft, layer) | gC/m2 | Carbon density |
| c\_fna\_w | (longitude, latitude, pft, week) | None | Nitrogen availability |
| c\_ssha | (longitude, latitude, pft, layer) | None | Shaded canopy absorption for solar radiation |
| c\_ssun | (longitude, latitude, pft, layer) | None | Sunlit canopy absorption for solar radiation |

19 variables are written down into bgc restart file. A brief description can be found in the following tables.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Unit | Description |
| nu | (nbox, ktype)\*nbox = Number of carbon boxes\*ktype = numpft |  | Nu (?) for ground vegetation (GV) and nonwoody tree parts (NW) |
| nu0 | (nbox, ktype) |  | Initial nu for ground vegetation (GV) and nonwoody tree parts (NW) |
| rho | (nbox, ktype) |  | Rho for ground vegetation (GV) and nonwoody tree parts (NW) |
| rho0 | (nbox, ktype) |  | Initial rho for ground vegetation (GV) and nonwoody tree parts (NW) |
| alai | (nbox, ktype) | None | Modified respiration exchange coefficients |
| alai0 | (nbox, ktype) |  | Initial modified respiration exchange coefficients |
| alsm0ij | (nbox, ktype) |  | Sum of all alpha0s |
| ligcon\_str | (longitude, latitude, ktype) |  | Ligcon (?) |
| veg\_n\_store | (longitude, latitude, ktype) |  | Nitrogen storage in vegetation (I guess so) |
| mineral\_no3 | (longitude, latitude, ktype) |  | Mineral NO3 (nitrate N) |
| mineral\_nh4 | (longitude, latitude, ktype) |  | Mineral NH4 (ammonium N) |
| alpha | (nbox, nbox, ktype) |  | Modified transfer coefficients between carbon pools (i.e. each two boxes) |
| alpha0 | (nbox, nbox, ktype) |  | Initial modified transfer coefficients between carbon pools (i.e. each two boxes) |
| agcbox | (longitude, latitude, box1, ktype)\*box1 = 4, number of above ground box |  | Above ground carbon boxes |
| agnbox | (longitude, latitude, box1, ktype) |  | Above ground nitrogen boxes |
| n\_max\_pt | (longitude, latitude, ktype, week)\*week = 52 for one year |  | Nitrogen max uptake |
| bgcbox | (longitude, latitude, box2, ktype) |  | Below ground carbon boxes |
| bgnbox | (longitude, latitude, box2, ktype) |  | Below ground nitrogen boxes |
| cmbox\_n | (longitude, latitude, nbox, ktype) |  | Cmbox\_n (?) |

When start bgc run the model also need another type of initial dataset called bgp\_to\_bgc initial data. Litter estimated by biogeophysical processes are needed to drive biogeochemical processes. These litter fall are separated into nine different reservoirs. (need correction and further expansion)

Disturbance files are used to import changing factors when simulating ISAM model. In current ISAM model the disturbance of five factors are available: climate data, carbon dioxide, land cover type, nitrogen and fna (need further expansion).

