Supplement of Geosci. Model Dev., 17, 3041–3062, 2024
https://doi.org/10.5194/gmd-17-3041-2024-supplement

Geoscientific Model Development
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EGU

Supplement of

CLASH – Climate-responsive Land Allocation model with carbon Storage and Harvests

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This Supplementary Material provides technical information on the model and additional figures to support the main text. The figures portray annual mean temperature and precipitation for each biome in the EC-Earth3 scenarios, the fits for litter and soil carbon in forests, pastures and croplands, and validations using the parametrizations of CLASHS based on CanESM and MPI models.

Model structure and use

CLASH is written in GAMS. The land-use module files are located in the main directory and the ecological module in its own subdirectory, which further contains separate subdirectories for the three parametrizations of CLASH based on the different ESMs' climate scenarios.

The ecological module produces GDX files that contain the parameterization of the land-use module. The input parameters are read from text files produced by the calibration scripts written in R. These text files are provided as a part of CLASH, and running the R scripts would be necessary only if the CLASH would be recalibrated for new ESM scenarios, regional definitions, or functional forms. The ecological module also reads a scenario for temperature change and atmospheric CO_2 concentration. This file can be provided externally, based on the ESM scenarios, or it can be produced by the IAM to which CLASH is embedded.

For using the model within an IAM, the CLASH_Core.gms file needs to be included in the IAM source code. The IAM needs to provide the set *time* (alias *t*), subsets *tfirst* and *tlast*, the objective function and the model and solve statements. To run CLASH as a stand-alone model, as was done in this manuscript, a main file needs to provide these sets, the objective function and the MODEL and SOLVE statements. The CLASH code repository contains CLASH_Wrapper.gms file, which can be used for this purpose as the main file.

Specifications of climate the scenario experiments used in LPJ-GUESS

Table S1. Climate scenario experiments used in LPJ-GUESS.

Model	Experiments	Variant	Original resolution (gridpoints)	DOI	Citation
EC-Earth	Historical, ssp245	r1i1p1f1	512 x 256 longitude/latitude	https://doi.org/10.22033/ESGF/CMIP6.4700, https://doi.org/10.22033/ESGF/CMIP6.4880	EC-Earth Consortium, 2019a,b
CanESM5	Historical, ssp245	r10i1p1f1	128 x 64 longitude/latitude	https://doi.org/10.22033/ESGF/CMIP6.3610, https://doi.org/10.22033/ESGF/CMIP6.3685	Swart et al, 2019a,b
MPI-ESM	Historical, ssp245	r1i1p1f1	192 x 96 longitude/latitude	https://doi.org/10.22033/ESGF/CMIP6.6595, https://doi.org/10.22033/ESGF/CMIP6.6693	Wieners et al, 2019a,b

EC-Earth: historical **r1i1p1f1**

EC-Earth Consortium (EC-Earth) **(2019)**. *EC-Earth-Consortium EC-Earth3 model output prepared for CMIP6 CMIP historical*. Version *20200310*. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.4700

EC-Earth s**sp245 r1i1p1f1f r1i1p1f1**

EC-Earth Consortium (EC-Earth) **(2019)**. *EC-Earth-Consortium EC-Earth3 model output prepared for CMIP6 ScenarioMIP ssp245*. Version *20200310*. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.4880
Original grid TL255, linearly reduced Gaussian grid equivalent to 512 x 256 longitude/latitude

CanESM5 **historical r10i1p1f1**

Swart, N.C., Cole, J.N.S., Kharin, V.V., Lazare, M., Scinocca, J.F., Gillett, N.P., Anstey, J., Arora, V., Christian, J.R., Jiao, Y., Lee, W.G., Majaess, F., Saenko, O.A., Seiler, C., Seinen, C., Shao, A., Solheim, L., von Salzen, K., Yang, D., Winter, B., Sigmond, M. **(2019)**. *CCCma CanESM5 model output prepared for CMIP6 CMIP historical*. Version 20190429. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.3610

CanESM5 ssp245 r10i1p1f1

Swart, N.C., Cole, J.N.S., Kharin, V.V., Lazare, M., Scinocca, J.F., Gillett, N.P., Anstey, J., Arora, V., Christian, J.R., Jiao, Y., Lee, W.G., Majaess, F., Saenko, O.A., Seiler, C., Seinen, C., Shao, A., Solheim, L., von Salzen, K., Yang, D., Winter, B.,

Sigmond, M. **(2019)**. *CCCma CanESM5 model output prepared for CMIP6 ScenarioMIP ssp245*. Version *20190429*. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.3685

Original grid: T63 Linear Gaussian Grid; 128 x 64 longitude/latitude

MPI-ESM historical **r1i1p1f1**

Wieners, Karl-Hermann; Giorgetta, Marco; Jungclaus, Johann; Reick, Christian; Esch, Monika; Bittner, Matthias; Legutke, Stephanie; Schupfner, Martin; Wachsmann, Fabian; Gayler, Veronika; Haak, Helmuth; de Vrese, Philipp; Raddatz, Thomas; Mauritsen, Thorsten; von Storch, Jin-Song; Behrens, Jörg; Brovkin, Victor; Claussen, Martin; Crueger, Traute; Fast, Irina; Fiedler, Stephanie; Hagemann, Stefan; Hohenegger, Cathy; Jahns, Thomas; Kloster, Silvia; Kinne, Stefan; Lasslop, Gitta; Kornblueh, Luis; Marotzke, Jochem; Matei, Daniela; Meraner, Katharina; Mikolajewicz, Uwe; Modali, Kameswarrao; Müller, Wolfgang; Nabel, Julia; Notz, Dirk; Peters-von Gehlen, Karsten; Pincus, Robert; Pohlmann, Holger; Pongratz, Julia; Rast, Sebastian; Schmidt, Hauke; Schnur, Reiner; Schulzweida, Uwe; Six, Katharina; Stevens, Bjorn; Voigt, Aiko; Roeckner, Erich **(2019)**. *MPI-M MPI-ESM1.2-LR model output prepared for CMIP6 CMIP historical*. Version *20190710*. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.6595

