

# OSCAR v3.1

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## Manual

## Basic simulation

Essentially, to make a basic simulation one must:

1. import the `OSCAR` object from `core_fct.fct_process`;
2. define the `Ini` (initial state), `For` (forcing data) and `Par` (parameters) arguments;
3. call `OSCAR` with these arguments (and possibly other optional arguments).

The `run_model` function found in `core_fct.fct_wrap` is a wrapper that does all that and more, using internal data for forcings and parameters. However, this function may not be adequate for advanced usage of OSCAR, in which case it should be used as inspiration for defining one's own run scripts. To further help with this, the `run_scripts` folder contains a few basic examples.

## Core structure

Here is a quick overview of the files contained in the `core_fct` folder and their content.

File	Content
<code>cls_main</code>	definition of the <code>Model</code> and <code>Process</code> classes upon which OSCAR v3 is based
<code>fct_calib</code>	functions to calibrate some of the model's parameters
<code>fct_genD</code>	functions to generate consistent timeseries of drivers
<code>fct_genMC</code>	functions to generate the Monte Carlo setup
<code>fct_loadD</code>	functions to load the primary drivers
<code>fct_loadP</code>	functions to load the primary parameters, some of them being loaded from files and others manually written there
<code>fct_misc</code>	a bunch of useful functions, notably including the solving schemes, a generic loading function called <code>load_data</code> , and a function to regionally aggregate datasets called <code>aggreg_region</code>
<code>fct_process</code>	equations for the physical processes constituting OSCAR; also contains <code>OSCAR</code> and submodels
<code>fct_wrap</code>	wrapper function to run the model in a not-so-flexible standard mode

## Dimensions, drivers, variables and parameters

### Dimensions

Here is a table summerizing the various dimensions over which OSCAR's input, internal and output data may be defined. Additional dimensions can be added freely to the `Ini`, `For` and/or `Par` arguments, in which case

they will be conserved throughout the run, which allows easily parallelizing experiments (e.g. scenarios). This can be heavy on the memory, however.

Dims	Description
<code>year</code>	time axis
<code>config</code>	Monte Carlo elements
<code>spc_halo</code>	species of halogenated compounds
<code>box_osurf</code>	pools for the surface ocean carbon cycling
<code>reg_land</code>	land carbon-cycle regions
<code>bio_land</code>	land carbon-cycle biomes
<code>bio_from</code>	origine biomes of the land-use perturbations
<code>bio_to</code>	destination biomes of the land-use perturbations
<code>box_hwp</code>	pools of harvested wood products
<code>reg_pf</code>	regions specific to the permafrost module
<code>box_thaw</code>	pools of thawed permafrost
<code>spc_bb</code>	species from biomass burning
<code>reg_slcf</code>	regions specific to SLCF regional saturation effects
<code>reg_bcsnow</code>	regions specific to BC deposition on snow

## Drivers

Drivers are the forcing data that need to be prescribed to the model for it to be able to run. They must be prescribed using the `For` argument when calling a `Model` object. The model automatically connects the various processes it is made of, and deduces what input data are required, so that it will display an error message if some drivers are missing in `For`. Assuming `OSCAR` has been imported, a list of the model's drivers can be displayed with `OSCAR.var_in`. More information on the drivers is available in `core_fct.fct_loadD`.

In code	In papers	Units	Dims
<code>E<sub>ff</sub></code>	$E_{FF}$	PgC yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code>
<code>E<sub>CH4</sub></code>	$E_{CH_4}$	TgC yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code>
<code>E<sub>N2O</sub></code>	$E_{N_2O}$	TgN yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code>
<code>E<sub>Xhalo</sub></code>	$E_X$	Gg yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code> , <code>spc_halo</code>
<code>E<sub>NOX</sub></code>	$E_{NO_x}$	TgN yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code>
<code>E<sub>CO</sub></code>	$E_{CO}$	TgC yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code>
<code>E<sub>VOC</sub></code>	$E_{VOC}$	Tg yr <sup>-1</sup>	<code>year</code> , <code>reg_land</code>

In code	In papers	Units	Dims
E_S02	$E_{\text{SO}_2}$	TgS yr <sup>-1</sup>	year, reg_land
E_NH3	$E_{\text{NH}_3}$	TgN yr <sup>-1</sup>	year, reg_land
E_OC	$E_{\text{OC}}$	TgC yr <sup>-1</sup>	year, reg_land
E_BC	$E_{\text{BC}}$	TgC yr <sup>-1</sup>	year, reg_land
d_Acover	$\delta A$	Mha yr <sup>-1</sup>	year, reg_land, bio_from, bio_to
d_Hwood	$\delta H$	PgC yr <sup>-1</sup>	year, reg_land, bio_land
d_Ashift	$\delta S$	Mha yr <sup>-1</sup>	year, reg_land, bio_from, bio_to
RF_contr	$\text{RF}_{\text{con}}$	W m <sup>-2</sup>	year
RF_volc	$\text{RF}_{\text{volc}}$	W m <sup>-2</sup>	year
RF_solar	$\text{RF}_{\text{solar}}$	W m <sup>-2</sup>	year

## Variables

Each of the model's variable is defined through a **Process** object; and a **Model** object is essentially a collection of connected processes. Prognostic variables (i.e. state variables) are those defined through a time-differential equation, while diagnostic variables are defined at any time  $t$  as a function of prognostic variables and/or other diagnostic variables at that same time  $t$ . When solving, at every single timestep, the model first solves all prognostic variables, and only then calculates the diagnostic variables. Assuming **OSCAR** has been imported, a list of the model's variables can be displayed with **OSCAR.proc\_all**, or somewhat equivalently with **OSCAR.var\_mid | OSCAR.var\_out**. Prognostic and diagnostic variables can be displayed with **OSCAR.var\_prog** and **OSCAR.var\_diag**, respectively. More information on each variable/process is available in **core\_fct.fct\_process**.