ISAM model creates different history output data for biogeophysical and biogeochemical mode for both annual and monthly average. Biogeophysical output data has the name convention like “${casename}.bgp-{yearly/monthly}\_{2d/3d}\_${outputyear}”. It would be automatically created under the directory user defined in namelist. Available output variables in yearly history file can be found in the table below.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Unit | Description |
| agpp\_avg\_yr | (longitude, latitude) | gC/m2/yr | Annual gpp |
| anpp\_avg\_yr | (longitude, latitude) | gC/m2/yr | Annual npp |
| NPP\_GPP\_ratio | (longitude, latitude) | None | NPP/GPP ratio |
| ara\_avg\_yr | (longitude, latitude) | gC/m2/yr | Annual autorespiration |
| litter\_ag\_avg\_yr | (longitude, latitude) | gC/m2/yr | Annual litter above ground |
| litter\_bg\_avg\_yr | (longitude, latitude) | gC/m2/yr | Annual litter below ground |
| lfevpa\_avg\_yr | (longitude, latitude) | W/m2 | Annual latent heat |
| fsena\_avg\_yr | (longitude, latitude) | W/m2 | Annual sensible heat |
| fevpl\_avg\_yr | (longitude, latitude) | W/m2 | Annual evapotranspiration from leaves |
| fevpg\_avg\_yr | (longitude, latitude) | mm/s | Annual evaporation from ground |
| srad\_avg\_yr | (longitude, latitude) | W/m2 | Annual solar radiation |
| q\_avg\_yr | (longitude, latitude) | Kg/Kg | Specific humidity |
| tavg\_avg\_yr | (longitude, latitude) | K | Annual average temperature |
| precip\_avg\_yr | (longitude, latitude) | mm | Annual latent heat |
| net\_rad\_avg\_yr | (longitude, latitude) | W/m2 | Net radiation (sabg-sabv+frl-olrg) |
| xmf\_avg\_yr | (longitude, latitude) | W/m2 | Latent heat of phase change of ground water |
| fgrnd\_avg\_yr | (longitude, latitude) | W/m2 | Net ground heat flux |
| sabg\_avg\_yr | (longitude, latitude) | W/m2 | Annual solar radiation absorbed by ground |
| sabvg\_avg\_yr | (longitude, latitude) | W/m2 | Annual solar radiation absorbed by ground and vegetation |
| olrg\_avg\_yr | (longitude, latitude) | W/m2 | Outgoing longwave radiation from ground and vegetation |
| daylen | (longitude, latitude) | Hour/day | Annual average day length |
| daylen\_fact | (longitude, latitude) | None, form 0 to 1 | Annual average day length factor |
| xerr\_avg\_yr | (longitude, latitude) | m/m2/yr | Water balance error |
| zer\_avg\_yr | (longitude, latitude) | W/m2 | Energy balance error |
| qflx\_surf\_avg\_yr | (longitude, latitude) | mm/yr | Annual surface runoff |
| qflx\_drain\_avg\_yr | (longitude, latitude) | mm/yr | Annual subsurface drainage |
| tsoil\_d95\_avg\_yr | (longitude, latitude) | K | Annual soil temperature till d95 |
| tsoil\_nlevgrnd\_avg\_yr | (longitude, latitude) | K | Soil temperature at bottom most layer |
| tl\_avg\_yr | (longitude, latitude) | K | Annual leaf temperature |
| wliq\_vol\_1\_5\_avg\_yr | (longitude, latitude) | vol/vol | Annual volumetric liquid water (1-5th layer) |
| wliq\_vol\_6\_10\_avg\_yr | (longitude, latitude) | vol/vol | Annual volumetric liquid water (6-10th layer) |
| ald\_annual | (longitude, latitude) | m | Annual active layer depth |
| ald\_day | (longitude, latitude) | day | Day when active layer depth is reached |

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Unit | Description |
| AGPP | (longitude, latitude, numpft) | gC/m2/yr | Annual GPP |
| ANPP | (longitude, latitude, numpft) | gC/m2/yr | Annual NPP |
| ARA | (longitude, latitude, numpft) | gC/m2/yr | Annual autorespiration |
| C\_leaf | (longitude, latitude, numpft) | gC/m2/yr | Leaf carbon density |
| C\_stem | (longitude, latitude, numpft) | gC/m2/yr | Stem carbon density |
| C\_root | (longitude, latitude, numpft) | gC/m2/yr | Root carbon density |
| Gv\_ag | (longitude, latitude, numpft) | gC/m2/yr | Ground vegetation carbon (above ground) density |
| Gv\_bg | (longitude, latitude, numpft) | gC/m2/yr | Ground vegetation carbon (below ground) density |
| Litter\_ag | (longitude, latitude, numpft) | gC/m2/yr | Above ground litter production |
| Litter\_bg | (longitude, latitude, numpft) | gC/m2/yr | Below ground litter production |
| Vcmax | (longitude, latitude, numpft) | None | The maximum rate of Rubisco-mediated carboxylation |

Biogeochemical output data has the name convention like “${casename}.bgc-{yearly/monthly}\_{2d/3d}\_${outputyear}”. It would be automatically created under the same directory as biogeophysical output. Available output variables in yearly history file can be found in the table below.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable name | Dimensions | Unit | Description |
| isitok | (longitude, latitude) | None | Points in steady state |
| soil\_c | (longitude, latitude) | kgC/m2 | Soil carbon |
| soil\_n | (longitude, latitude) | kgN/m2 | Soil nitrogen |
| veg\_n | (longitude, latitude) | kgN/m2 | Vegetation nitrogen |
| resp | (longitude, latitude) | kgC/m2 | Respiration |
| total\_mineral\_n | (longitude, latitude) | kgN/m2 | Total mineral nitrogen |
| litter\_n\_ag | (longitude, latitude) | kgN/m2 | Litter N above ground |
| litter\_n\_bg | (longitude, latitude) | kgN/m2 | Litter N below ground |
| litter\_n\_total | (longitude, latitude) | kgN/m2 | Litter N total |
| soil\_c\_pft | (longitude, latitude, numpft) | kgC/m2 | Soil carbon by pft |
| soil\_n\_pft | (longitude, latitude, numpft) | kgN/m2 | Soil nitrogen by pft |
| veg\_n\_pft | (longitude, latitude, numpft) | gN/ha (hectare) | Vegetation nitrogen by pft |

Section C. Brief description of model working flow

Legend:

Main entry of the whole model Plain text

***subroutine open\_co2\_data()***  Subroutine, Module or Program

“co2\_annual\_1765\_2010.nc” Data

\*Crop model is not included in this description

Part A: Main Frame

Isam\_offline/main.F90

Main entry of the BGP model part, ***Program ISAM***.