MPI-ESM **ssp245 r1i1p1f1**

Wieners, Karl-Hermann; Giorgetta, Marco; Jungclaus, Johann; Reick, Christian; Esch, Monika; Bittner, Matthias; Gayler, Veronika; Haak, Helmuth; de Vrese, Philipp; Raddatz, Thomas; Mauritsen, Thorsten; von Storch, Jin-Song; Behrens, Jörg; Brovkin, Victor; Claussen, Martin; Crueger, Traute; Fast, Irina; Fiedler, Stephanie; Hagemann, Stefan; Hohenegger, Cathy; Jahns, Thomas; Kloster, Silvia; Kinne, Stefan; Lasslop, Gitta; Kornblueh, Luis; Marotzke, Jochem; Matei, Daniela; Meraner, Katharina; Mikolajewicz, Uwe; Modali, Kameswarrao; Müller, Wolfgang; Nabel, Julia; Notz, Dirk; Peters-von Gehlen, Karsten; Pincus, Robert; Pohlmann, Holger; Pongratz, Julia; Rast, Sebastian; Schmidt, Hauke; Schnur, Reiner; Schulzweida, Uwe; Six, Katharina; Stevens, Bjorn; Voigt, Aiko; Roeckner, Erich **(2019)**. *MPI-M MPI-ESM1.2-LR model output prepared for CMIP6 ScenarioMIP ssp245*. Version *20190710*. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.6693

Original resolution spectral T63; 192 x 96 longitude/latitude

Global mean temperature and precipitation

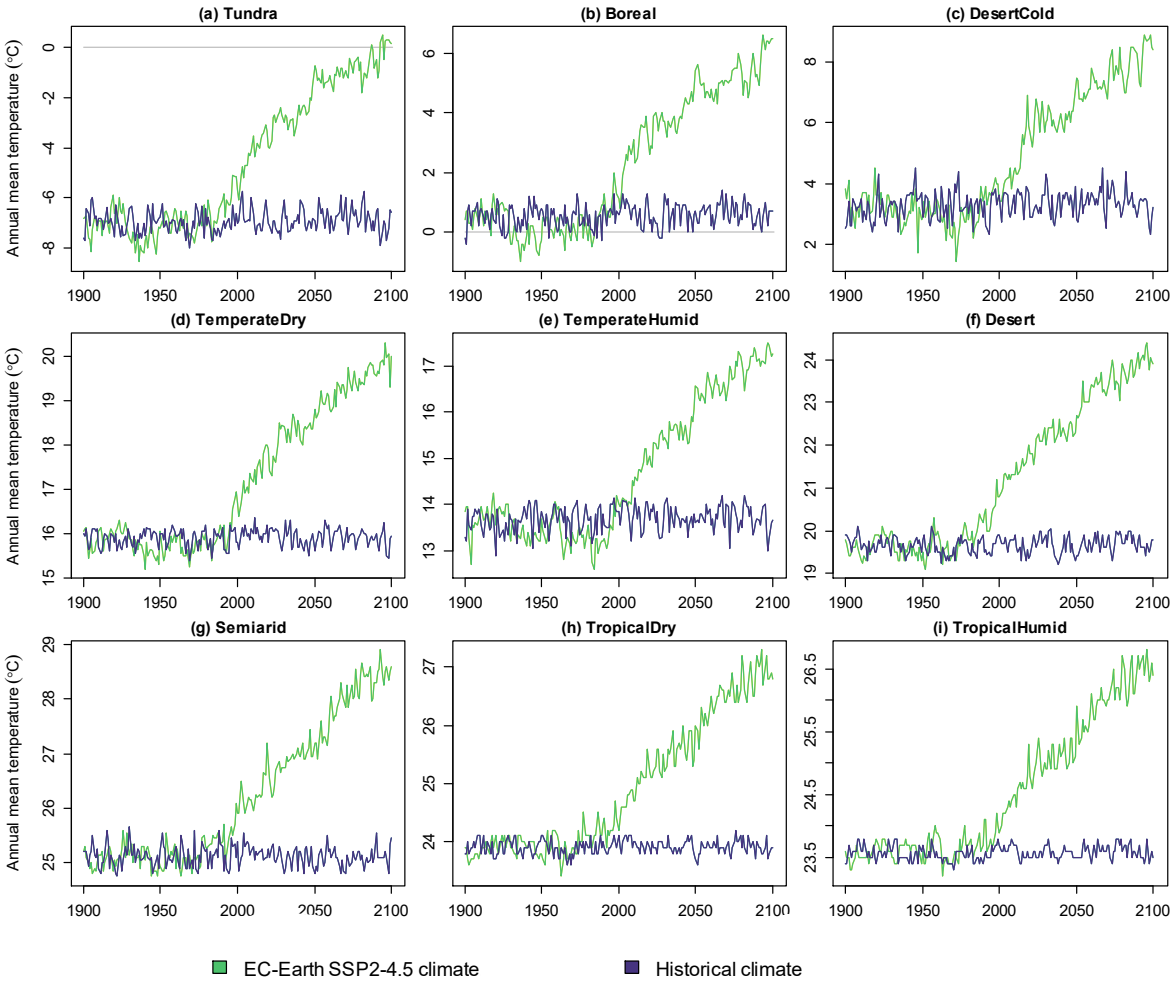

Figure S1. Mean temperature in the nine main biomes with historical climate and EC-Earth SSP2-4.5 scenario.