In code	In papers	Units	Dims	Prog?
D_pCO2	$\mathcal{F}_{\text{pCO}_2}$	ppm	-	
D_mld	$\Delta h_{\text{mld}}$	m	-	
D_dic	$\Delta \text{dic}$	μmol kg <sup>-1</sup>	-	
D_Fin	$\Delta F_{\text{in}}$	PgC yr <sup>-1</sup>	box_osurf	
D_Fout	$\Delta F_{\text{out}}$	PgC yr <sup>-1</sup>	box_osurf	
D_Fcirc	$\Delta F_{\text{circ}}$	PgC yr <sup>-1</sup>	box_osurf	
D_Focean	$\Delta F_{\downarrow \text{ocean}}$	PgC yr <sup>-1</sup>	-	
D_Cosurf	$\Delta C_{\text{surf}}$	PgC	-	yes

In code	In papers	Units	Dims	Prog?
f_fert	$\mathcal{F}_{\text{fert}}$	1	reg_land, bio_land	
D_npp	$\Delta n_{\text{pp}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
f_igni	$\mathcal{F}_{\text{igni}}$	1	reg_land, bio_land	
D_efire	$\Delta e_{\text{fire}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_eharv	$\Delta e_{\text{harv}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_egrav	$\Delta e_{\text{graz}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_fmort1	$\Delta f_{\text{mort1}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_fmort2	$\Delta f_{\text{mort2}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
f_resp	$\mathcal{F}_{\text{resp}}$	1	reg_land, bio_land	
D_rh1	$\Delta r_{\text{h1}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_fmet	$\Delta f_{\text{met}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_rh2	$\Delta r_{\text{h2}}$	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_nbp	-	PgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land, bio_land	
D_cveg	$\Delta c_{\text{veg}}$	PgC Mha <sup>-1</sup>	reg_land, bio_land	yes
D_csoil1	$\Delta c_{\text{soil1}}$	PgC Mha <sup>-1</sup>	reg_land, bio_land	yes
D_csoil2	$\Delta c_{\text{soil2}}$	PgC Mha <sup>-1</sup>	reg_land, bio_land	yes
D_Fveg_bk	$\delta C_{\text{veg,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fsoil1_bk	$\delta C_{\text{soil1,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	

In code	In papers	Units	Dims	Prog?
D_Fsoil2_bk	$\delta C_{\text{soil2,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fslash	-	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fslash1	$\Delta F_{\text{slash1}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fslash2	$\Delta F_{\text{slash2}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fhwp	$\Delta F_{\text{hwp}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to, box_hwp	
D_NPP_bk	$\Delta \text{NPP}_{\text{bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Efire_bk	$\Delta E_{\text{fire,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Eharv_bk	$\Delta E_{\text{harv,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Egraz_bk	$\Delta E_{\text{graz,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fmort1_bk	$\Delta F_{\text{mort1,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fmort2_bk	$\Delta F_{\text{mort2,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Rh1_bk	$\Delta \text{Rh}_{1,\text{bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Fmet_bk	$\Delta F_{\text{met,bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Rh2_bk	$\Delta \text{Rh}_{2,\text{bk}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Ehwp	$\Delta E_{\text{hwp}}$	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to, box_hwp	
D_NBP_bk	-	PgC yr <sup>-1</sup>	reg_land, bio_from, bio_to	
D_Eluc	$\Delta E_{\text{LUC}}$	PgC yr <sup>-1</sup>	-	
D_Fland	$\Delta F_{\downarrow \text{land}}$	PgC yr <sup>-1</sup>	-	
D_Aland	$\Delta A$	Mha	reg_land, bio_land	yes
D_Cveg_bk	$\Delta C_{\text{veg,bk}}$	PgC	reg_land, bio_from, bio_to	yes
D_Csoil1_bk	$\Delta C_{\text{soil1,bk}}$	PgC	reg_land, bio_from, bio_to	yes
D_Csoil2_bk	$\Delta C_{\text{soil2,bk}}$	PgC	reg_land, bio_from, bio_to	yes
D_Chwp	$\Delta C_{\text{hwp}}$	PgC	reg_land, bio_from, bio_to, box_hwp	yes
f_resp_pf	-	1	reg_pf	
D_pthaw_bar	$\Delta \bar{p}_{\text{thaw}}$	1	reg_pf	
d_pthaw	$\frac{d}{dt} p_{\text{thaw}}$	yr <sup>-1</sup>	reg_pf	

