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The GRENE-TEA model intercomparison project (GTMIP): overview and experiment protocol for Stage 1

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Table S1. Lists of variables submitted for the model intercomparison

Status values should be input into this table (1: model driving, 2: prescribed parameter, 3: prognostic variable, 4: diagnostic variable, 5: not applicable) for each variable according to each model treatment for (a) model driving, (b) energy and water budget, (c) snowpack, (d) vegetation/phenology, (e) subsurface hydrological and thermal state, and (f) carbon budget. The time step column in this table requires the time step input (e.g., 30 min., daily, etc.) of the output from each model.

(a): Model driving

Variable	Priority	Definition	Units	Direction (+)	status	Time step
Pr	1	Total precipitation	$kg/m^2/s$	Downward		
Psn	1	Snowfall	$kg/m^2/s$	Downward		
Tair	1	Air temperature at reference height	K	-		
Psurf	1	Surface pressure	hPa	-		
Wind	1	Wind speed at reference height	m/s	-		
SWdown	1	Surface incident short wave radiation	W/m^2	Downward		
LWdown	1	Surface incident long wave radiation	W/m^2	Downward		
Qair	1	Specific humidity at reference height	kg/kg	-		
PAR_in	2	Surface incident photosynthetically active radiation	$mol/m^2/s$	Downward		
CO2air	2	CO_2 concentration at reference height	ppmv	-		

(b): Energy and water budgets

Variable	priority	Definition	Units	Direction (+)	status	Time step
SWup_total	1	Total outgoing short wave radiation (total over snow-free and snow-covered canopy, snow-free and snow-covered ground)	W/m^2	Upward		
LWup_total	1	Total outgoing long wave radiation (same as SWup_total)	W/m^2	Upward		
Qh_total	1	Total sensible heat flux (same as SWup_total)	W/m^2	Upward		
Qle_total	1	Total latent heat flux (same as SWup_total)	W/m^2	Upward		
Qg_total	1	Total ground heat flux (on snow-free and snow-covered ground)	W/m^2	Downward		
ET_total	1	Total evapotranspiration (i.e., Et_veg + E_soil + Ei + Ei_snw)	$kg/m^2/s$	Upward		
Qs	1	Surface runoff	$kg/m^2/s$	-		
Qsb	1	Subsurface runoff	$kg/m^2/s$	-		
alpha_sw	1	Total shortwave albedo	-	-		
Et_veg	1	Total transpiration of vegetation (e.g. forest transpiration + forest floor transpiration)	$kg/m^2/s$	Upward		
E_soil	1	Soil evaporation from snow-free ground	$kg/m^2/s$	Upward		
Ei	2	Canopy interception evaporation on snow-free canopy	$kg/m^2/s$	Upward		
Ei_snw	2	Canopy interception evaporation on snow-covered canopy	$kg/m^2/s$	Upward		

1 (b): continued

Variable	priority	Definition	Units	Direction (+)	status	Time step
Sub_snow	1	Sublimation from the ground snow pack	kg/m^2 /s	Upward		
SWup_can	2	Outgoing shortwave radiation on snow-free canopy	W/m^2	Upward		
LWup_can	2	Outgoing long wave radiation on snow-free canopy	W/m^2	Upward		
Qh_can	2	Sensible heat flux on snow-free canopy	W/m^2	Upward		
Qle_can	2	Total latent heat flux on snow-free canopy	W/m^2	Upward		
SWup_gnd	2	Outgoing short wave radiation on snow-free ground	W/m^2	Upward		
LWup_gnd	2	Outgoing long wave radiation on snow-free ground	W/m^2	Upward		
Qh_gnd	2	Sensible heat flux on snow-free ground	W/m^2	Upward		
Qle_gnd	2	Total latent heat flux on snow-free ground	W/m^2	Upward		
Qg_gnd	2	Total ground heat flux on snow-free ground	W/m^2	Downward		
SWup_can_snw	2	Outgoing short wave radiation on snow-covered canopy	W/m^2	Upward		
LWup_can_snw	2	Outgoing long wave radiation on snow-covered canopy	W/m^2	Upward		
Qh_can_snw	2	Sensible heat flux on snow-covered canopy	W/m^2	Upward		
Qle_can_snw	2	Total latent heat flux on snow-covered canopy	W/m^2	Upward		
SWup_snw	2	Outgoing short wave radiation on snow-covered ground	W/m^2	Upward		