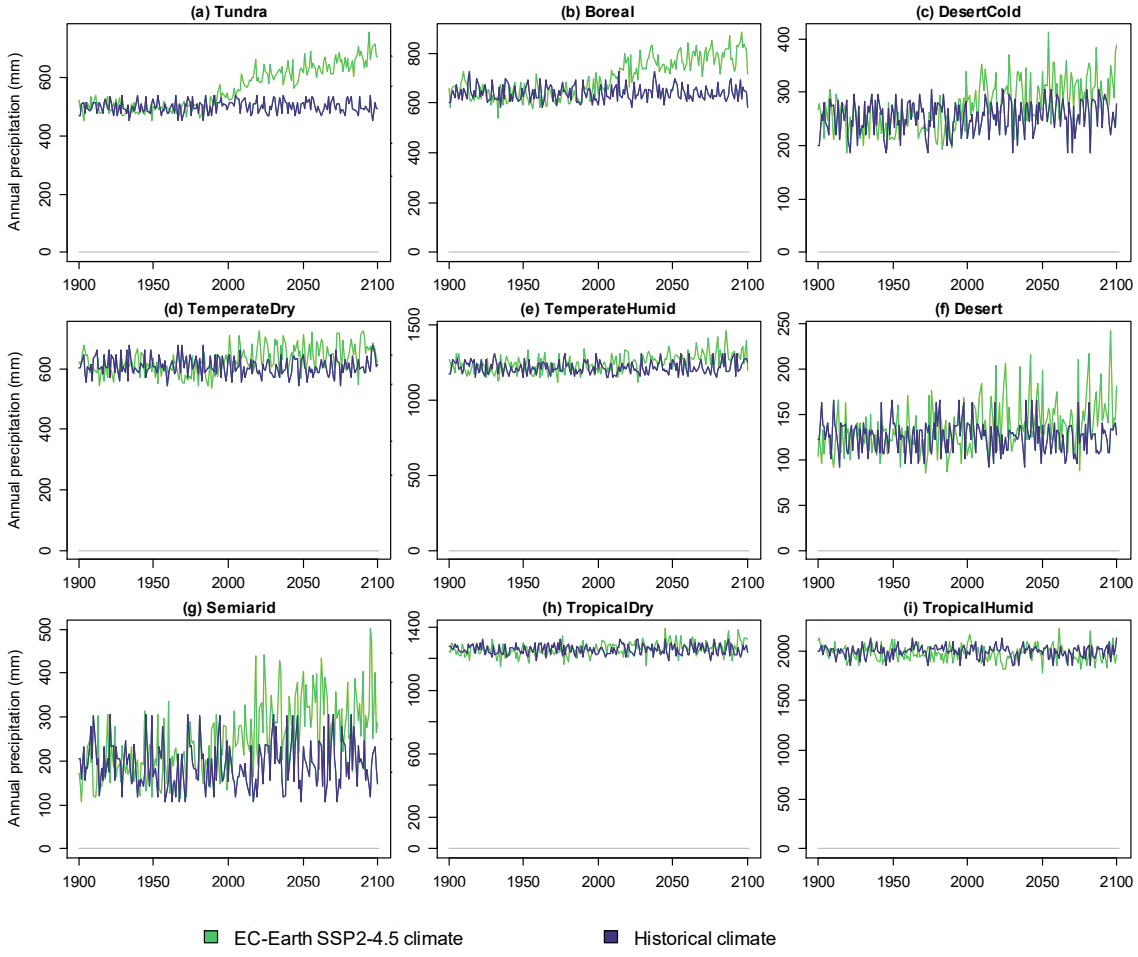

Figure S2. Annual precipitation in the nine main biomes with historical climate and EC-Earth SSP2-4.5 scenario.

Fits of litter and soil carbon stocks

The following figures portray the litter and soil carbon stocks simulated with LPJ-Guess, and the simulations with fitted functions to the results. These results are discussed in section **Error! Reference source not found.**.

