

TIPMIP Permafrost Tier 1 Experimental Protocol Technical documentation

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In the Tipping Points Modelling Intercomparison Project (TIPMIP; Winkelmann et al., 2025), land surface models, as well as soil ice and carbon budget models, are used to assess the extent to which permafrost may exhibit tipping-like dynamics. Building on TIPMIP-ESM (Jones et al, 2025), the TIPMIP permafrost Tier 1 experiments, defined as the core, priority experiments required for MIP participation, aim to investigate the path dependency and reversibility of permafrost area, ground ice, and carbon content across the warming, stabilization, and cooling phases. In addition, during the stabilization period we will assess whether the system exhibits any nonlinear responses. Where applicable, global Tier 1 experiments conducted using LSMs can also serve as contributions to the TIPMIP-biosphere domain.

Deadlines for delivering simulations output:

Tier 1 – 15.10.2026.

Process selection, model setup and requested variables

Given the complex, multi-process nature of permafrost dynamics and the limited representation of several key mechanisms in the CMIP6 ensemble, we encourage modelling groups to contribute simulations that include as many tipping-relevant processes as possible, in particular those related to soil thermal regimes, freeze-thaw dynamics, soil and surface hydrology, vegetation-soil interactions, fire impacts, carbon and nitrogen cycle.

To keep track of the available features across the model ensemble, modelling groups are requested to complete the **model-configuration form** available online:

https://docs.google.com/spreadsheets/d/1T5JJNNaGxfvZWf0IHZSX-4dkGPO__jYX72MYSeuJiiY/edit?pli=1&gid=834036249#gid=834036249 (Please add what you know so far, and you can fill in the rest later).

We do not prescribe model vertical structure, spatial or temporal resolution, initial conditions or process configuration. Modelling groups are encouraged to activate as many permafrost-relevant process modules as available within their modelling framework e.g., dynamic vegetation, wetland distribution, fire disturbance, coupled nitrogen cycling, and vertically resolved carbon decomposition into CO₂ and CH₄. Depending on the number of activated processes and the overall complexity of each model, we do not expect all models to generate exactly the same set of output variables. Consequently, analyses that focus on specific processes may require only the subset of variables needed for that particular study. For reference, an overview of **requested variables** that may be required for a given process analysis is available online:

https://docs.google.com/spreadsheets/d/1qUK2R7FCWSgQp0ZgjhnmPhGKRCxT_whj/edit?gid=540399770#gid=540399770

The list of required variables comprises both model outputs and reporting initialization variables, including their data sources. The variable request priorities, along with the minimum set of required variables and processes to be represented, will be decided through community agreement. Therefore, the required list of variables is intentionally kept flexible, accommodating distinct criteria for land surface models on one hand, and for permafrost process and carbon budget models on the other, the latter being expected to provide complementary and process-specific information (variables) to that obtained from land surface models.

The requested data should be delivered at the participating model's native resolution and time axis, and should ideally adhere to the CMIP7 naming convention as outlined in Taylor et al. (2026; 2025):

<variable_id><branding_suffix><frequency><region><grid_label><source_id><experiment_id><variant_label>[<timeRangeDD>].nc

These keywords are strictly defined in the CMIP7 framework, and possibly not always available for the LSMs, e.g., source_id specifically identifies registered ESMs or institutionally coupled ESM configurations. Because the models expected to participate in this project are standalone LSMs or permafrost models forced by external ESMs, they will not typically have a pre-registered source_id. Therefore, we propose the following approach:

To maintain compatibility with CMIP7 filename conventions while reflecting the modelling setup, each participating model should construct a custom source_id combining:

- 1) The participating LSM/permafrost model (e.g., JSBACH3-2, CLM5), and
- 2) The forcing ESM (e.g., UKESM1-2-LL, MIROC-ESL2).

This can be formatted as:

<lsm>-<esm> (e.g., JSBACH3-2-UKESM1-2-LL, CLM5-MIROC-ESL2).

Following CMIP7 experiment naming convention, experiment_id that enters the file name should be defined as follows:

tip-<domain-id>-p<phase>t<tier>-<exp-id>

where <domain-id> is either “Ind” or “pmf”. Tier 1 experiments run with global LSMs are identical for the biosphere and permafrost domains. Consequently, the domain identifier for these experiments is set to “Ind.” For all other experiment sets the identifier is “pmf.” The building block for the <exp-id> will be inherited from the forcing TIPMIP-ESMs.