1. Model initialization phase. Call ***subroutine lnd\_init\_mct()*** (located in isam\_offline/lnd\_comp\_mct\_isam.F90). See details in part B.
2. Enter first simulation cycle
3. Enter year loop
4. Determine annual CO2 by namelist variable “co2\_disturb”. If true, open co2 data by calling ***subroutine open\_co2\_data()*** (located in isam\_offline/co2\_module.F90) and read co2 data from “co2\_annual\_1765\_2010.nc”, else set co2=280.84ppm.
5. If running BGC or Coupled case, initialize annual Nitrogen deposition by calling ***subroutine open\_ndep\_data()*** (located in isam\_offline/ndep\_module.F90) and then distribute it on every grid via ***subroutine distrib\_ndep\_grid()*** (located in comm/isam\_data\_distribute.F90). The initialization type is determined by namelist variable “n\_disturb”, if it equals 0 use N-deposition rate on 1860 level; if not, read N-deposition data from ”ndep\_annual\_1860\_2000\_05x05.nc”.

If running BGP case, all N-deposition rates (NHx and NOy) are set to 0.

1. Enter month loop
2. Enter day loop
3. Enter timestep loop
4. Catch the case mode. If current case is running under BGP mode or BGP coupling with BGC mode then **read in static climate data**. Single site and global scale are singly treated with each other. Interpolate solar radiation based on solar zenith angle at last.
5. For single point case and user defined ‘generate\_site\_met\_nc\_from\_global’ option turned on, initialize and store single site meteorological data.
6. Call subroutine lnd\_run\_mct() (located in isam\_offline/lnd\_comp\_mct\_isam.F90) to enter ISAM calculation phase. See details in part C.
7. Exit to Cycle loop level
8. Call subroutine lnd\_final\_mct()(located in isam\_offline/lnd\_comp\_mct\_isam.F90) to finalize ISAM model. See details in part D.

Part B: Model initialization

Isam\_offline/ lnd\_comp\_mct\_isam.F90

***subroutine lnd\_init\_mct()***

1. Setup MPI communication by calling subroutine start\_isam\_comm()
2. Read in ISAM model configurations from namelist. (isam\_runtime\_opts.f90)
3. Initialize model time. (isam\_time.f90)
4. Set model data path. (isam\_data\_path\_module.f90)
5. Read ISAM mask and do vectorization. (subroutine open\_mask(), isam\_domain.f90)
6. Decompose domain to each processor. (subroutine decompose\_domain(),isam\_domain.f90)
7. Call ***subroutine isam\_init()*** to perform model related initialization.

Isam\_offline/ isam\_comp.F90

***subroutine isam\_init ()***

1. Call subroutine bgp\_allocate\_variables(), subroutine crop\_allocate\_variables() and subroutine bgc\_allocate\_variables() to allocate model variables.
2. Initialize BGP output file.
3. Verify and write domain decomposition
4. Read initial land cover and static soil data
5. Check consistency for soil data
6. Initialize biogeophysical parameters and variables. (subroutine bgp\_initialization(), bgp\_initialization\_module.f90)
7. Initialize lake parmeters and variables (subroutine lake\_initialization(), lake\_initialization\_module.f90).
8. Initialize biome-specific biophysiological parameters. (subroutine biomeparameter\_init(), biomeparmeter\_module.f90)
9. Read in BGP initial state from biogeophysical initial file. (subroutine bgp\_open\_state(), bgp\_restart\_module.f90)
10. Initialize BGC constants. (subroutine vegprop(), vegprop\_module.f90)
11. Keep biome parameter to be consistent between BGP and BGC.
12. Set some flags (e.g. steady-state flag) and time interval (1 week) for BGC mode.
13. Calculate area of each biome type in every gridcell.
14. Read in BGC initial state from biogeochemical initial file. (subroutine bgc\_open\_state(), bgc\_restart\_module.f90)
15. Initialize BGP to BGC variables
16. If model is in BGC case (mode = 2), read the BGP to BGC initial file

Part C: Model Run

Isam\_offline/ lnd\_comp\_mct\_isam.F90

***subroutine lnd\_run\_mct()***

1. Set ISAM logical time and the calendar day to calculate cosine of solar zenith angle
2. Call ***subroutine isam\_run()*** to proceed model calculation.