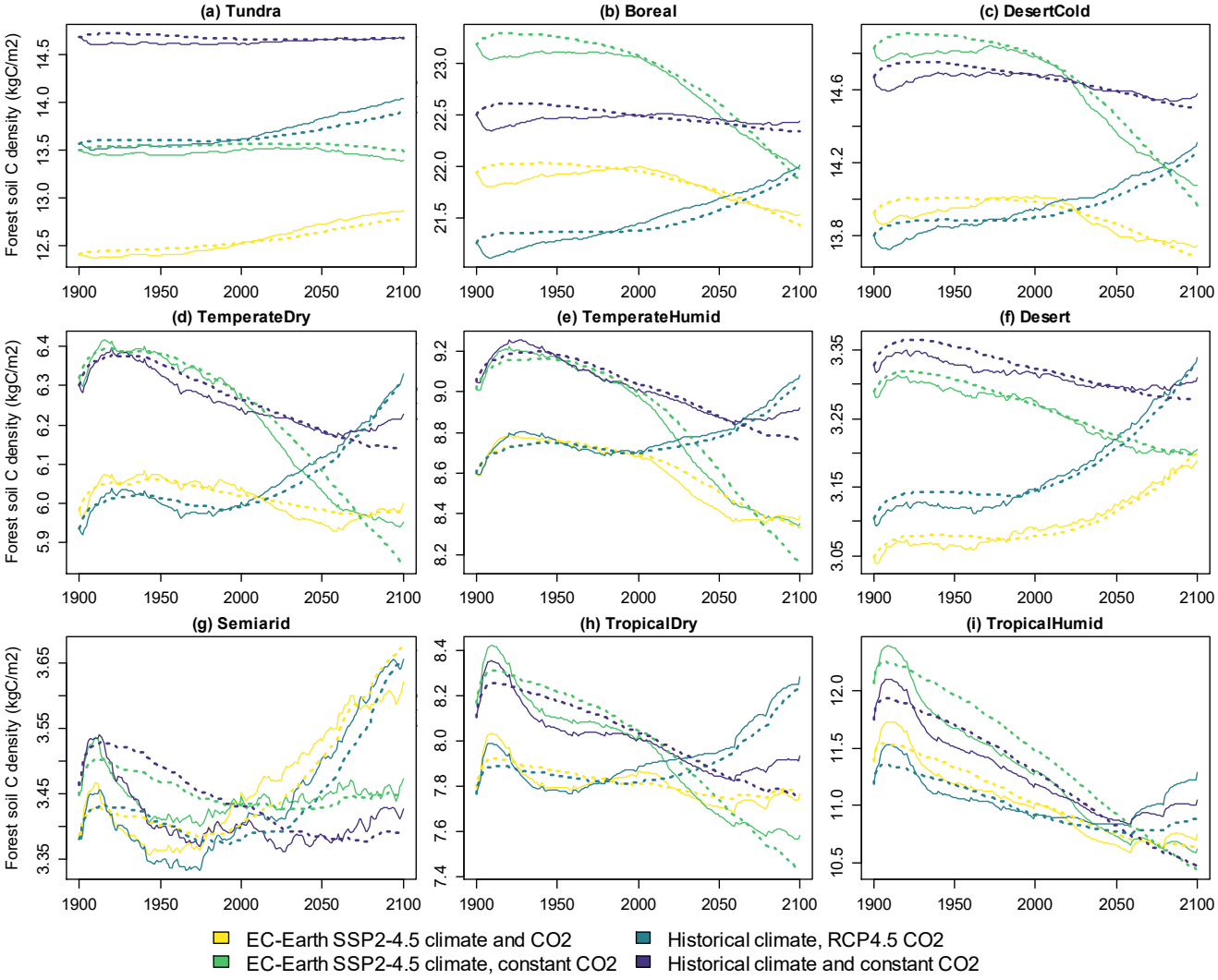

Figure S3 Carbon density in forest soil in the four simulated scenarios. Solid lines indicate LPJ-GUESS simulations and dashed lines indicate functions fitted to the results.

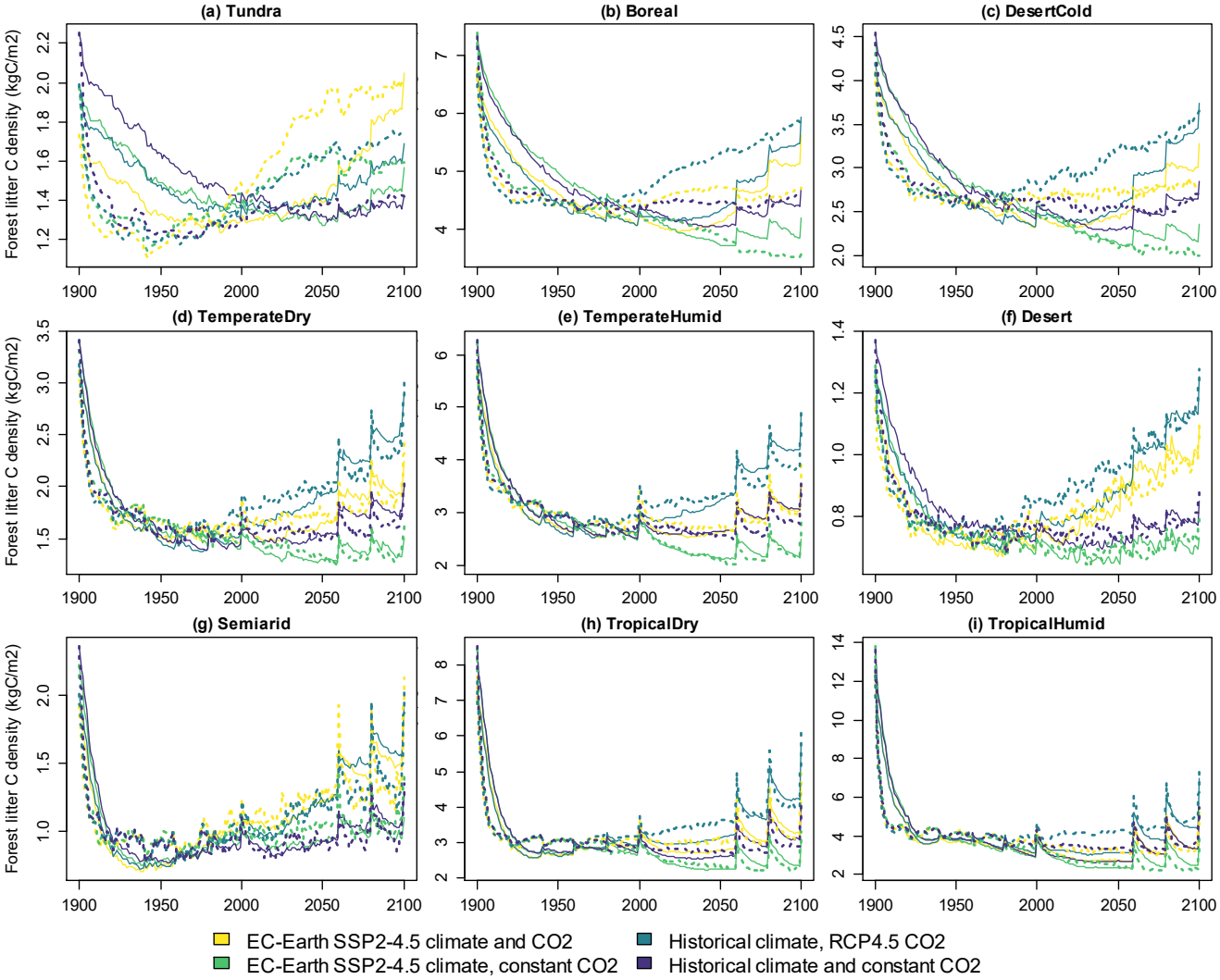

Figure S4 Carbon density in forest litter in the four simulated scenarios. Solid lines indicate LPJ-GUESS simulations and dashed lines indicate functions fitted to the results.