In code	In papers	Units	Dims	Prog?
D_pthaw	$\Delta p_{\text{thaw}}$	1	reg_pf	yes
D_Fthaw	$\Delta F_{\text{thaw}}$	PgC yr <sup>-1</sup>	reg_pf	
D_Ethaw	-	PgC yr <sup>-1</sup>	reg_pf, box_thaw	
D_Epf	$\Delta E_{\text{pf}}$	PgC yr <sup>-1</sup>	reg_pf	
D_Epf_CO2	-	PgC yr <sup>-1</sup>	reg_pf	
D_Epf_CH4	-	TgC yr <sup>-1</sup>	reg_pf	
D_Cfroz	$\Delta C_{\text{froz}}$	PgC	reg_pf	yes
D_Cthaw	$\Delta C_{\text{thaw}}$	PgC	reg_pf, box_thaw	yes
D_CO2	$\Delta \text{CO}_2$	ppm	-	yes
AF	-	1	-	
kS	-	yr <sup>-1</sup>	-	
RF_CO2	$\Delta \text{RF}^{\text{CO}_2}$	W m <sup>-2</sup>	-	
D_Efire	$\Delta E_{\text{fire}}$	PgC yr <sup>-1</sup>	reg_land, bio_land	
D_Ebb_nat	-	TgX yr <sup>-1</sup>	reg_land, bio_land, spc_bb	
D_Ebb_ant	-	TgX yr <sup>-1</sup>	reg_land, bio_land, spc_bb	
D_Ebb	$\Delta E_{\text{bb}}$	TgX yr <sup>-1</sup>	reg_land, bio_land, spc_bb	
D_CH4_lag	$\Delta \text{CH}_4_{\text{lag}}$	ppb	-	yes
D_N2O_lag	$\Delta \text{N}_2\text{O}_{\text{lag}}$	ppb	-	yes
D_Xhalo_lag	$\Delta X_{\text{lag}}$	ppt	spc_halo	yes
D_Ta	$\Delta T_A$	K	-	
D_f_Qa	$\frac{\Delta Q_A}{Q_{A,0}}$	1	-	
f_kOH	$\mathcal{F}_{\text{OH}}$	1	-	
D_Foh_CH4	-	TgC yr <sup>-1</sup>	-	
D_Fhv_CH4	-	TgC yr <sup>-1</sup>	-	
D_Fsoil_CH4	-	TgC yr <sup>-1</sup>	-	

In code	In papers	Units	Dims	Prog?
D_Focean_CH4	-	TgC yr <sup>-1</sup>	-	
D_Fsink_CH4	$\Delta F_{\downarrow}^{\text{CH}_4}$	TgC yr <sup>-1</sup>	-	
D_Foxi_CH4	-	PgC yr <sup>-1</sup>	-	
D_ewet	$\Delta e_{\text{wet}}$	TgC Mha <sup>-1</sup> yr <sup>-1</sup>	reg_land	
D_Awet	$\Delta A_{\text{wet}}$	Mha	reg_land	
D_Ewet	$\Delta E_{\text{wet}}$	TgC yr <sup>-1</sup>	reg_land	
D_CH4	$\Delta \text{CH}_4$	ppb	-	yes
tau_CH4	-	yr	-	
RF_CH4	$\Delta \text{RF}^{\text{CH}_4}$	W m <sup>-2</sup>	-	
RF_H2Os	$\Delta \text{RF}^{\text{H}_2\text{Os}}$	W m <sup>-2</sup>	-	
D_f_ageair	-	1	-	
f_hv	$\mathcal{F}_{\text{hv}}$	1	-	
D_Fhv_N2O	-	TgN yr <sup>-1</sup>	-	
D_Fsink_N2O	$\Delta F_{\downarrow}^{\text{N}_2\text{O}}$	TgN yr <sup>-1</sup>	-	
D_N2O	$\Delta \text{N}_2\text{O}$	ppb	-	yes
tau_N2O	-	yr	-	
RF_N2O	$\Delta \text{RF}^{\text{N}_2\text{O}}$	W m <sup>-2</sup>	-	
D_Foh_Xhalo	-	Gg yr <sup>-1</sup>	spc_halo	
D_Fhv_CH4	-	Gg yr <sup>-1</sup>	spc_halo	
D_Fother_CH4	-	Gg yr <sup>-1</sup>	spc_halo	
D_Fsink_CH4	$\Delta F_{\downarrow}^{\text{X}}$	Gg yr <sup>-1</sup>	spc_halo	
D_Xhalo	$\Delta \text{X}$	ppt	spc_halo	yes
RF_Xhalo	$\Delta \text{RF}^{\text{X}}$	W m <sup>-2</sup>	spc_halo	
RF_halo	$\Delta \text{RF}^{\text{halo}}$	W m <sup>-2</sup>	-	
D_O3t	$\Delta \text{O}_3\text{t}$	DU	-	

In code	In papers	Units	Dims	Prog?
RF_O3t	$\Delta RF^{O_3t}$	$W\ m^{-2}$	-	
D_EESC	$\Delta E_{ESC}$	ppt	-	
D_O3s	$\Delta O_3s$	DU	-	
RF_O3s	$\Delta RF^{O_3s}$	$W\ m^{-2}$	-	
D_Edms	$\Delta E_{DMS}$	$Tg\ yr^{-1}$	-	
D_Ebvoc	$\Delta E_{BVOC}$	$Tg\ yr^{-1}$	-	
D_Edust	-	$Tg\ yr^{-1}$	-	
D_Esalt	-	$Tg\ yr^{-1}$	-	
D_SO4	$\Delta SO_4$	Tg	-	
D_POA	$\Delta POA$	Tg	-	
D_BC	$\Delta BC$	Tg	-	
D_NO3	$\Delta NO_3$	Tg	-	
D_SOA	$\Delta SOA$	Tg	-	
D_Mdust	-	Tg	-	
D_Msalt	-	Tg	-	
RF_SO4	$\Delta RF^{SO_4}$	$W\ m^{-2}$	-	
RF_POA	$\Delta RF^{POA}$	$W\ m^{-2}$	-	
RF_BC	$\Delta RF^{BC}$	$W\ m^{-2}$	-	
RF_NO3	$\Delta RF^{NO_3}$	$W\ m^{-2}$	-	
RF_SOA	$\Delta RF^{SOA}$	$W\ m^{-2}$	-	
RF_dust	-	$W\ m^{-2}$	-	
RF_salt	-	$W\ m^{-2}$	-	
D_AERsol	$\Delta AER_{sol}$	Tg	-	
RF_cloud1	-	$W\ m^{-2}$	-	
RF_cloud2	-	$W\ m^{-2}$	-	
RF_cloud	$\Delta RF^{cloud}$	$W\ m^{-2}$	-	