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(b): continued

Variable	priority	Definition	Units	Direction (+)	status	Time step
LWup_snw	2	Outgoing long wave radiation on snow-covered ground	W/m^2	Upward		
Qh_snw	2	Sensible heat flux on snow-covered ground	W/m^2	Upward		
Qle_snw	2	Total latent heat flux on snow-covered ground	W/m^2	Upward		
Qg_snw	2	Total ground heat flux on snow-covered ground	W/m^2	Downward		
fPAR	2	Absorbed fraction incoming PAR on canopy	-	-		

(c): Snowpack

Variable	priority	Definition	Units	Direction (+)	status	Time step
SnowT_*layer*	1	Snow temperature at surface and in each user-defined snow layer (m)	K	-		
SWE	1	Snow water equivalent	kg/m^2	-		
SnowDepth	1	Total snow depth	m	-		
Rho_sn_bulk	1	Bulk density of snow	kg/m^3	-		
Rho_sn_*layer*	1	Density of snow in each user-defined snow layer (m)	kg/m^3	-		
Wsn_liq_*layer*	1	Liquid water content of snow in each user-defined snow layer (m)	kg/m^2	-		
Alpha_sn	1	albedo of snow	-	-		
Ksn_*layer*	1	thermal conductivity of snow in each user-defined snow layer (m)	W/m/K	-		
Fcompact_sn	2	Compaction rate of snow (snow density change due to compaction)	$kg/s•m^3$	-		
SIF	2	Snow impurity factor (which expresses the effects of black carbon and mineral dust as a single parameter: composite mass absorption cross sections of snow impurities per unit snow mass)	-	-		

1 (d): Vegetation/ Phenology

Variable	Priority	Definition	Units	Direction (+)	status	Time step
AvgSurfT	1	Average of all vegetation, bare soil and snow skin temperatures	K	-		
VegT_*layer*	1	Vegetation canopy temperature in user-defined canopy layer (m)	K	-		
W_can_liquid_*layer*, W_can_solid_*layer*, W_can_total_*layer*	2	Canopy water in user-defined canopy layer in the liquid and solid phases	kg/m^2	-		
LAI_total	1	Total leaf area index	m^2/m^2	-		
LAI_up_can	1	Leaf area index of upper canopy	m^2/m^2	-		
LAI_forest_floor	1	Leaf area index of forest floor	m^2/m^2			
Ce, Ch, Cd	1	Exchange coefficient of leaf (vapor, heat, momentum)	-	-		
r_a	1	Aerodynamic resistance between canopy air space and reference height	s/m			
VgH	1	Vegetation height	m	-		
VgB	1	Canopy base height	m	-		
Root_frac_*layer*	1	Root fraction in each user-defined soil layer (The cumulative root fraction from the surface to the bottom depth with root in the soil should be 1.0)	-	-		
Alpha_leaf	2	Leaf albedo (VIS, NIR)	-	-		
T_leaf	2	Leaf transmissivity (VIS, NIR)	-	-		

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Variable	priority	Definition	Units	Direction (+)	status	Time step
VC	2	Vegetation coverage	-	-		
gc	2	Canopy conductance	m/s	-		
fBurn	3	Burnt area fraction	-	-		
fPFT	3	Fraction of plant functional types (PFT) or dominant PFT, which is based on the classification in each model (e.g. high latitude deciduous forest and woodland, tundra)	-	-		

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(e): Subsurface hydrological and thermal states