85

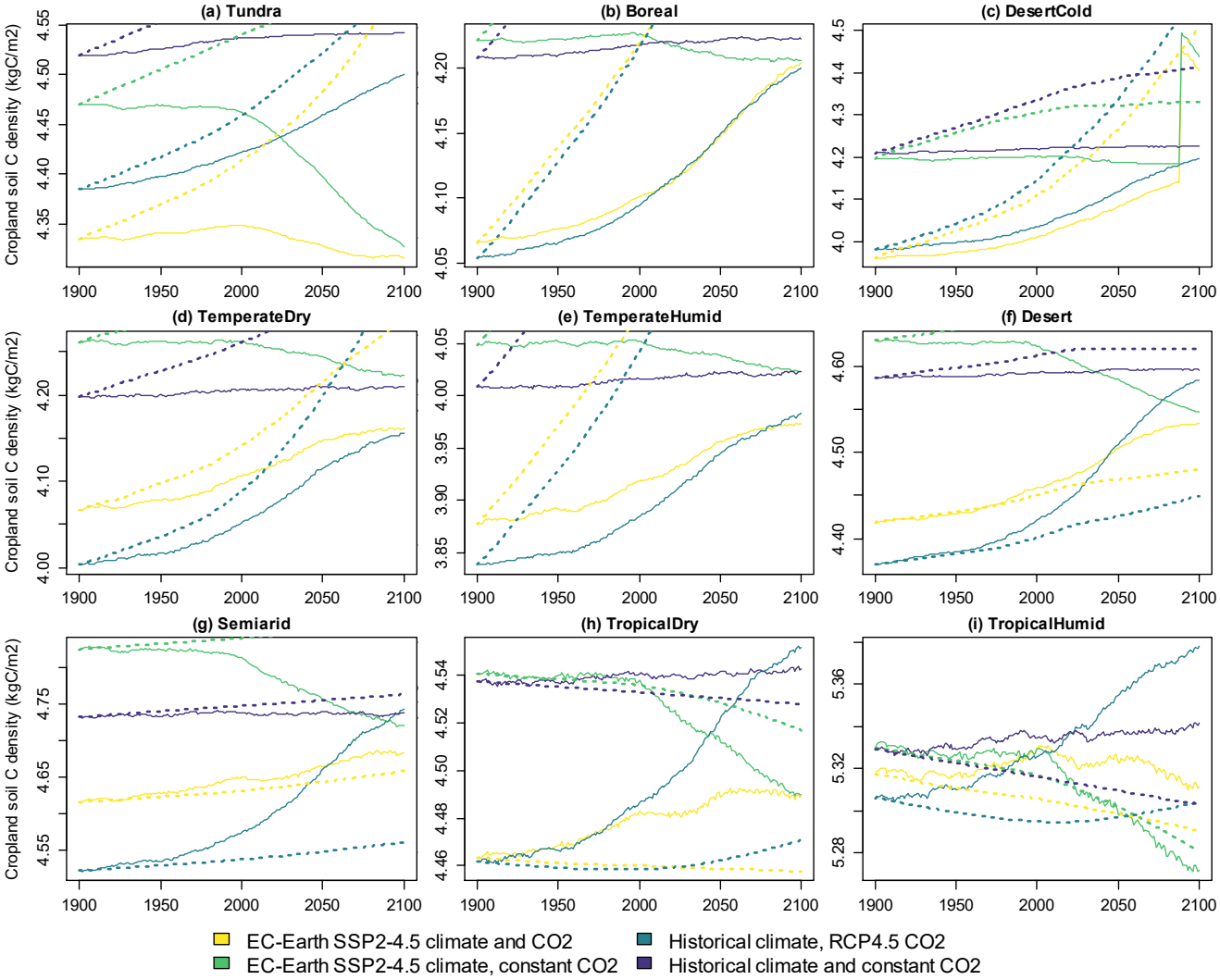

Figure S5 Carbon density in cropland soil in the four simulated scenarios. Solid lines indicate LPJ-GUESS simulations and dashed lines indicate functions fitted to the results.