TIPMIP-ESM forcing

The daily forcing fields (Table 1) for the two TIPMIP-ESMs (UKESM1-2-LL already available for download and likely MIROC-ES2L will be available from mid-August) at their native time axes (e.g., 360_day, and Gregorian) and native spatial resolutions are selected as mandatory. These two ESMs were selected because their global-mean temperature responses to rising CO₂ nearly span the full uncertainty envelope of the TIPMIP-ESM ensemble (Jones et al., 2025) and provide all necessary forcing data at the time of protocol preparation. Apart from mandatory set of experiments, modelling groups are welcome to include additional forcing datasets from other TIPMIP-ESMs, depending on their available resources. This can be especially useful for groups that run global LSMs,

because Tier 1 simulations can be shared with the TIPMIP-Biosphere domain (Tardif et al., in prep). Modelling groups are responsible for remapping these forcing fields to the resolution and time axis of their respective models. All datasets will follow CMOR formatting standards.

CMOR Name	Table	Frequency	Long Name	Units	Dimensions
Hurs	Day	Day	Near-Surface Relative Humidity	%	longitude latitude time height2m
Huss	Day	Day	Near-Surface Specific Humidity	1	longitude latitude time height2m
Pr	Day	Day	Precipitation	kg m-2 s-1	longitude latitude time
PrRa	Eday	Day	Rainfall Flux over Land	kg m-2 s-1	longitude latitude time
Prsn	Day	Day	Snowfall Flux	kg m-2 s-1	longitude latitude time
Ps	Emon	Mon	Surface Air Pressure	Pa	longitude latitude time
Rlds	Day	Day	Surface Downwelling Longwave Radiation	W m-2	longitude latitude time
Rsds	Day	Day	Surface Downwelling Shortwave Radiation	W m-2	longitude latitude time
sfcWind	Day	Day	Daily-Mean Near-Surface Wind Speed	m s-1	longitude latitude time height10m
Tas	Day	Day	Near-Surface Air Temperature	K	longitude latitude time height2m
Tasmax	Day	Day	Daily Maximum Near-Surface Air Temperature	K	longitude latitude time height2m
Tasmin	Day	Day	Daily Minimum Near-Surface Air Temperature	K	longitude latitude time height2m
co2s(*)	Emon	Mon	Atmosphere CO2	1e-06	longitude latitude time
co2mass(*)	Amon	Mon	Total Atmospheric Mass of CO2	Kg	Time

Table 1: List of prescribed climatic forcing variables serving as boundary conditions for all TIPMIP permafrost simulations. Variables are provided at daily temporal and the native spatial resolution of the driving ESMs dataset and should be interpolated to the model grid where necessary. (*) CO₂ is the only greenhouse-gas forcing used. We provide its global-mean annual concentration in ppm. Monthly CO₂ time series, either as co2s or co2mass are available upon request.

The data will be available for download with wget command, here:

https://swiftbrowser.dkrz.de/objects/TIPMIP-ESM_forcing_4_LSM/

after requesting access, which will be authorized by José Luis Licon-Salaiz (joseli@pik-potsdam.de) or Sina Loriani (sina.loriani@pik-potsdam.de) in his absence.

The login account is bm1448. The username and password will be set by the administrator and shared with participating modelling group members.