Isam\_offline/ isam\_comp.F90

***subroutine isam\_run ()***

1. Treatment of some model logical time variables.
2. Read land cover data and land conversion data if set luc\_disturb to true
3. When in BGC or BGPBGC mode, check the number of gridcells that reached steady state.
4. Reset pools used by BGC to zeros at the beginning of each year.
5. Entering gridpoint loop (**integer,** **dimension(:,:),** **allocatable** **::** mask *!< Vector list of points and regions.*) This can be used to obtain geographical information of current gridcell
6. Determine CO2 concentration for current year. (either by reading the input data or by calculating from atmospheric CO2 partial pressure)
7. Determine Nitrogen deposition from the atmosphere
8. Determine dominant vegetation type for each gridcell by comparing every biome’s area.
9. Entering BGP module
10. Calculate daily average temperature, daily maximal and minimal temperature and daily accumulated precipitation
11. Assign LAI value read from static data
12. Part of crop model, temporary ignored.
13. Calculate daylength, daylength scaling factor and cumulative daylength.
14. Call ***subroutine bgp\_driver()*** as main part of BGP calculation. (To be continue)
15. Calculate root zone temperature, moisture, water deficit, field capacity, wilting point and other physical variables related to plant physiological processes for calculating NPP, respiration, leaf litter and phenology.
16. Call ***subroutine calnpp()*** (npp\_module.f90) to calculate daily respiration, NPP, allocation and leaf litter. (See Section D.1 NPP calculation for more detail)
17. Call ***subroutine phenology()*** to determine plant phenology at the end of each day.
18. Another part of crop model, temporary not included in this version.
19. Call ***subroutine bgp\_accumulate\_output()*** to accumulate monthly and annual BGP states and fluxes for model output.
20. Accumulate BGP to BGC weekly variables
21. Call ***subroutine bgc\_driver\_weekly()*** as main part of BGC weekly process. (See Section D.6 BGC processes for more detail)
22. Call ***subroutine bgc\_driver\_annual()*** as main part of BGC annual process. (See Section D.6 BGC processes for more detail)
23. Exiting gridcell loop.
24. Call subroutines to save BGP initial and output files and BGC initial and output files.
25. Call ***subroutine bgp\_to\_bgc\_weekly\_write()*** to save BGP to BGC variables (leaf litter and physical variables related to BGC).

Part D: Model Finalization

Isam\_offline/ lnd\_comp\_mct\_isam.F90

***subroutine lnd\_final\_mct()***

1. Call isam\_final to execute model finalization.

Isam\_offline/ isam\_comp.F90

***subroutine isam\_final ()***

1. Deallocate BGP and Crop variables
2. Say goodbye.

Section D. Model technical description

D.1. NPP calculation (Not in current model version) **Not been used by current model**

 is the intercellular CO2 concentration. equals 0.7 for C3 plant and 0.4 for C4 plant. is the CO2 compensation point in the absence of day respiration.

NPP is calculated per day while respiration is evaluated every timestep.

Laimax2 – laimax for phenology stage

D\_gpp – accumulated daily gpp

Gpp – assimilation rate for the whole timestep

Fna – nitrogen limitation factor

K\_l – Maintenance respiration rate for leaves

K – Maintenance respiration rate

K\_r – Maintenance respiration rate for roots

D\_rm – Daily maintenance respiration for each part

Resp\_m\_total – Total of maintenance respiration

Resp\_g\_total – Total of grow respiration

Rcn – C:N ratio of stem and root

Vegc – Carbon for different pool

Allo\_fm\_t – allocation for tree

Allo\_fm\_g - allocation for grass

D.1. Assimilation

subroutine stomata: (Modified SiB2 scheme)

calculation of canopy photosynthetic rate using the integrated model relating assimilation and stomatal conductance.

Gamma – co2 compensation point (pa)

1. Judge C3 or C4 plant using effcon (quantum efficiency of RuBP regeneration (mol CO2/mol quanta) ). Effcon >0.07, C3 and else C4.
2. Modify kc (Michaelis-Menton constant for co2), ko (Michaelis-Menton constant for o2) and gamma (CO2 compensation point in the absence of day respiration) by Q10 coefficient:
3. Scale vmax25 (maximum carboxylation rate at 25C at canopy top) based on daylength correction factor
4. Calculate vm (maximum catalytic capacity of Rubisco):

Here,

are temperature modification terms (high and low temperature inhibition parameters) for Vm.

are soil moisture stress factor and is the critical soil water potential minus root zone soil water potential. is the nitrogen availability modification factor for Rubisco activity and is a user defined coefficient ranging from 0 – 1 in the current model version.

Then Vm is transformed from leaf scale to canopy scale by scale factor cint.

Next is jmax (potential rate of whole-chain electron transport), epar (elctron transport rate for a given absorbed photon radiation)

Respc (dark respiration) is modified by temperature and water stress and evaluated using following equation

Both trda and trdm are temperature coefficients. equals to 0.015 for both C3 and C4 plant.