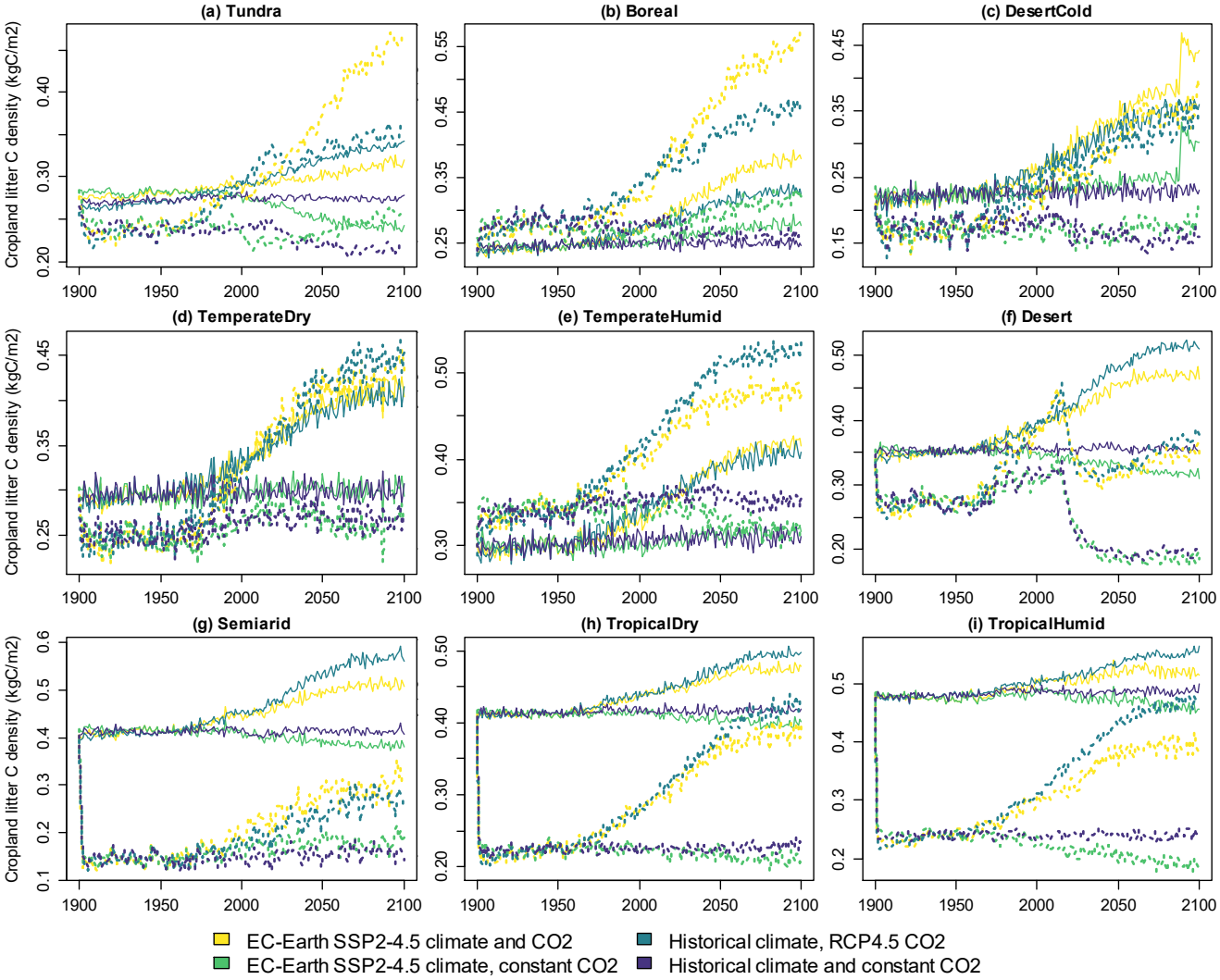

Figure S6 Carbon density in cropland litter in the four simulated scenarios. Solid lines indicate LPJ-GUESS simulations and dashed lines indicate functions fitted to the results.

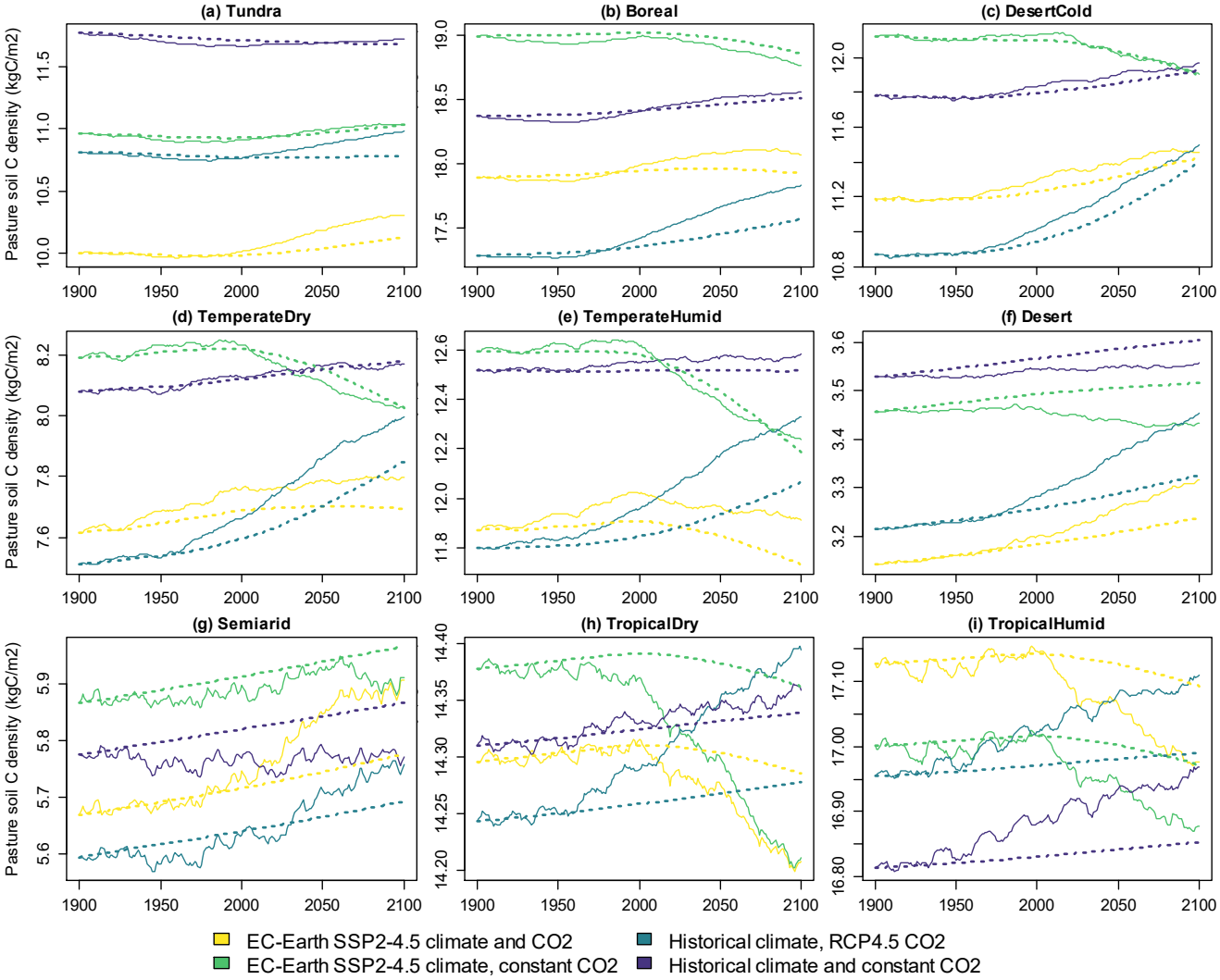

Figure S7 Carbon density in pasture soil in the four simulated scenarios. Solid lines indicate LPJ-GUESS simulations and dashed lines indicate functions fitted to the results.