In code	In papers	Units	Dims	Prog?
RF_BCsnow	$\Delta RF^{BCsnow}$	W m <sup>-2</sup>	-	
RF_lcc	$\Delta RF^{LCC}$	W m <sup>-2</sup>	-	
RF_nonCO2	-	W m <sup>-2</sup>	-	
RF_wmghg	-	W m <sup>-2</sup>	-	
RF_strat	-	W m <sup>-2</sup>	-	
RF_scatter	-	W m <sup>-2</sup>	-	
RF_absorb	-	W m <sup>-2</sup>	-	
RF_AERtot	-	W m <sup>-2</sup>	-	
RF_slcf	-	W m <sup>-2</sup>	-	
RF_alb	-	W m <sup>-2</sup>	-	
RF	$\Delta RF$	W m <sup>-2</sup>	-	
RF_warm	$\Delta RF_{warm}$	W m <sup>-2</sup>	-	
RF_atm	$\Delta RF_{atm}$	W m <sup>-2</sup>	-	
D_Tg	$\Delta T_G$	K	-	yes
D_Td	$\Delta T_D$	K	-	yes
d_Tg	$\frac{d}{dt} T_G$	K yr <sup>-1</sup>	-	
D_Tl	$\Delta T_L$	K	reg_land	
D_To	$\Delta T_S$	K	-	
D_Pg	$\Delta P_G$	mm yr <sup>-1</sup>	-	yes
D_Pl	$\Delta P_L$	mm yr <sup>-1</sup>	reg_land	
D_OHC	$\Delta OHC$	ZJ	-	yes
D_pH	-	1	-	

## Parameters

Parameters are implicitly defined when creating a model's processes. When OSCAR is run, it does not check whether the needed parameters are actually provided in the `Par` argument. Primary parameters can be loaded with the `load_all_param` function defined in `core_fct.fct_loadP`. Many parameters have several possible

values, and these different configurations are defined along the various `mod_` dimensions of the dataset containing the primary parameters. Sets of randomly drawn parameters for Monte Carlo runs can be generated using the `generate_config` function defined in `core_fct.fct_genMC`. More information on each parameter is available in `core_fct.fct_loadP`.

In code	In papers	Units	Dims	Mods
<code>a_dic</code>	$\alpha_{\text{sol}}$	$\mu\text{mol kg}^{-1} [\text{ppm m}^{-3}]^{-1}$	-	-
<code>mld_0</code>	$h_{\text{mld},0}$	m	-	<code>mod_Focean_struct</code>
<code>A_ocean</code>	$A_{\text{ocean}}$	$\text{m}^2$	-	<code>mod_Focean_struct</code>
<code>To_0</code>	$T_{S,0}$	K	-	<code>mod_Focean_struct</code>
<code>v_fg</code>	$\nu_{\text{fg}}$	$\text{yr}^{-1}$	-	<code>mod_Focean_struct</code>
<code>p_circ</code>	$\pi_{\text{circ}}$	1	<code>box_osurf</code>	<code>mod_Focean_struct</code>
<code>t_circ</code>	$\tau_{\text{circ}}$	yr	<code>box_osurf</code>	<code>mod_Focean_struct</code>
<code>pCO2_is_Pade</code>	-	<code>bool</code>	-	<code>mod_Focean_chem</code>
<code>p_mld</code>	$\pi_{\text{mld}}$	1	-	<code>mod_Focean_trans</code>
<code>g_mld</code>	$\gamma_{\text{mld}}$	$\text{K}^{-1}$	-	<code>mod_Focean_trans</code>
<code>fert_is_Log</code>	-	<code>bool</code>	-	<code>mod_Fland_fert</code>
<code>t_shift</code>	$\tau_{\text{shift}}$	yr	-	-
<code>npp_0</code>	$\eta$	$\text{PgC Mha}^{-1} \text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Fland_preind</code>
<code>igni_0</code>	$\iota$	$\text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Efire_preind</code>
<code>harv_0</code>	$\epsilon_{\text{harv}}$	$\text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Eharv_preind</code>
<code>graz_0</code>	$\epsilon_{\text{graz}}$	$\text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Egraz_preind</code>
<code>mu1_0</code>	$\mu_1$	$\text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Fland_preind</code>
<code>mu2_0</code>	$\mu_2$	$\text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Fland_preind</code>
<code>muM_0</code>	$\mu_{\text{met}}$	$\text{yr}^{-1}$	<code>reg_land,</code> <code>bio_land</code>	<code>mod_Fland_preind</code>