Omss (capacity of the leaf to export or utilize the products of photosynthesis)

1. Calculate leaf conductance (gbh2o) and aerodynamic conductance between canopy air space (cas) and reference height (gah2o). Because current model use boundary scheme from CLM (rb is for one side leaf) and photosynthetic scheme from SiB2 (rb is for 2-side leaf), we need to

where is the boundary resistance from canopy to canopy air space and tprcor is the coefficient for unit transfer. Then we transform to canopy scale, and calculate aerodynamic conductance

where is the aerodynamic resistance from canopy air space to reference height.

1. Give a first guess of carbon then iterate for a steady cabon assimilation rate. First we transform CO2 partial pressure to concentration:

 is the CO2 in atmosphere

 is the CO2 in canopy air space

Then determine the changing range of CO2:

where grad is the conductance-photosynthesis slope parameter.

1. Next entering the iteration and net assimilation is determined by iteration that finding.

Canopy assimilation (or gross photosynthesis) rate is described as the minimum of three limiting rates:

omc: the efficiency of the photosynthetic enzyme system (Rubisco-limited);

 is the partial pressure of CO2 in leaf interior.

ome: the amount of PAR captured by leaf chlorophyll;

oms: the capacity of the leaf to export or utilize the products of photosynthesis.

to aviod the abrupt transitions from one limitation to another, two quadratic equations are used:

OMP is a “smoothed” minimum of OMC and OME, and are two coupling coefficients. In every iteration we can solve OMP and A, and A is the final assimilation rate we want.

Net assimilation rate is calculated by final assimilation rate minus dark respiration.

D.2. GPP calculation

O\_assim – assimilation for each time step, simulated from leaf stomata process

D\_gpp – daily gpp by accumulating assimilation every timestep

D\_gpp = d\_gpp + o\_assim

In ISAM model, vegetation carbon is separated stored into eight pools. Ncpool – Number of carbon pool: 1 – grass leaf, 2- grass stem, 3 - grass fine root, 4 – grass coarse root (grain for crop), 5 – tree leaf, 6- tree stem, 7 - tree fine root, 8 – tree coarse root.

D.3. Respiration and NPP:

Leaf (both grass and tree leaf) maintenance respiration is calculated every timestep:

 is the leaf carbon (kgm-2), is the respiration rate per unit leaf carbon at 20, is dimensionless modifying function based on LAI, is the soil temperature. Q10 is a factor illustrates the dependent relationship of respiration to surface temperature.

Stem maintenance respiration doesn’t need to consider LAI effect, so the equation retreated to:

For some biome type tree and grass coexist in a same gridcell, the LAI-overlapping effect on the root respiration only happened on tree.

Other biome type the grass root respiration will be affected by LAI:

On the daily scale, maintenance respiration of every timestep on every pool is summed together as total maintenance respiration as below:

Growth respiration is regarded as 25% of the daily “pure NPP” (daily GPP minus total maintenance respiration) if npp is greater than 0. Otherwise, growth respiration is set to 0:

Then the growth respiration from every vegetation pool is divided according to the ratio of carbon in one of pools to the total vegetation carbon.

Then vegetation autorespiration is calculated as:

NPP is calculated once every day as:

Potential NPP is evaluated by filtering the effect from nitrogen availability:

D.4. Allocation: (Arora et al., 2005)

Allocation process is considered once every day.

To illustrate the characteristic of biomes having both grass and tree part (eg. savanna), ISAM use grass-tree fraction to divide the biome into grass part and tree part and both part have their independent carbon pool boxes.

First calculate allocation fraction for each vegetation part, in the case of tree:

Here,

is the availability of light measured by a scalar index. And the same situation is applied on the availability of water:

, and are PFT-dependent initial allocation fraction (allocation fraction without light and water modification) and , is the PFT-dependent parameter.

For grass (grass do not has stem), allocation fraction became:

ISAM separate root into two parts: fine root and coarse root. 60% of the root allocation is distributed to coarse root for grass and 80% of the root allocation translated to coarse root for tree:

Then the model considers several out of rule criteria calculating allocation fraction:

First one is that for cold deciduous (biome = 1, 3, 5, 14, 16 and 18) trees, all NPP is allocated to leaves at the time of leaf onset.

Second, allocation is ceased at leaf fall for deciduous trees and at harvest for crops.

For evergreen plants, there will be no phenology effect.

When phenology = 1 (leaf onset), all the net primary production will be allocated to leaf carbon box or when the net primary production is negative, this part will be subtracted from the leaf carbon box:

Details can be found from the comments of the code.

D.5. Litter production: (Arora et al., 2005)

Calculate above ground litter, below ground litter, litter from each component (leaf, wood, fine root and coarse root) and total litter.

For leaf, we consider normal turnover rate, water stress loss and temperature stress loss.

For root and wood we only consider the normal turnover rate.