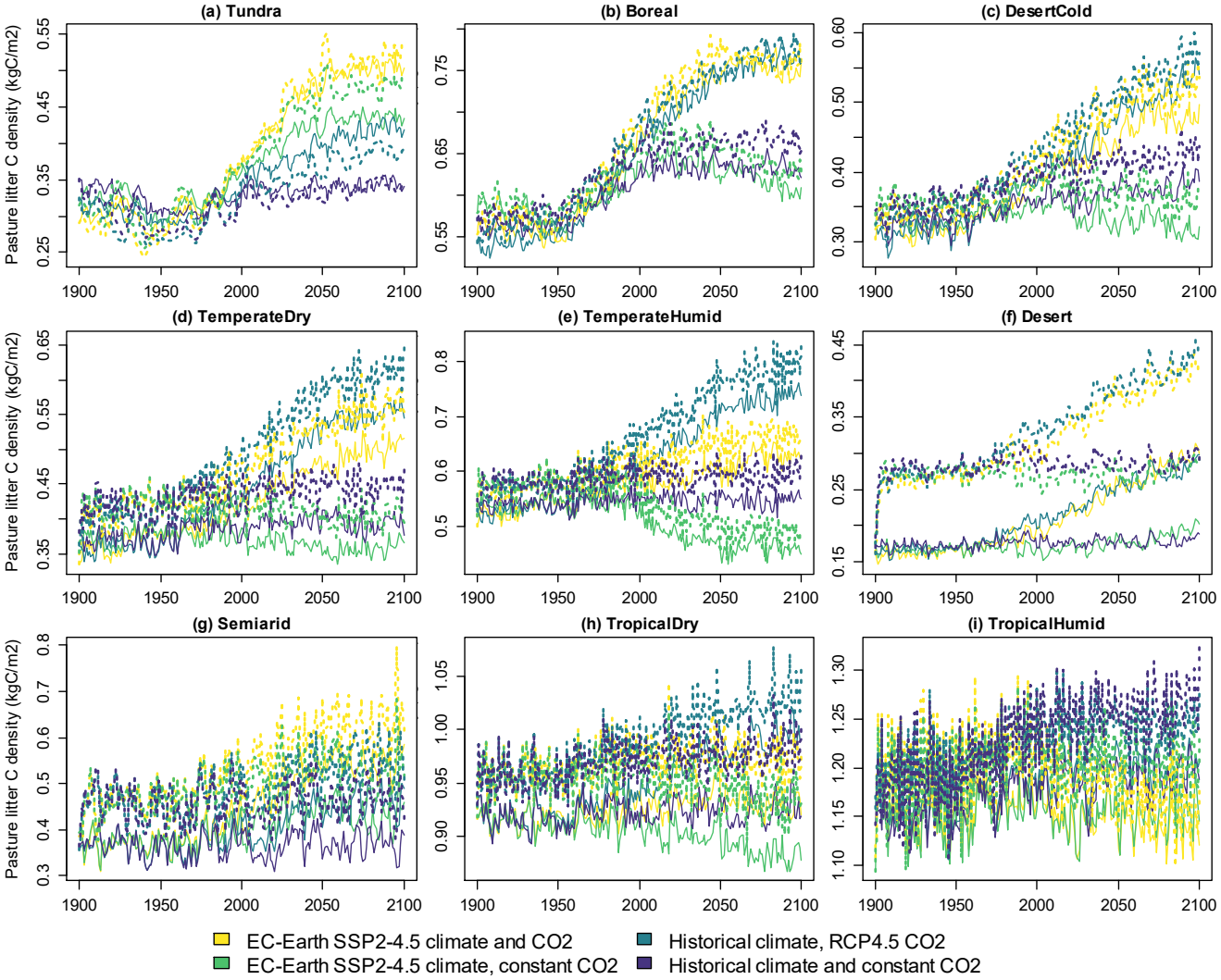

Figure S8 Carbon density in pasture litter in the four simulated scenarios. Solid lines indicate LPJ-GUESS simulations and dashed lines indicate functions fitted to the results.