Variable	priority	Definition	Units	Direction (+)	status	Time step
Tg_*depth*	1	Ground temperature at surface and in each user-defined soil layer (m)	K	-		
Wg_*depth*	1	Volumetric soil water content including the liquid, vapor and solid phases of water in each user-defined soil layer (m)	m^3/m^3	-		
Wg_frac_*depth*	1	Fraction of saturation of soil water content in each user-defined soil layer (m) (wilting=0, saturation=1)	-	-		
Wg_frozfrac_*depth*	1	Fraction of soil moisture mass in the solid phase in each user-defined soil layer (m)	-			
kg_*depth*	1	Soil thermal conductivity in each user-defined soil layer (m)	J/K/m/s			
Cg_*depth*	1	Soil heat capacity in each user-defined soil layer (m)	$J/K/m^3$			
Theta_s_*depth*	1	Porosity of soil in each user-defined soil layer (m)	-			
K_s_*depth*	1	Saturation hydraulic conductivity of soil in each user-defined soil layer (m)	m/s			
Psi_s_*depth*	1	Saturation matric potential in each user-defined soil layer (m)	m			
b, n, alpha_*depth*	1	Empirical factor for soil retention curve in each user-defined soil layer (m)	-			

1 (f): Carbon budget

Variable	priority	Definition	Units	Direction(+)	status	Time step
GPP	1	Gross Primary Production on land	kgC/m^2/s	Downward		
NPP	1	Net Primary Production on land (GPP – Ra)	kgC/m^2/s	Downward		
Ra	1	Autotrophic (plant) respiration on land	kgC/m^2/s	Upward		
Rh	1	Heterotrophic Respiration on land	kgC/m^2/s	Upward		
TotCarLitSoil	1	Total soil organic carbon	kgC/m^2	-		
NEP	1	Net ecosystem productivity (=NPP - Rh)	kgC/m^2/s	Downward		
Pmax or Vcmax	1	Maximum photosynthesis rate or maximum rate of Rubisco carboxylase activity	mol/m^2/s	-		
Q10	1	Temperature sensitivity in soil respiration	-	-		
NBP	2	Net Biome production (=NEP - other efflux from the land by natural or anthropogenic disturbances)	kgC/m^2/s	Downward		
cLeaf	2	Carbon mass in leaves	kgC/m^2	-		
cStemCRoot	2	Carbon mass in stems and coarse roots	kgC/m^2	-		
cFRoot	2	Carbon mass in fine roots	kgC/m^2	-		
cOtherLiving	2	Carbon mass in other living compartments	kgC/m^2	-		
cLitter	2	Carbon mass in litter pool	kgC/m^2	-		
cSoilMineral	2	Carbon mass in soil mineral	kgC/m^2	-		
cOtherDead	2	Carbon mass in other forms	kgC/m^2	-		
CO2fire	3	CO2 emission from fire	kgC/m^2/s	Upward		

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Variable	priority	Definition	Units	Direction(+)	status	Time step
Carbon_alloc	3	Carbon allocation ratio to each organ of vegetation (leaf, stem and root)	-	-		
M	3	Mortality/Senescence ratio (ratio of mortality and senescence of each organ (leaf, stem and root) per unit time)	-	-		

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1 Table S2. File naming convention for submitting the results of each model