BGP\_driver

1. Solar radiation absorbed and reflected
2. Update snow and water from previous step
3. Precipitation intercepted by canopy
4. Surface energy (Monin-Obukhov Similarity, Plant Photosynthesis)
5. Ground temperature
6. Update surface energy using new temperature and the derivative of energy to temperature
7. Snow water
8. Hydrology (Richards equation, RTM not included)
9. Snow dynamics
10. Checking energy and water balance
11. Lake
12. Albedo (radiative transfer)

D.6. BGC\_driver\_weekly

1. Load variables adapted from BGP
2. Calculate soil water deficit
3. Calculate Nitrogen fixation and atmospheric deposition through different vegetation type
4. Update CN ratio
5. Passing litter generated from BGP to BGC
6. Update nitrogen demand for each biome as a whole box (i.e., added all boxes together)
7. Call ***subroutine vegnstore*** to calculate nitrogen content in litter and nitrogen translocation
8. **Enter biome loop**
9. Calculate litter
10. Call ***function defac\_func*** to evaluate temperature, water stress term and climate decomposition factor
11. Start above ground litter decomposition by calling ***subroutine litter\_decomp***
12. Call ***function rothamsted*** to evaluate root litter and soil organic matter (below ground boxes) decomposition (Use Rothamsted model)
13. Calculate litter nitrogen, mineralization and NEE (NPP – litter and soil respiration)
14. Calculate nitrification (ammonium transform to nitrate N) by calling ***function nitri\_func***

 is the basic rate constant for nitrification.

1. Calculate the N uptake by vegetation

 is the maximum rate of nitrogen uptake by vegetation, is the parameter that accounting for relative difference in the conductance of the soil to nitrogen diffusion and

 is the soil water content and is the field capacity. is the concentration of available nitrogen at which N uptake proceeds at one-half its maximum rate. The root factor for N uptake is expressed as:

1. Call ***function denitri*** to calculate the denitrification for nitrate nitrogen.

where is the C loss due to respiration during the decomposition of SOM (acting as a surrogate for biological activity), is the denitrification factor and is the ratio of soil moisture over field capacity

1. Call ***function leach*** to calculate the nitrogen leaching.

where is the water excess the field capacity.

1. Cannot understand this part.
2. **End of biome loop**
3. Calculate nitrogen availability for plant

where and are constants depend on biome type, is the ratio of N supply and demand for plants.

1. Cannot understand this part.
2. Calculate plant nitrogen after N uptake and total available nitrogen from vegetation (N\_in\_box + uptake - litter) and then call ***subroutine n\_allocation*** to allocate the change of nitrogen to each vegetation box :

Where

1. Update vegetation carbon (but haven’t been modified in BGC part) and nitrogen boxes.
2. Update CN ratio for each vegetation box and the mean CN ratio for each biome. (Have not finished)
3. If set land use perturbation, calculate carbon and nitrogen emission by calling ***subroutine atmosems*** and ***subroutine atmosems\_n***.

Subroutine Vegprop –

1. Define the parameters for vegetation

Subroutine Vegnstore –

1. Call ***subroutine globalinit*** to initialize global average carbon, define initial value for 6 box terrestrial carbon cycle model (looks like this model has been abandoned) and initial transfer coefficient (Kheshig) between carbon pools.
2. Calculate nitrogen content

Subroutine Globalinit –

1. Use pre-saved global average NPP (GtC), NPP of specific area (gC/ha), vegetation carbon (GtC), vegetation carbon of specific area (gC/ha), soil carbon (GtC), soil carbon of specific area (gC/ha), total carbon (veg+soil, GtC) and fraction of tree cover (dimensionless) for each biome.
2. Perform unit conversion for each biome.
3. Define initial value for 6 box terrestrial carbon cycle model

Subroutine Litter\_decomp –

1. Define diagnostic decomposition rate for reservoir, microbial efficiency and fraction of decomposition that transferred to humus pool as constants
2. Calculate the partition between metabolic and structural litter
3. Distribute litter input to above ground box 1 (Above Ground Structural Litter) and 2 (Above Ground Metabolic Litter) and update their C:N ratio
4. Calculate C:N ratio for above ground box 3 (Above Ground Microbial soil) and 4 (Above Ground Humus soil)
5. Update lignin concentration in structural pool and its decomposition (decay) rate due to lignin addition
6. Calculate potential carbon and nitrogen released from decomposition
7. Calculate potential demand of nitrogen and available total nitrogen limitation fraction
8. Capture user defined nitrogen limitation (namelist option ‘fna\_func’) switcher to determine if clear or keep using nitrogen limitation.
9. Calculate real litter decomposition, nitrogen immobilization and mineralization using nitrogen limitation fraction and update C and N for all pools. (Calculation are all applied on Carbon, Nitrogen is calculated by dividing by CN ratio)

Decomposition:

Decomposed part of AGSL (box = 1) will go to box3, box4 and loss pool

Decomposed part of AGML (box = 2) will go to box3 and loss pool

Decomposed part of AGMS (box = 3) will go to loss pool, stabilize into box4 and some remain in box3

Decomposed part of AGHS (box = 4) will go to below ground box (stabilized humus soil) and loss pool

Nitrogen immobilization (nitrogen from plant and micro-organism fixation) / mineralization:

Nitrogen immobilization/mineralization is the difference between total nitrogen entering into other boxes (use CN ratio of these boxes to calculate) and the decomposed nitrogen part. Positive value stands for immobilization (plant provide nitrogen to soil) and negative value stands for mineralization (soil nitrogen leaching).