Initialization (spin-up), and piControl simulation

To ensure consistent initialization across participating models, we provide 20 years of daily forcing from the selected TIPMIP-ESMs at its native spatial resolution, formatted according to CMOR standards. For models unable to recycle a 20-year loop, the full time series are available as an alternative. For spin-up and piControl, CO₂ concentration may be set at constant value 283.7 ppm or available timeseries may be used. Modelling groups are responsible for remapping these forcing fields to their respective land-surface model (LSM) resolutions. Models should first conduct a spin-up using the TIPMIP-ESM piControl CO₂ concentration and pre-industrial land-cover conditions, here defined as the year 1850. The 20-year forcing period should be looped repeatedly until the simulation attains a stationary pre-industrial baseline climate state. No dedicated output is required for submission. However, modelling groups are expected to assess the long-term stability of their model state and the acceptable residual drift which may be unavoidable in some cases, especially for variables with substantial inertia, such as soil moisture, carbon stocks, and vegetation fractions, which may be prone to slow drift. Consistent with other MIPs (C4MIP, WIEMIP), a land-carbon drift of approximately 10 Pg C (or less) per century is acceptable. At the end of the spin-up simulations, soil (including frozen soil) carbon stocks, ground temperature, and active-layer thickness should exhibit no long-term drift. Land-use and land-cover (LULC) states, including harvest, must remain fixed at pre-industrial values throughout the piControl simulation, and no land-use transitions should be applied. All other aspects of model configuration are left to the modelling groups, with the requirement that the resulting piControl represents a stable pre-industrial equilibrium suitable for branching the idealized warming experiments. The subsequent piControl simulation uses exactly the same 20-year forcing and (cyclic) application of the sequence to assess if there is any residual drift from stationary pre-industrial baseline climate. The piControl run should extend for at least as long as warming up phase up to 4°C warming (200 years), however, typical recommendation is to extend it to 600 years.

Permafrost Response to Warming – Stabilization – Cooling (WSC) cycle, Tier 1 experiments

Tier 1 experiments should be branched from spin-up / piControl runs as shown on Figure 1. Global-mean temperature forcing for Warming – Stabilization – Cooling (WSC) experiments is shown on Figure 1b. Temperature increases at a rate of 2°C per 100 years (exp_id: esm-up2p0) until reaching either 2°C or 4°C of global warming level, after which it is held constant for at least 200 years (esm-up2p0-gwl2p0 and esm-up2p0-gwl4p0, respectively). From each stabilized state, additional simulations are branched after 50 years with cooling at the same rate as the initial warming (esm-up2p0-gwl2p0-50y-dn2p0 and esm-up2p0-gwl4p0-50y-dn2p0). Table 2 is showing branching years for each experiment for 2 models.

Experiment	UKESM	MIROC
esm-up2p0	1850.0	2001.0
esm-up2p0-gwl2p0	1944.0	2100.0
esm-up2p0-gwl4p0	2044.0	2215.0
esm-up2p0-gwl2p0-50y-dn2p0	1994.0	2150.0
esm-up2p0-gwl4p0-50y-dn2p0	2095.0	2265.0
esm-up2p0-gwl4p0-50y-dn2p0-gwl2p0	2233.0	2370.0

Table 1: Branching years for two models.

For Phase 1, we recommend conducting the stabilization experiments for a minimum duration of 50 years. Based on the results obtained in Phase 1, these simulations will likely be extended by several hundred years in Phase 2.