In code	In papers	Units	Dims	Mods
<code>rho1_0</code>	$\rho_1$	$\text{yr}^{-1}$	reg_land, bio_land	mod_Fland_preind
<code>rho2_0</code>	$\rho_2$	$\text{yr}^{-1}$	reg_land, bio_land	mod_Fland_preind
<code>p_agb</code>	$\pi_{\text{agb}}$	1	reg_land, bio_land	mod_Eluc_agb
<code>b_npp</code>	$\beta_{\text{npp}}$	1	reg_land, bio_land	mod_Fland_trans
<code>b2_npp</code>	$\tilde{\beta}_{\text{npp}}$	1	reg_land, bio_land	mod_Fland_trans
<code>CO2_cp</code>	$\text{CO}_{2\text{cp}}$	ppm	reg_land, bio_land	mod_Fland_trans
<code>g_nppT</code>	$\gamma_{\text{npp},T}$	$\text{K}^{-1}$	reg_land, bio_land	mod_Fland_trans, mod_Fland_fert
<code>g_nppP</code>	$\gamma_{\text{npp},P}$	$[\text{mm yr}^{-1}]^{-1}$	reg_land, bio_land	mod_Fland_trans, mod_Fland_fert
<code>g_rhoT</code>	$\gamma_{\text{resp},T}$	$\text{K}^{-1}$	reg_land, bio_land	mod_Fland_trans, mod_Fland_resp
<code>g_rhoT1</code>	$\gamma_{\text{resp},T_1}$	$\text{K}^{-1}$	reg_land, bio_land	mod_Fland_trans, mod_Fland_resp
<code>g_rhoT2</code>	$\gamma_{\text{resp},T_2}$	$\text{K}^{-2}$	reg_land, bio_land	mod_Fland_trans, mod_Fland_resp
<code>g_rhoP</code>	$\gamma_{\text{resp},P}$	$[\text{mm yr}^{-1}]^{-1}$	reg_land, bio_land	mod_Fland_trans
<code>g_igniC</code>	$\gamma_{\text{igni},C}$	$\text{ppm}^{-1}$	reg_land, bio_land	mod_Efire_trans
<code>g_igniT</code>	$\gamma_{\text{igni},T}$	$\text{K}^{-1}$	reg_land, bio_land	mod_Efire_trans
<code>g_igniP</code>	$\gamma_{\text{igni},P}$	$[\text{mm yr}^{-1}]^{-1}$	reg_land, bio_land	mod_Efire_trans
<code>t_hwp</code>	$\tau_{\text{hwp}}$	yr	box_hwp	mod_Ehwp_tau
<code>w_t_hwp</code>	-	1	-	mod_Ehwp_speed
<code>p_hwp_bb</code>	-	1	box_hwp	-

In code	In papers	Units	Dims	Mods
p_hwp	$\pi_{\text{hwp}}$	1	reg_land, bio_land, box_hwp	mod_Ehwp_bb
a_bb	$\alpha_{\text{bb}}$	TgX PgC <sup>-1</sup>	reg_land, bio_land, spc_bb	-
Cfroz_0	$C_{\text{froz},0}$	PgC	reg_pf	mod_Epf_main
w_clim_pf	$\omega_{T_{\text{pf}}}$	1	reg_pf	mod_Epf_main
g_respT_pf	$\gamma_{\text{pf},T_1}$	K <sup>-1</sup>	reg_pf	mod_Epf_main
g_respT2_pf	$\gamma_{\text{pf},T_2}$	K <sup>-2</sup>	reg_pf	mod_Epf_main
k_resp_pf	$\kappa_{\text{resp,pf}}$	1	reg_pf	mod_Epf_main
pthaw_min	$p_{\text{thaw,min}}$	1	reg_pf	mod_Epf_main
g_pthaw	$\gamma_{p_{\text{thaw}}}$	K <sup>-1</sup>	reg_pf	mod_Epf_main
k_pthaw	$\kappa_{p_{\text{thaw}}}$	1	reg_pf	mod_Epf_main
v_thaw	$\nu_{\text{thaw}}$	yr <sup>-1</sup>	reg_pf	mod_Epf_main
v_froz	$\nu_{\text{froz}}$	yr <sup>-1</sup>	reg_pf	mod_Epf_main
p_pf_thaw	$\pi_{\text{thaw}}$	1	reg_pf, box_thaw	mod_Epf_main
t_pf_thaw	$\tau_{\text{thaw}}$	yr	reg_pf, box_thaw	mod_Epf_main
p_pf_inst	-	1	-	-
p_pf_CH4	-	1	-	mod_Epf_CH4
ewet_0	$e_{\text{wet},0}$	TgC yr <sup>-1</sup>	reg_land	mod_Ewet_preind
Awet_0	$A_{\text{wet},0}$	Mha	reg_land	mod_Ewet_preind
p_wet	$\pi_{\text{wet}}$	1	reg_land, bio_land	mod_Ewet_preind
g_wetC	$\gamma_{\text{wet},C}$	ppm <sup>-1</sup>	reg_land	mod_Awet_trans
g_wetT	$\gamma_{\text{wet},T}$	K <sup>-1</sup>	reg_land	mod_Awet_trans
g_wetP	$\gamma_{\text{wet},P}$	[mm yr <sup>-1</sup> ] <sup>-1</sup>	reg_land	mod_Awet_trans