1. Calculate the carbon and nitrogen flux entering below ground humus soil pool

Function Rothamsted –

1. Assign values to constants (fraction of turnover to each below ground box)
2. Calculate the decomposable and resistant matter ratio and root litter CN ratio for root
3. Calculate the fraction of litter turning to resistant litter pool (f\_rpm), decomposable litter pool (f\_dpm),
4. Update decomposable (below ground decomposable litter, box = 1) and resistant (below ground resistant litter, box = 2) pools and their corresponding nitrogen pool using their fraction of turnover.
5. calculate C:N ratios for DPM and RPM pools depending on the DPM:RPM ratio and C:N ratio for roots
6. Determine CN ratio for other three pools (box3: below ground microbial soil pool, box4: below ground stabilized humus soil pool, box5: below ground inert organic soil pool)
7. Calculate temperature factor, soil moisture factor and plant protection factor for decay. Then determine the decaying rate for each box.
8. calculate N mineralization / immobilization and carbon loss
9. calculate co2 released by soil
10. update carbon and nitrogen for each pool then calculate total soil organic matter by summing all boxes.

Soil carbon & nitrogen pools:

Aboveground:

box = 1, above ground structural litter

box = 2, above ground metabolic litter

box = 3, above ground microbial soil

box = 4, above ground Humus soil

Belowground:

box = 1, below ground decomposable litter

box = 2, below ground resistant litter

box = 3, below ground microbial soil pool

box = 4, below ground stabilized humus soil pool

box = 5, below ground inert organic soil pool

Subroutine Atmosems –

1. Initialize inter-box transition rate when there happened conversion between each two land cover type for each box.
2. Initialize transition rate to atmosphere when there happened conversion between each two land cover type for each box.
3. Initialize decay fraction on 4 product pools in different timescale (1yr, 10yr, 100yr, 1000yr) and detritus pool. The decay fraction is depend on the region, the land cover conversion type (the source land cover type and the destination land cover type).
4. Define zeros for accumulation variables.
5. Perform vegetation carbon transition to the atmosphere for each biome in each gridcell.
6. Perform root carbon transition to the atmosphere for each biome in each gridcell.
7. Update product (1yr, 10yr, 100yr, 1000yr) and detritus pools.
8. Perform inter-box transition for each biome in each gridcell.
9. Update carbon in every box after transition
10. Note: ‘tbempt’ is the total carbon emitted to atmosphere each year.

Appendix A: Region mask

1 – North America

2 – Latin America

3 – Europe

4 – North Africa

5 – Tropical Africa

6 – USSR

7 – China

8 – South and South East Asia

9 – Pacific Developed

10 – Antarctica and Greenland

Appendix B: Dimensions in model

Longitude – longitude of the gridcell

Latitude – latitude of the gridcell

Ncpool – Number of carbon pool: 1 – grass leaf, 2- grass stem, 3 - grass fine root, 4 – grass coarse root (grain for crop), 5 – tree leaf, 6- tree stem, 7 - tree fine root, 8 – tree coarse root.

Numpft – Maximum number of pfts. PFT is the same as ‘biome type’ in BGC model. Currently we considered 24 PFT.

1 tropical evergreen

2 tropical deciduous

3 temperate evergreen

4 temperate deciduous

5 boreal forest !!Evergreen needleleaf forest

6 savanna

7 grassland

8 shrubland

9 tundra

10 desert

11 polar desert

12 crop

13 pastureland

14-18 secondary forest

19 bare ground

20 deciduous boreal forest

21 C4 grassland

22 C4 crop

23 C4 pastureland

24 Secondary boreal deciduous forest

Appendix C: Biogeochemical 6 box terrestrial carbon model

Six boxes are standing for:

1. ground vegetation box (bgv)
2. woody tree box (bnw)
3. non-woody tree box (bwt)
4. detritus box (bdt)
5. mobile soil box (bms)
6. resistance soil box (brs)

Appendix D: Calculating the area of one grid on the Earth used in model

I think I found what I needed from the Dr. Math Archives. For anyone who is interested here it is:

We started with the formula for the area of the earth between a line of latitude and the north pole (the area of a spherical cap, listed in the Dr. Math FAQ on Geometric Formulas).

