TIPMIP Permafrost experimental protocol

Technical documentation and user guide

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The experimental design of TIPMIP is structured into three coordinated tiers, illustrated in Figure 1. This framework (Winkelmann et al, 2025) links climate forcing derived from TIPMIP-ESM (Jones et al, 2025) with stand-alone permafrost and land-surface models to systematically explore the conditions under which permafrost may exhibit path dependence, reversibility, or potentially tipping-like behaviour. These efforts will be coordinated with TIPMIP-BIOSPHERE (Tardif et al, tba), TIPMIP-WHATIF (Otto-Blisner et al, tba), TIPMIP-OCEAN (Swingedouw et al, 2026).

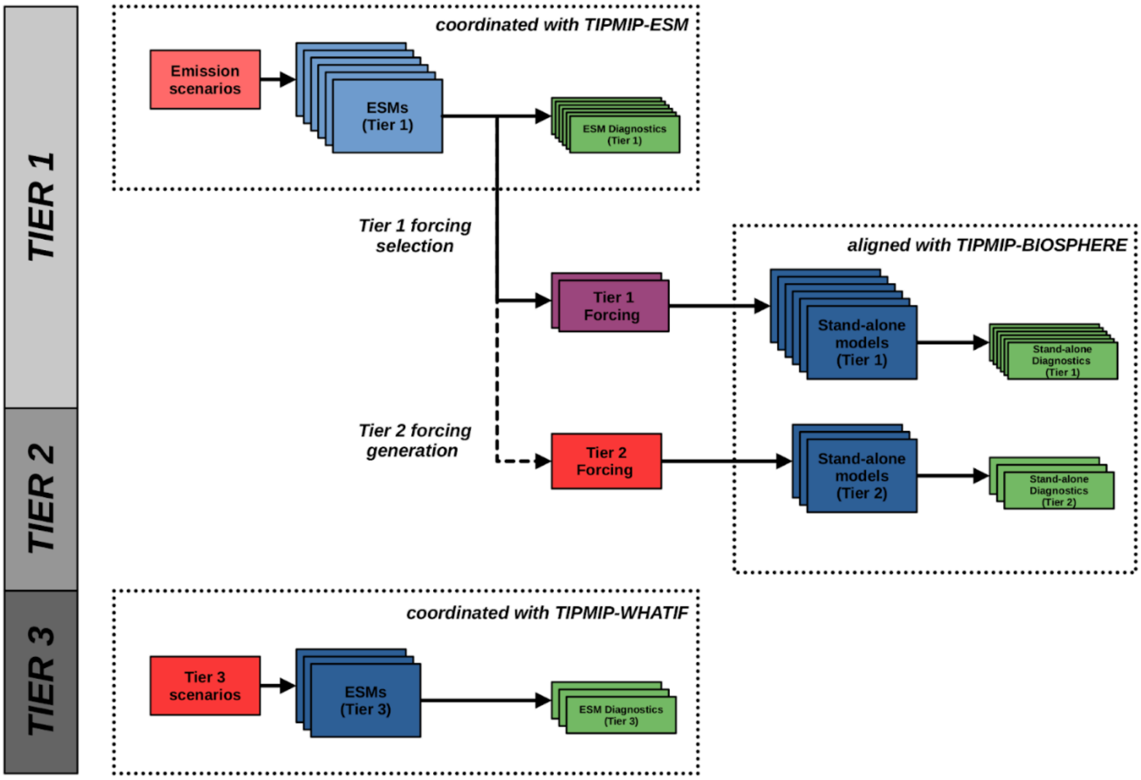

Figure 1: The three-tier TIPMIP experimental framework for stand-alone permafrost and land surface model experiments. Tier 1 forcing is taken from the TIPMIP-ESM simulations consistently across TIPMIP domains. Tier 2 experiments will branch from Tier 1, with forcing designed to explore the sensitivity of permafrost state variables to changes in hydrometeorological extremes, in coordination with TIPMIP-BIOSPHERE. Tier 3 ESM experiments, coordinates with TIPMIP-BIOSPHERE, TIPMIP-WHATIF and potentially TIPMIP-OCEAN, will investigate interactions between permafrost and other climate tipping elements.

Deadlines for delivering simulations output:
Tier 1 - 15.9.2026.
Tier 2 - ?
Tier 3 - ?

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, and carbon release. To keep track of the available features across the model ensemble, modelling groups are requested to complete the model-configuration form available here: https://docs.google.com/spreadsheets/d/1T5JJNNaGxfvZWf0lHZSX-4dkGPO__jYX72MYSeuJiiY/edit?pli=1&gid=327731307#gid=327731307

We do not prescribe model vertical structure, spatial or temporal resolution, initial conditions or process configuration. Daily forcing data will be provided by the two (or three?) mandatory TIPMIP-ESMs at their native time axis (e.g., calendars could be 365_day, gregorian, etc…) and native spatial resolutions (Table 1).

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 resolution of the driving ESMs dataset and should be interpolated to the model grid where necessary.