In code	In papers	Units	Dims	Mods
a_CO2	$\alpha_{\text{atm}}^{\text{CO}_2}$	PgC ppm <sup>-1</sup>	-	-
a_CH4	$\alpha_{\text{atm}}^{\text{CH}_4}$	TgC ppb <sup>-1</sup>	-	-
a_N2O	$\alpha_{\text{atm}}^{\text{N}_2\text{O}}$	TgC ppb <sup>-1</sup>	-	-
a_Xhalo	$\alpha_{\text{atm}}^X$	Gg ppt <sup>-1</sup>	spc_halo	-
a_S04	-	Tg TgS <sup>-1</sup>	-	-
a_POM	$\alpha_{\text{OM}}^{\text{OC}}$	Tg TgC <sup>-1</sup>	-	mod_POA_conv
a_N03	-	Tg TgN <sup>-1</sup>	-	-
CO2_0	CO <sub>20</sub>	ppm	-	-
CH4_0	CH <sub>40</sub>	ppb	-	-
N2O_0	N <sub>2</sub> O <sub>0</sub>	ppb	-	-
Xhalo_0	X <sub>0</sub>	ppt	spc_halo	-
p_CH4geo	-	1	-	-
g_ageair	$\gamma_{\text{age}}$	K <sup>-1</sup>	-	mod_Fhv_ageair
w_t_OH	-	1	-	-
w_t_hv	-	1	-	-
t_OH_CH4	$\tau_{\text{OH}}^{\text{CH}_4}$	yr	-	mod_Foh_tau
t_hv_CH4	$\tau_{\text{hv}}^{\text{CH}_4}$	yr	-	-
t_soil_CH4	$\tau_{\text{soil}}^{\text{CH}_4}$	yr	-	-
t_ocean_CH4	$\tau_{\text{ocean}}^{\text{CH}_4}$	yr	-	-
x_OH-Ta	$\chi_{\text{TA}}^{\text{OH}}$	1	-	mod_Foh_trans
x_OH-Qa	$\chi_{\text{QA}}^{\text{OH}}$	1	-	mod_Foh_trans
x_OH_O3s	$\chi_{\text{O}_3\text{s}}^{\text{OH}}$	1	-	mod_Foh_trans
x_OH_CH4	$\chi_{\text{CH}_4}^{\text{OH}}$	1	-	mod_Foh_trans
x_OH_NOX	$\tilde{\chi}_{\text{NO}_x}^{\text{OH}}$	1	-	mod_Foh_trans

In code	In papers	Units	Dims	Mods
x_OH_CO	$\tilde{\chi}_{\text{CO}}^{\text{OH}}$	1	-	mod_Foh_trans
x_OH_VOC	$\tilde{\chi}_{\text{VOC}}^{\text{OH}}$	1	-	mod_Foh_trans
x2_OH_NOX	$\chi_{\text{NO}_x}^{\text{OH}}$	$[\text{TgN yr}^{-1}]^{-1}$	-	mod_Foh_trans
x2_OH_CO	$\chi_{\text{CO}}^{\text{OH}}$	$[\text{TgC yr}^{-1}]^{-1}$	-	mod_Foh_trans
x2_OH_VOC	$\chi_{\text{VOC}}^{\text{OH}}$	$[\text{Tg yr}^{-1}]^{-1}$	-	mod_Foh_trans
w_clim-Ta	$\kappa_{T_A}$	1	-	-
k_Qa	$\kappa_{Q_A}$	1	-	-
Ta_0	$T_{A,0}$	K	-	-
k_svp	$\kappa_{\text{svp}}$	1	-	-
T_svp	$T_{\text{svp}}$	K	-	-
O3s_0	$\text{O}_3\text{S}_0$	DU	-	-
Enat_NOX	$E_{\text{nat}}^{\text{NO}_x}$	$\text{TgN yr}^{-1}$	-	-
Enat_CO	$E_{\text{nat}}^{\text{CO}}$	$\text{TgC yr}^{-1}$	-	-
Enat_VOC	$E_{\text{nat}}^{\text{VOC}}$	$\text{Tg yr}^{-1}$	-	-
kOH_is_Log	-	bool	-	mod_Foh_fct
t_hv_N2O	$\tau_{\text{h}\nu}^{\text{N}_2\text{O}}$	yr	-	mod_Fhv_tau
x_hv_N2O	$\chi_{\text{N}_2\text{O}}^{\text{h}\nu}$	1	-	mod_Fhv_trans
x_hv_EESC	$\chi_{\text{EESC}}^{\text{h}\nu}$	1	-	mod_Fhv_trans
x_hv_age	$\chi_{\text{age}}^{\text{h}\nu}$	1	-	mod_Fhv_trans
t_OH_Xhalo	$\tau_{\text{OH}}^X$	yr	spc_halo	-
t_hv_Xhalo	$\tau_{\text{h}\nu}^X$	yr	spc_halo	-
t_other_Xhalo	$\tau_{\text{other}}^X$	yr	spc_halo	-
p_reg_slcf	$\pi_{\text{reg}}$	1	reg_land, reg_slcf	-
w_reg_NOX	$\omega_{\text{NO}_x}$	1	reg_slcf	mod_O3t_regsat