A = 2\*pi\*R\*h

where R is the radius of the earth and h is the perpendicular distance from the plane containing the line of latitude to the pole. We can calculate h using trigonometry as

h = R\*(1-sin(lat))

Thus the area north of a line of latitude is

A = 2\*pi\*R^2(1-sin(lat))

The area between two lines of latitude is the difference between the area north of one latitude and the area north of the other latitude:

A = |2\*pi\*R^2(1-sin(lat2)) - 2\*pi\*R^2(1-sin(lat1))|
= 2\*pi\*R^2 |sin(lat1) - sin(lat2)|

The area of a lat-long rectangle is proportional to the difference in the longitudes. The area I just calculated is the area between longitude lines differing by 360 degrees. Therefore the area we seek is

A = 2\*pi\*R^2 |sin(lat1)-sin(lat2)| |lon1-lon2|/360
= (pi/180)R^2 |sin(lat1)-sin(lat2)| |lon1-lon2|

BGC Parameters:

Decomp.f90 (Litter decomposition)

Rothc\_residual.f90 (Soil transfer coefficients)

Vegprop\_module.f90 (Lignen concentration):

Obseleted: leaf\_cnratio

C Budget For Vegetation pools

Veg\_Fluxes = NPP – DIR\_Litter (Only direct litter you calculate in BGP) – Lit\_LU\_Dec + Fluxes\_Yr\_pools

Note that land use change litter, LU\_Litter, is defined by the following equation. Here Lit\_LU\_Dec is the amount of litter which goes to soil carbon for decomposition (it may be zero in the model, but we need to check)

LU\_Litter = (Lit\_1yr + Lit\_10yr + Lit\_100yr ) + Lit\_LU\_Dec

Fluxes\_Yr\_Pools = Lit\_1yr + Lit\_10yr + Lit\_100yr – Dir\_Emi\_1yr\_10yr\_100Yr

So, Part of the lu litter goes to the pools and part is released from the pools.

Veg\_Fluxes = NPP – DIR\_Litter – ((Lit\_1yr + Lit\_10yr + Lit\_100yr ) + Lit\_LU\_Dec) + (Lit\_1yr + Lit\_10yr + Lit\_100yr – Dir\_Emi\_1yr\_10yr\_100Yr) Or

Veg\_Fluxes = NPP – DIR\_Litter –Lit\_LU\_Dec – Dir\_Emi\_1yr\_10yr\_100Yr Eq. (1)

Note that in the model we have litter MINUS NPP. Make sure you use the right sign for the balance calculation

So, the equation for the veg balance

Del Plant Pools + Del\_Lit\_1yr\_Pool + Del\_Lit\_10yr\_pool + Del\_Lit\_100yr\_pool = Veg\_Fluxes

Del is the change in pool sizes per time. Not that per time should be the same for fluxes and pools. If you are calculating the budget over ten years then you sum fluxes over ELEVEN year and del will be 10 year pool size MINUS zero year (zero is your first year). Note that if you do 10 year pool size MINUS one year then you are calculating the change only for 9 years not for 10 years.

Fluxes for Soil Carbon

Soil\_Fluxes = DIR\_Litter + Lit\_LU\_Dec - Soil\_Res(Rh) – Dir\_Soil\_Res

Here Dir\_Soil\_Res relates to direct emission (of about 25%) due to LUC. We can also add another term for 90%

EQUATION FOR Soil Carbon Balance

Del (Soil + litter Pools) = DIR\_Litter + Lit\_LU\_Dec - Soil\_Res(Rh) – Dir\_Soil\_Res

Balance for Complete system:

Del Plant Pools + Del\_Lit\_1yr\_Pool + Del\_Lit\_10yr\_pool + Del\_Lit\_100yr\_pool + Del (Soil + litter Pools)= Veg\_Fluxes + Soil\_Fluxes

Or

Del Plant Pools + Del\_Lit\_1yr\_Pool + Del\_Lit\_10yr\_pool + Del\_Lit\_100yr\_pool + Del (Soil + litter Pools) = (NPP – DIR\_Litter –Lit\_LU\_Dec – Dir\_Emi\_1yr\_10yr\_100Yr) + (DIR\_Litter + Lit\_LU\_Dec - Soil\_Res(Rh) – Dir\_Soil\_Res)

Or

Del(Of All Pools) = NPP – Dir\_Emi\_1yr\_10yr\_100Yr - Soil\_Res(Rh) – Dir\_Soil\_Res (Eq.3)

Let me know if anything is not clear. We will meet tomorrow to discuss the modeled C budget. Check in the meantime if the model has carbon budget based on the above equations.

It is likely possible that I may have missed something in the above equations, Let me know if you find any error in my calculations.

Land use disturbance false, so the Fluxes\_Yr\_pools and Lit\_LU\_Dec should also be true.