Model-name	Model-ID	Stage-name	Stage-ID	Forcing-data set	Forcing- ID	Station-name	Station-ID
2LM	2LM	Stage 1.0A	1.0A	Level 0.2	Lv0.2	Fairbanks	FB
FROST	FROST	Stage 1.0B	1.0B	Level 1.0	Lv1.0	Kevo	KV
SMAP	SMAP	----------	--------	----------	----------	Tiksi	TK
SNOWPACK	SNOWPACK	----------	--------	----------	----------	Yakutsk	YK
HAL	HAL	----------	--------	----------	----------	Chokurdakh	CH
MATSIRO-ssnowd	MATsnow	----------	--------	----------	----------	Tura	TR
MATSIRO-MIROC4	MAT4	----------	--------	----------	----------	----------	--------
MATSIRO-Permafrost	MATpf	----------	--------	----------	----------	----------	--------
MATSIRO-MIROC5	MAT5	----------	--------	----------	----------	----------	--------
SPAC-multilayer	SPAC	----------	--------	----------	----------	----------	--------
LPJ	LPJ	----------	--------	----------	----------	----------	--------
BEAMS	BEAMS	----------	--------	----------	----------	----------	--------
PB-SDM	PBSDM	----------	--------	----------	----------	----------	--------
STEM1	STEM1	----------	--------	----------	----------	----------	--------
VISIT	VISIT	----------	--------	----------	----------	----------	--------
CHANGE	CHANGE	----------	--------	----------	----------	----------	--------
SEIB-DGVM-MIROC	SEIB-M	----------	--------	----------	----------	----------	--------
SEIB-DGVM-Noah	SEIB-N	----------	--------	----------	----------	----------	--------
JULES	JULES	----------	--------	----------	----------	----------	--------
Biome-BGC	B-BGC	----------	--------	----------	----------	----------	--------

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1 Table S3. Questionnaire for determining the model habitat

		Investigator name				
		Model name				
Section	Category	Process	Explanation	Complexity of process	Existence of spatial structure	Description of incorporated process
				A: Detailed formulation B: Formulation/Diagnosis C: Forcing (input)/Fixed -: Not considered	B: more than 1-dimensional structure C: zero dimension -: No	
Overall	Energy	Does the energy conserve?	Yes or No			
	Water	Does the water conserve?	Yes or No			
	Biogeochemical cycle	Carbon cycle process	Yes or No			
		Biogeochemical cycle except carbon	Yes or No			
		Plant competition	Yes or No			
		Biogeochemical transport of non CO2 for outside of ecosystem	Yes or No			
		Wildfire & anthropogenic disturbances	Yes or No			
Above ground	Energy	Radiation	Shortwave, long wave, albedo			
		Temperature	Air temperature, canopy temperature, leaf temperature			
		Sensible heat flux				
	Water	Transpiration				
		Other evaporation and latent heat flux				
		Precipitation (vertical water movement)	Precipitation, interception			
		Snowpack	Snow depth, snow metamorphism,			

			snow albedo, heat insulation etc.			
		Inland water (surface water)	pond, lake, swamp, wetland			
		Surface runoff	Including horizontal water movement within grid cell			
		River routine (inter-grid)	Transport the water, heat, geochemical material?			
	Biogeochemical cycle	Carbon pool	leaf, stem, root etc.			
		Treatment of species	With or without the plant functional type, competition			
		Photosynthesis	leaf photosynthesis and scale up to the canopy			
		Autotrophic Respiration	growth respiration, maintenance respiration etc.			
		Growth	Carbon allocation to organs			
		Leaf and canopy	Representation of canopy and floor vegetation regarding LAI			
		Phenology	Calculation of timing of leaf emergence, senescence			
		Shedding & mortality	litter & mortality			
Below ground	Energy	Soil temperature	Dependence of phase change (liquid/ice) on			

			heat transfer, physical properties (heat conductivity etc.) and cooperation between heat and water			
		Heat flow	Ground heat transfer from upper and lower boundary (soil surface and underground)			
	Water	Soil moisture	Soil water content			
		ground ice	w/ & w/o ice, freezing and thawing			
		water vapour	vapor transfer, vapor pressure			
		water flow	water transfer from inside and outside of soil			
		ground water	existence of aquifer and change			
	Biogeochemical cycle	carbon pool	litter, and active, slow and passive decomposition			
		Heterotrophic Respiration	Response to the environmental change such as soil temperature, soil moisture and pH			

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Appendix. The file naming convention for submitting the model result.

[Model-ID]_[stage-ID]_[forcing ID]_[station-ID]_[yymmdd (date of submission)].csv,

where stage_ID is either “1a” or “1b,” forcing_ID is “L0,” “L1,” or “L1H,” and station_ID is shown in Table S2.