All datasets will follow CMOR formatting standards. Apart from mandatory set of experiments, modelling groups are welcome to include additional forcing datasets from other TIPMIP-ESMs, depending on their available resources. Modelling groups are responsible for remapping these forcing fields to the resolution and time axis of their respective models. Participants 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 CO_2 and CH_4. Please indicate in the table above which of these processes are enabled in your configuration.

A comprehensive list of the requested variables is available at the link below. It draws on the CMIP6 and CMIP6+ CMOR tables and will be updated as needed. For now, it serves as a useful reference point for overview of variables that will be required. Participating groups are required to complete the table by listing the initial-condition variables used in their model setup.

https://docs.google.com/spreadsheets/d/1qUK2R7FCWSgQp0ZgjhnmPhGKRCxT_whj/edit?gid=855487116#gid=855487116

The variable request priorities, along with the minimum set of required variables and processes to be represented in participating models, are still under active discussion. However, the design should intentionally remain flexible, enabling one set of criteria for land-surface models and a separate set for permafrost process and carbon budget models. The requested data should be delivered at the participating model's native resolution and time axis, and should 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

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. 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 below 10 Pg C 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 the exactly the same 20-year forcing and (cyclic) application of the sequence to control 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).

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

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

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

Within the TIPMIP framework (Winkelmann et, al 2025), 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 use land surface models (LSMs) 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. These experiments should be branched from spin-up runs as follows (Figure 2):

Warming up to 4°C global warming level (GWL) – 200 years; exp_id: W__
Stabilization run branched from W__ after 100 years at 2°C (GWL) – 300 years; exp_id: S2__
Stabilization run branched from W__ after 200 years at 2°C (GWL) – 300 years; exp_id: S4__
Colling down branched from S2__ after 50, 200, 300 years – 100 years each; C2_50__, C2_200__, C2_300__
Colling down branched from S4__ after 50, 200, 300 years – 100 years each; C4_50__, C4_200__, C4_300__
Stabilizing at 2 GWL after cooling from 4 GWL, i.e. branching from C4_50__, C4_200__, C4_300__;

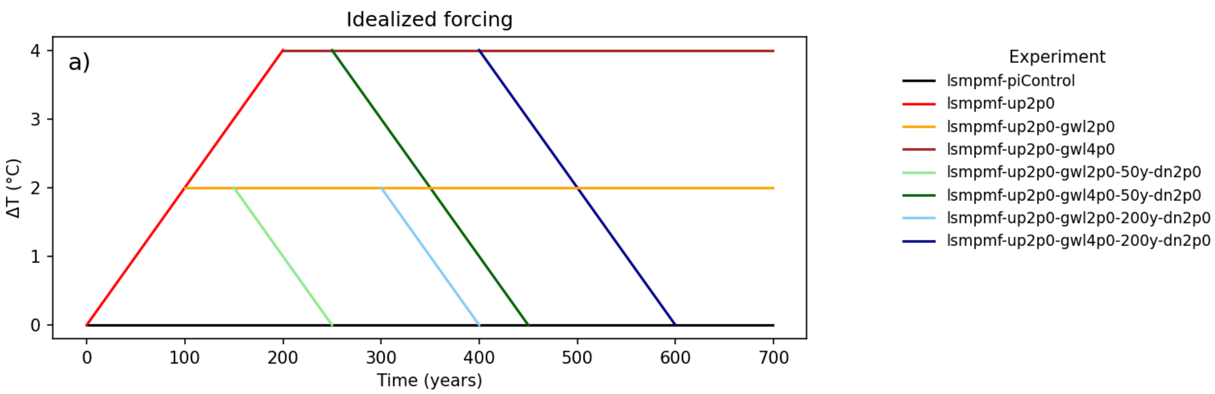

Figure 2: Global-mean temperature forcing for Warming – Stabilization – Cooling (WSC) experiments. Temperature increases at a rate of 2°C per 100 years until reaching either 2°C or 4°C of global warming level, after which it is held constant for at least 300 years. From each stabilized state, additional simulations are branched after 50 years and 200 years and forced with cooling at the same rate as the initial warming. Further cooling branches (not shown) are initiated after 300 years at both warming levels; for the 4°C experiments, additional branches are considered once cooling reduces temperatures back to 2°C.

Permafrost Response to modified hydrometeorological forcing, Tier 2 experiments

The **Tier 2** experiments constitute an additional suite of sensitivity studies with LSMs, for which we are developing targeted forcing to accelerate permafrost degradation and eventually induce tipping. The focus is on altering hydrometeorological forcing to explore how these factors influence the onset and dynamics of tipping behaviour.

Permafrost role in the tipping world, Tier 3 experiments

Tier 3 experiments, which are also sensitivity-oriented, are still under development. These experiments aim to explore the interactions between permafrost dynamics and other climate tipping elements. This includes assessing how the tipping of another element (e.g., an AMOC collapse or a boreal-forest shift) influences high-latitude permafrost stability, as well as examining the wider Earth-system consequences of prescribed abrupt permafrost tipping.

Reference

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