In code	In papers	Units	Dims	Mods
w_reg_CO	$\omega_{CO}$	1	reg_slcf	mod_03t_regsat
w_reg_VOC	$\omega_{VOC}$	1	reg_slcf	mod_03t_regsat
x_03t_CH4	$\chi_{CH_4}^{O_3t}$	DU	-	mod_03t_emis
x_03t_NOX	$\chi_{NO_x}^{O_3t}$	DU [TgN yr <sup>-1</sup> ] <sup>-1</sup>	-	mod_03t_emis
x_03t_CO	$\chi_{CO}^{O_3t}$	DU [TgC yr <sup>-1</sup> ] <sup>-1</sup>	-	mod_03t_emis
x_03t_VOC	$\chi_{VOC}^{O_3t}$	DU [Tg yr <sup>-1</sup> ] <sup>-1</sup>	-	mod_03t_emis
G_03t	$\Gamma_{O_3t}$	DU K <sup>-1</sup>	-	mod_03t_clim
t_lag	$\tau_{lag}$	yr	-	-
p_fracrel	$\pi_{rel}^X$	1	spc_halo	mod_03s_fracrel
k_Br_Cl	$\alpha_{Cl}^{Br}$	1	-	-
n_Cl	$n_{Cl}^X$	1	spc_halo	-
n_Br	$n_{Br}^X$	1	spc_halo	-
EESC_x	EESC <sub>x</sub>	ppt	-	-
k_EESC_N2O	$\frac{\chi_{N_2O}^{O_3s}}{\chi_{EESC}^{O_3s}}$	ppt ppb <sup>-1</sup>	-	mod_03s_nitrous, mod_03s_fracrel
x_03s_EESC	$\chi_{EESC}^{O_3s}$	DU ppt <sup>-1</sup>	-	mod_03s_trans
G_03s	$\Gamma_{O_3s}$	DU K <sup>-1</sup>	-	mod_03s_trans
w_reg_SO2	$\omega_{SO_2}$	1	reg_slcf	mod_S04_regsat
w_reg_OC	$\omega_{OC}$	1	reg_slcf	mod_POA_regsat
w_reg_BC	$\omega_{BC}$	1	reg_slcf	mod_BC_regsat
t_S02	$\tau_{SO_2}$	yr	-	mod_S04_load
t_DMS	$\tau_{DMS}$	yr	-	mod_S04_load
G_S04	$\Gamma_{SO_4}$	Tg K <sup>-1</sup>	-	mod_S04_load
t_OMff	$\tau_{OM,ff}$	yr	-	mod_POA_load
t_OMbb	$\tau_{OM,bb}$	yr	-	mod_POA_load

In code	In papers	Units	Dims	Mods
G_POA	$\Gamma_{\text{POA}}$	Tg K <sup>-1</sup>	-	mod_POA_load
t_BCff	$\tau_{\text{BC,ff}}$	yr	-	mod_BC_load
t_BCbb	$\tau_{\text{BC,bb}}$	yr	-	mod_BC_load
G_BC	$\Gamma_{\text{BC}}$	Tg K <sup>-1</sup>	-	mod_BC_load
t_NOX	$\tau_{\text{NO}_x}$	yr	-	mod_NO3_load
t_NH3	$\tau_{\text{NH}_3}$	yr	-	mod_NO3_load
G_NO3	$\Gamma_{\text{NO}_3}$	Tg K <sup>-1</sup>	-	mod_NO3_load
t_VOC	$\tau_{\text{VOC}}$	yr	-	mod_SOA_load
t_BVOC	$\tau_{\text{BVOC}}$	yr	-	mod_SOA_load
G_SOA	$\Gamma_{\text{SOA}}$	Tg K <sup>-1</sup>	-	mod_SOA_load
t_dust	-	yr	-	mod_Mdust_load
G_dust	-	Tg K <sup>-1</sup>	-	mod_Mdust_load
t_salt	-	yr	-	mod_Msalt_load
G_salt	-	Tg K <sup>-1</sup>	-	mod_Msalt_load
p_sol_S04	$\pi_{\text{sol}}^{\text{SO}_4}$	1	-	mod_RFcloud_solub
p_sol_POA	$\pi_{\text{sol}}^{\text{POA}}$	1	-	mod_RFcloud_solub
p_sol_BC	$\pi_{\text{sol}}^{\text{BC}}$	1	-	mod_RFcloud_solub
p_sol_NO3	$\pi_{\text{sol}}^{\text{NO}_3}$	1	-	mod_RFcloud_solub
p_sol_SOA	$\pi_{\text{sol}}^{\text{SOA}}$	1	-	mod_RFcloud_solub
p_sol_dust	-	1	-	mod_RFcloud_solub
p_sol_salt	-	1	-	mod_RFcloud_solub
r_f_CO2	$\alpha_{\text{rf}}^{\text{CO}_2}$	W m <sup>-2</sup>	-	-
r_f_CH4	$\alpha_{\text{rf}}^{\text{CH}_4}$	W m <sup>-2</sup> ppb <sup>-0.5</sup>	-	-
r_f_N2O	$\alpha_{\text{rf}}^{\text{N}_2\text{O}}$	W m <sup>-2</sup> ppb <sup>-0.5</sup>	-	-
k_rf_H2Os	$\frac{\alpha_{\text{rf}}^{\text{H}_2\text{Os}}}{\alpha_{\text{rf}}^{\text{CH}_4}}$	1	-	-