Validation of CanESM and MPI parametrizations

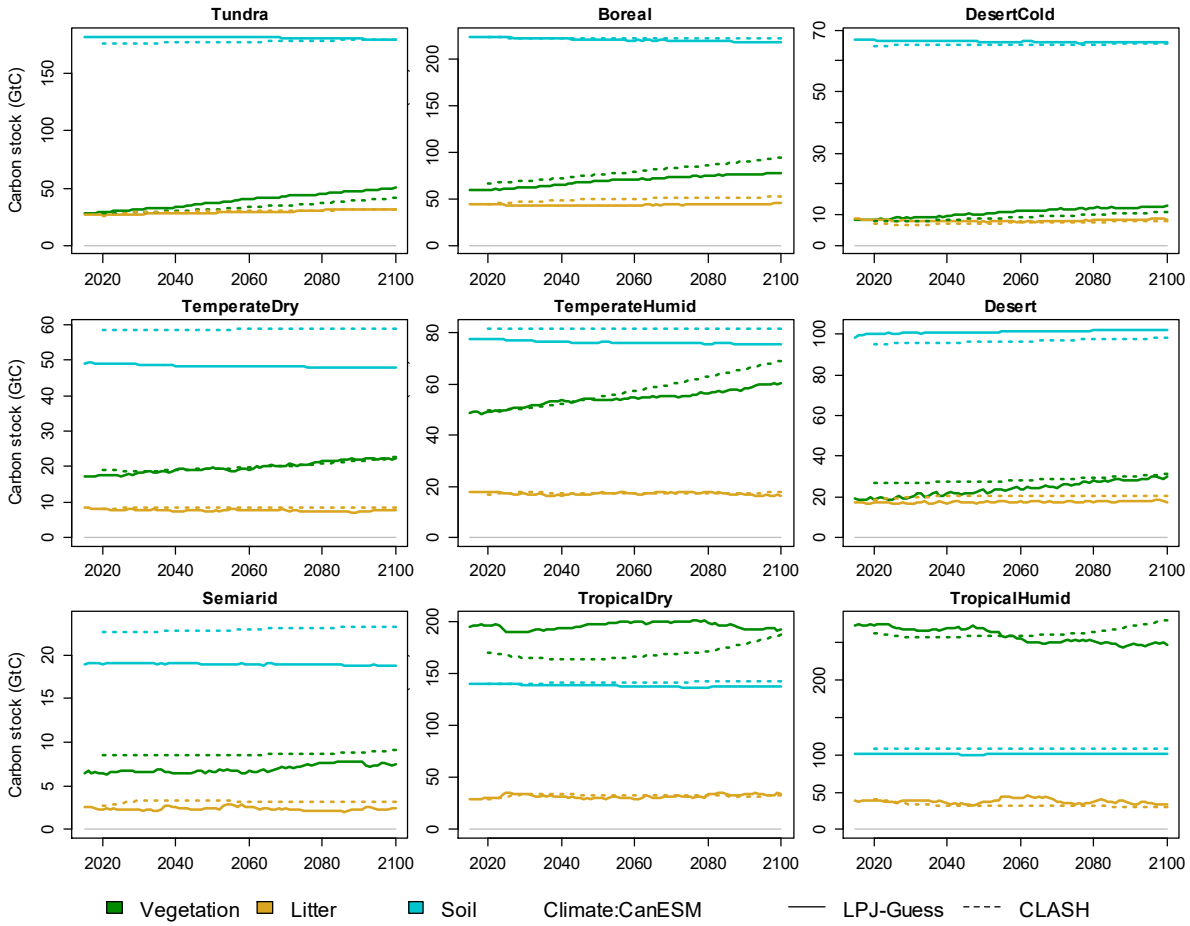

Figure S9 Validation of CLASH carbon stocks against LPJ-GUESS in the SSP2-4.5 scenario calculated with the CanESM model; separately for vegetation, litter and soil carbon in each biome. Solid lines indicate LPJ-GUESS results, dashes CLASH results.

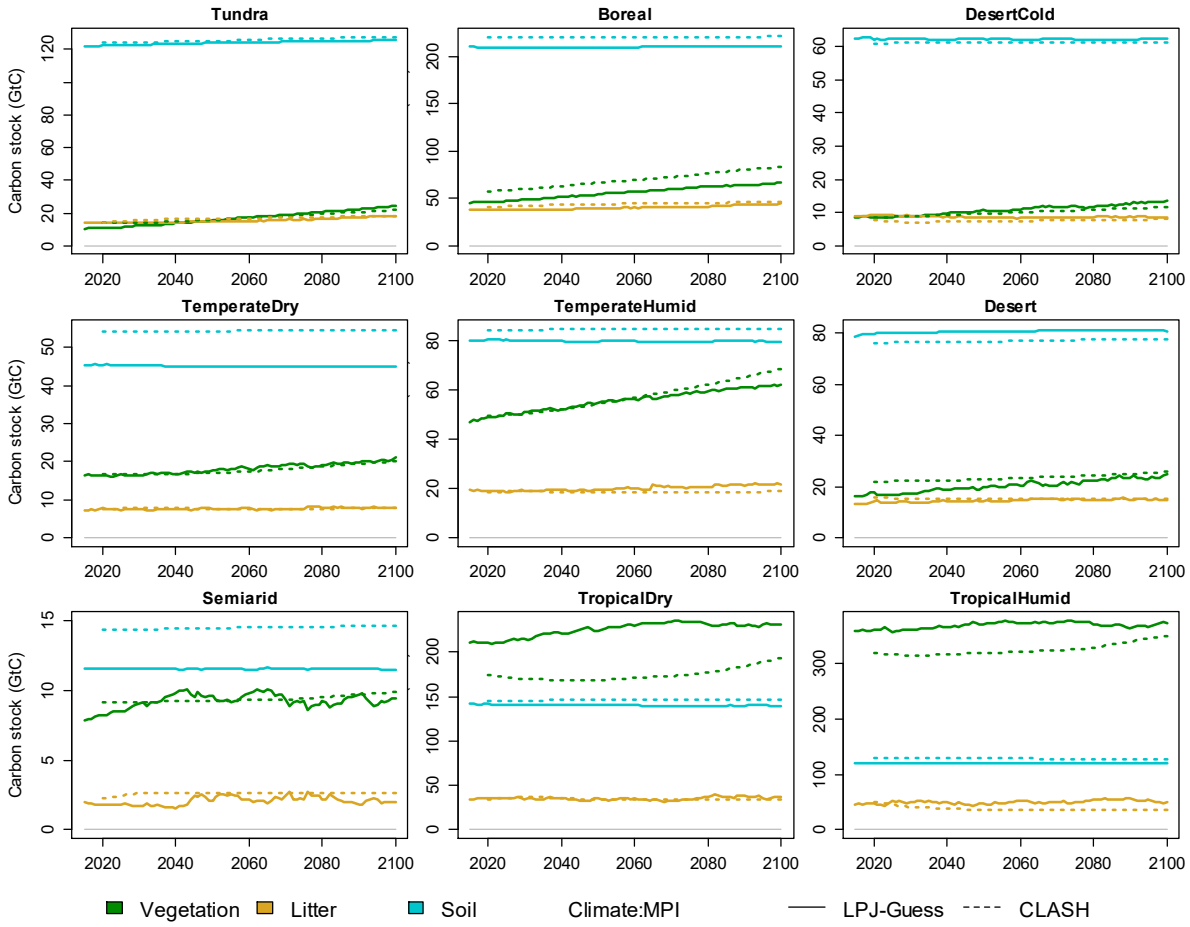

Figure S10 Validation of CLASH carbon stocks against LPJ-GUESS in the SSP2-4.5 scenario calculated with the MPI ESM model; separately for vegetation, litter and soil carbon in each biome. Solid lines indicate LPJ-GUESS results, dashes CLASH results.