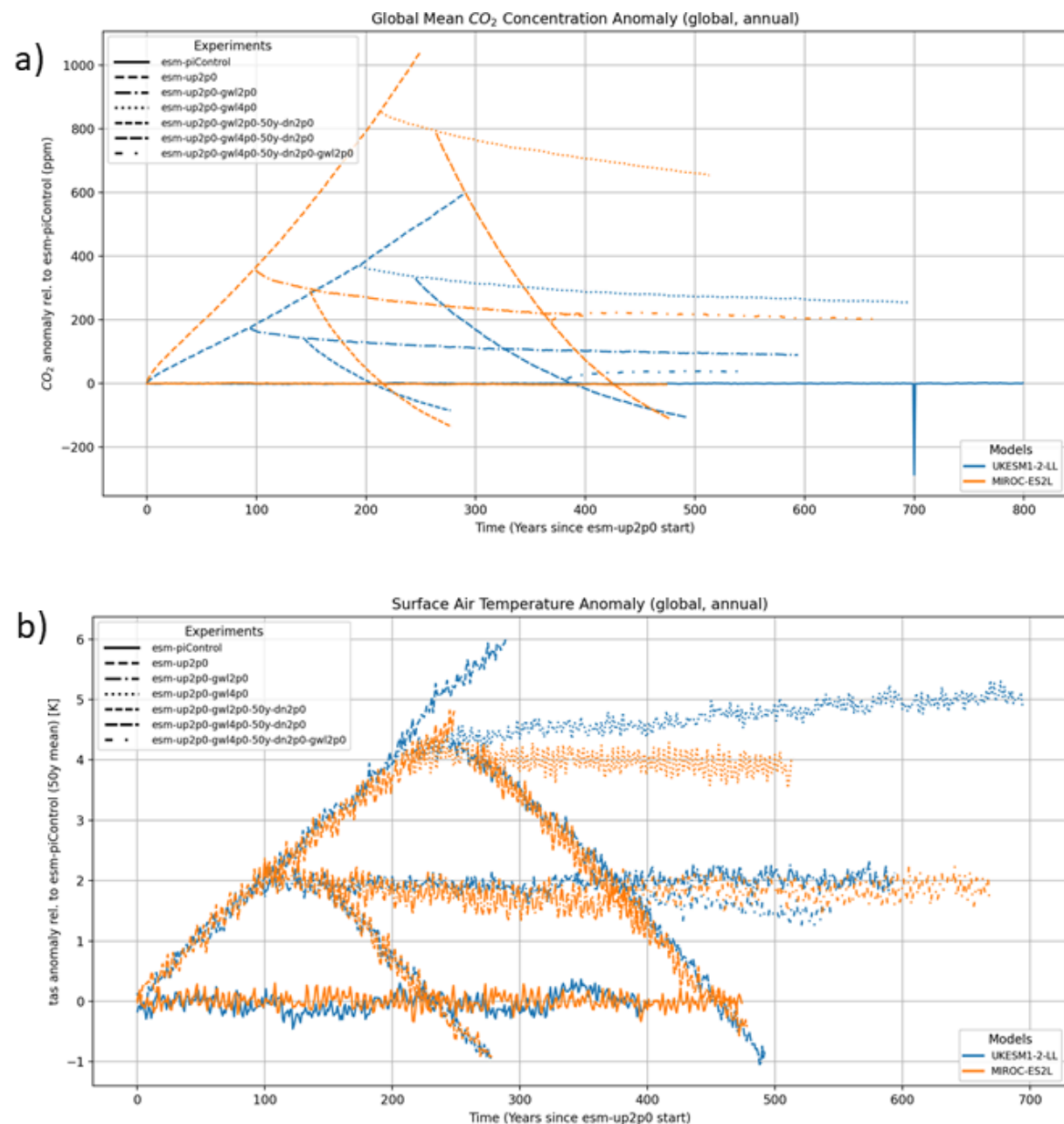


Figure 1: Global climate response in TIPMIP-ESM experiments. (a) Global mean CO₂ concentration anomaly (ppm) relative to the esm-piControl baseline for two ESMs (UKESM1-2-LL in blue, MIROC-ES2L in orange). (b) Surface air temperature anomaly (K) relative to esm-piControl for the same models and experiments. Time is measured in years since the start of the esm-up2p0 experiment.

Examples and the note on the requested variable file names

For the exp_id component of each experiment_id, we omit the “esm” prefix from the TIPMIP-ESM naming and retain only the remaining part. Therefore, couple of examples for experiment_id, following format:

tip-<domain-id>-p<phase>t<tier>-<exp-id>

are:

tip-pmf-p1t1-up2p0,

tip-lnd-p1t1-up2p0-gwl2p0.

Following the format:

<variable_id><branding_suffix><frequency><region><grid_label><source_id><experiment_id><variant_label>[<timeRangeDD>].nc

a couple of examples for requested variables file names:

tsl_tavg-sl-hxy-lnd_mon_glb_g121_JSBACH3-2-UKESM1-2-LL_tip-lnd-p1t1-up2p0-gwl2p0_r1i1p1f1_185001-210012.nc

mrfso_tavg-u-hxy-lnd_mon_nh_g121_JSBACH3-2-UKESM1-2-LL_tip-pmf-p1t1-up2p0-gwl2p0_r1i1p1f1_185001-210012.nc

csoil_tavg-d100cm-hxy-lnd_mon_glb_g121_JSBACH3-2-UKESM1-2-LL_tip-lnd-p1t1-up2p0-gwl2p0_r1i1p1f1_185001-210012.nc

However, we anticipate that not all models will be able to register all the keywords required to construct their filenames. Additionally, TIPMIP-ESM experiment names, and the CMIP7 controlled vocabulary, may evolve over time. Therefore, while the file naming convention remains open for discussion, we aim to develop a standardized naming convention that is applicable to all models and, where possible, aligned with CMIP7 standards.

Reference

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