In code	In papers	Units	Dims	Mods
rf_Xhalo	$\alpha_{\text{rf}}^X$	W m <sup>-2</sup> ppt <sup>-1</sup>	spc_halo	-
rf_03t	$\alpha_{\text{rf}}^{\text{O}_3\text{t}}$	W m <sup>-2</sup> DU <sup>-1</sup>	-	mod_03t_radeff
rf_03s	$\alpha_{\text{rf}}^{\text{O}_3\text{s}}$	W m <sup>-2</sup> DU <sup>-1</sup>	-	mod_03s_radeff
rf_S04	$\alpha_{\text{rf}}^{\text{SO}_4}$	W m <sup>-2</sup> Tg <sup>-1</sup>	-	mod_S04_radeff
rf_POA	$\alpha_{\text{rf}}^{\text{POA}}$	W m <sup>-2</sup> Tg <sup>-1</sup>	-	mod_POA_radeff
rf_BC	$\alpha_{\text{rf}}^{\text{BC}}$	W m <sup>-2</sup> Tg <sup>-1</sup>	-	mod_BC_radeff
rf_NO3	$\alpha_{\text{rf}}^{\text{NO}_3}$	W m <sup>-2</sup> Tg <sup>-1</sup>	-	mod_NO3_radeff
rf_SOA	$\alpha_{\text{rf}}^{\text{SOA}}$	W m <sup>-2</sup> Tg <sup>-1</sup>	-	mod_SOA_radeff
rf_dust	-	W m <sup>-2</sup> Tg <sup>-1</sup>	-	-
rf_salt	-	W m <sup>-2</sup> Tg <sup>-1</sup>	-	-
k_adj_BC	$\kappa_{\text{adj}}^{\text{BC}}$	1	-	mod_BC_adjust
Phi_0	$\Phi$	W m <sup>-2</sup>	-	mod_RFcloud_erf, mod_RFcloud_solub
AERsol_0	AER <sub>sol,0</sub>	Tg	-	mod_RFcloud_solub, mod_RFcloud_erf, mod_RFcloud_preind
p_reg_bcsnow	$\pi_{\text{reg}}$	1	reg_land, reg_bcsnow	-
w_reg_bcsnow	$\omega_{\text{BCsnow}}$	1	reg_bcsnow	mod_RFbcsnow_reg
rf_bcsnow	$\alpha_{\text{rf}}^{\text{BCsnow}}$	W m <sup>-2</sup> [TgC yr <sup>-1</sup> ] <sup>-1</sup>	-	mod_RFbcsnow_rf
p_trans	$\pi_{\text{trans}}$	1	-	-
alpha_alb	$\alpha_{\text{alb}}$	1	reg_land, bio_land	mod_RFlcc_alb, mod_RFlcc_flux, mod_RFlcc_cover
F_rsds	$\phi_{\text{rsds}}$	W m <sup>-2</sup>	reg_land	mod_RFlcc_flux
w_warm_volc	$\kappa_{\text{warm}}^{\text{volc}}$	1	-	-

In code	In papers	Units	Dims	Mods
w_warm_bcsnow	$\kappa_{\text{warm}}^{\text{BCsnow}}$	1	-	mod_RFbcsnow_warmeff
w_warm_lcc	$\kappa_{\text{warm}}^{\text{LCC}}$	1	-	mod_RFlcc_warmeff
p_atm_CO2	$\pi_{\text{atm}}^{\text{CO}_2}$	1	-	mod_Pg_radfact
p_atm_nonCO2	$\pi_{\text{atm}}^{\text{noCO}_2}$	1	-	mod_Pg_radfact
p_atm_O3t	$\pi_{\text{atm}}^{\text{O}_3\text{t}}$	1	-	mod_Pg_radfact
p_atm_strat	$\pi_{\text{atm}}^{\text{strat}}$	1	-	mod_Pg_radfact
p_atm_scatter	$\pi_{\text{atm}}^{\text{scatter}}$	1	-	mod_Pg_radfact
p_atm_absorb	$\pi_{\text{atm}}^{\text{absorb}}$	1	-	mod_Pg_radfact
p_atm_cloud	$\pi_{\text{atm}}^{\text{cloud}}$	1	-	mod_Pg_radfact
p_atm_alb	$\pi_{\text{atm}}^{\text{alb}}$	1	-	mod_Pg_radfact
p_atm_solar	$\pi_{\text{atm}}^{\text{solar}}$	1	-	mod_Pg_radfact
lambda_0	$\lambda$	K [W m <sup>-2</sup> ] <sup>-1</sup>	-	mod_Tg_resp
Th_g	$\frac{\tau_{T_G}}{\lambda}$	yr W m <sup>-2</sup> K <sup>-1</sup>	-	mod_Tg_resp
Th_d	$\frac{\tau_{T_D}}{\lambda}$	yr W m <sup>-2</sup> K <sup>-1</sup>	-	mod_Tg_resp
th_0	$\frac{\theta}{\lambda}$	W m <sup>-2</sup> K <sup>-1</sup>	-	mod_Tg_resp
w_clim_Tl	$\omega_{T_L}$	1	reg_land	mod_Tl_pattern, mod_Tg_resp
w_clim_To	$\omega_{T_S}$	1	-	mod_Tl_pattern, mod_Tg_resp
a_prec	$\alpha_{P_G}$	mm yr <sup>-1</sup> K <sup>-1</sup>	-	mod_Pg_resp
b_prec	$\beta_{P_G}$	mm yr <sup>-1</sup> [W m <sup>-2</sup> ] <sup>-1</sup>	-	mod_Pg_resp
w_clim_Pl	$\omega_{P_L}$	1	reg_land	mod_Pl_pattern, mod_Pg_resp
p_ohc	$\pi_{\text{ohc}}$	1	-	-
pH_is_Log	-	bool	-	mod_pH_fct

