

We are grateful to the referees for their time and energy in providing helpful comments and guidance that have improved the manuscript. In this document, we describe how we have addressed the reviewers' comments. Referee comments are shown in black italics and author responses are shown in blue regular text. A manuscript with tracking changes is attached at the end.

Reviewer #1

This manuscript presents and evaluates a new model framework that integrates the widely used ECHAM6 atmospheric general circulation model with the dynamic vegetation model iMAPLE. The evaluation compares simulated carbon and water fluxes and other variables such as soil temperature and moisture against observational benchmarks as well as against the ECHAM6 model coupled with the land surface model JSBACH.

While the manuscript itself is well presented and the figures are overall of good quality, I would argue that the manuscript requires substantial revision and restructuring before it can be published. The following main points would need to be addressed:

- Thank you for your positive evaluations. In this revision, we have made these major changes following your comments:
 - (1) We clarified that the primary objective of this study is to investigate whether improved carbon and water flux simulations by iMAPLE can enhance climate simulations in the original ECHAM6 framework with the JSBACH vegetation module.
 - (2) We emphasized the central role of land–atmosphere coupling and added more detailed descriptions of the related parameterizations and processes.
 - (3) We revised Figures 5 and 6 to more clearly demonstrate how ECHAM6-iMAPLE reduces the simulation biases present in ECHAM6-JSBACH.

1) As noted by the authors, both JSBACH and iMAPLE have already been extensively evaluated within the Global Carbon Budget (GCB) framework (the latest version being Friedlingstein et al. 2026, Figure S11), with results also publicly available online. The GCB2025 effort evaluates the same variables, using mostly the same benchmarks and

evaluation metrics. It is thus unclear what gap this study fills other than repeating this analysis (at least for carbon and water fluxes as well as LAI). The key difference is that both models here were coupled to ECHAM6, whereas GCB2025 evaluates the model 'offline' (i.e. using a common, prescribed forcing). The manuscript should therefore clearly articulate what coupling to the atmosphere changes and what additional insight is gained. I recommend restructuring the paper to focus more explicitly on coupling effects, as partially illustrated in Figures 5 and 6.

- We sincerely thank you for these insightful comments. We agree that the original manuscript failed to emphasize the central role of land–atmosphere coupling. In the revised manuscript, we have restructured the framing around land–atmosphere coupling rather than repeating an offline evaluation:

In the Introduction section, we have clarified the motivation for coupling iMAPLE into ECHAM6 as follows:

“The original ECHAM6 model employs the Jena Scheme for Biosphere–Atmosphere Coupling in Hamburg (JSBACH) to represent vegetation dynamics and terrestrial carbon cycling (Giorgetta et al., 2013). Here, we replace the carbon and water simulations by JSBACH with iMAPLE, a global dynamic vegetation model designed to simulate plant growth and terrestrial carbon cycle interactively (Yue et al., 2024). Both JSBACH and iMAPLE have been evaluated offline in the multi-model intercomparison project for Global Carbon Budget, where iMAPLE shows improved performance in simulating key carbon and water fluxes compared with JSBACH (Friedlingstein et al., 2025). We evaluate the dynamically simulated carbon and water fluxes from ECHAM6-iMAPLE, and compare them with simulations using the original ECHAM6-JSBACH framework. In particular, we investigate whether the updated vegetation representation improves the simulation of critical land-surface variables, including soil temperature, soil moisture, near-surface air temperature, and precipitation.” (Lines 84-97)

In the Methods section, we have provided a detailed description of the key land–atmosphere coupling processes. Please see our response below.

2) *Related to this, the Methods section needs to better reflect the Results. It is unclear*

why the Methods description focuses on photosynthesis even though this is the same as in the offline models, which have already been evaluated. The Methods should focus more on the coupling aspect of the model, i.e. addressing the question of how land-atmosphere feedbacks differ between the models and what effects this has on soil moisture, temperature, and other variables.

- Thank you for this constructive suggestion. In the revised paper, we have restructured Methods section accordingly. Detailed photosynthesis equations have been substantially shortened. Instead, we have expanded Section 2.3 to explain how key land-state variables from iMAPLE replace the corresponding JSBACH fields, how these replacements revise the surface energy and water balances, and how the resulting heat and moisture fluxes form the atmospheric lower boundary:

“ECHAM6 provides hourly meteorological variables to iMAPLE, including precipitation, surface air temperature, wind speed, humidity, surface pressure, CO₂ concentrations, direct and total radiation. In return, iMAPLE feeds back simulated soil temperature, soil moisture, and *ET* to ECHAM6. These variables further change the surface energy and water balance, thereby altering heat and moisture fluxes that define the atmospheric lower boundary conditions and regulate near-surface climate. Land-atmosphere energy exchange is governed by the surface energy balance, which constrains the transfer of energy between the land surface and the atmosphere:

$$C \frac{\partial T_{surf}}{\partial t} = R_{net} + H_{sensible} + H_{latent} + G \quad (15)$$

where T_{surf} is the surface temperature, C is the heat capacity of topmost soil layer, R_{net} denotes the net radiation, $H_{sensible}$ is the sensible heat flux, H_{latent} is the latent heat flux. G represents the ground heat flux, which is obtained from the soil temperature profile:

$$G = -\lambda_s \frac{\partial T}{\partial z} |_{z_{surf}} \quad (16)$$

where λ_s is the soil thermal conductivity and z is the depth. Replacing soil temperature therefore revises the near-surface thermal gradient and G , which in turn shifts the tendency of T_{surf} and the partitioning of surface energy into sensible heat. The latent heat flux is linked to *ET* as follows:

$$H_{latent} = L * ET \quad (17)$$

where L is the latent heat of vaporization. Replacing ET revises H_{latent} and affects the surface energy balance. The replacement of near-surface soil moisture updates the land hydrological state, thereby modifying available soil water and regulating subsequent land-atmosphere moisture exchange. The resulting surface heat and moisture fluxes provide the lower boundary conditions for vertical turbulent transport of dry static energy and specific humidity in ECHAM6. Specifically, an implicit surface-atmosphere coupling scheme uses surface dry static energy and saturated surface humidity, constrained by the surface energy balance, as lower boundary conditions, after which the atmospheric column is updated upward from the lowest model level. Consequently, changes in land surface states, including soil temperature, soil moisture, and ET, propagate to near-surface air temperature and humidity, and further influence the atmospheric column through turbulent diffusion.” (Lines 298-328)

3) Paper framing: in addition to the points above, both the abstract and the introduction would need to make clear that this manuscript is not just about an evaluation of ECHAM6-iMAPLE but also, in large parts, a comparison with ECHAM6-JSBACH. It is a bit surprising that JSBACH is mentioned fairly late in the manuscript (section 2.1.2).

- In the revised paper, we state explicitly that the study evaluates ECHAM6–iMAPLE relative to ECHAM6–JSBACH:

In the Abstract:

“... (iMAPLE v1.0) into the ECHAM6 atmospheric general circulation model, replacing carbon and water fluxes simulated by the original JSBACH vegetation module. The coupled model is evaluated against reanalysis, benchmark, and satellite datasets. Compared with the original ECHAM6–JSBACH configuration, ECHAM6-iMAPLE substantially improves simulations ...” (Lines 26-31)

In the Introduction:

“The original ECHAM6 model employs the Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg (JSBACH) to represent vegetation dynamics and terrestrial carbon cycling (Giorgetta et al., 2013). Here, we replace the carbon and water simulations by JSBACH with iMAPLE, a global dynamic vegetation

model designed to simulate plant growth and terrestrial carbon cycle interactively (Yue et al., 2024).” (Lines 84-88)

“We evaluate the dynamically simulated carbon and water fluxes from ECHAM6-iMAPLE, and compare them with simulations using the original ECHAM6-JSBACH framework. In particular, we investigate whether the updated vegetation representation improves the simulation of critical land-surface variables, including soil temperature, soil moisture, near-surface air temperature, and precipitation.” (Lines 92-96)

Furthermore, both the abstract and the conclusion refer to modelling aspects or improvements (e.g. carbon allocation, parameterisation of V_{cmax}) that are not described in the Methods, and it remains unclear which model differences drive the reported results. If these processes are used to explain differences between models, a more targeted analysis (e.g. sensitivity experiments or clearer attribution) would be needed to support these interpretations.

- We agree that key model configurations (e.g., V_{cmax} , phenology, and carbon allocation) should be described in greater detail in the Methods section. In the revised manuscript, we have provided a more comprehensive description of these physiological parameters to explicitly clarify the differences between the models.

For iMAPLE:

“The rates J_c , J_e , and J_s are parameterized as functions of environmental meteorological conditions and photosynthetic capacity, including the maximum carboxylation rate (V_{cmax} , $\mu\text{mol m}^{-2} \text{s}^{-1}$) (Collatz et al., 1991; Collatz et al., 1992). V_{cmax} is derived from its optimum value at 25 °C (V_{cmax25}) through a temperature-dependent Q_{10} function. PFT-specific V_{cmax25} values have been calibrated against extensive site-level eddy covariance measurements from more than 200 FLUXNET sites (Yue et al., 2024)” (Lines 134-140)

“Phenology in iMAPLE is represented by a prognostic phenological factor (f) that is updated daily. The phenology scheme is based on the framework of Kim et al. (2015) and was refined using multi-year LAI measurements at four U.S. forest sites and leaf phenology records from hundreds of ground sites within the U.S. National

[Phenology Network \(Yue et al., 2015\)](#). For short-stature vegetation such as tundra, savanna, and shrubland, the phenological state is governed by temperature and/or soil moisture, with the dominant control set by PFT and regional climate (Delbart and Picard, 2007). Deciduous forests likewise use temperature- and moisture-dependent thresholds, whereas evergreen needleleaf and evergreen broadleaf PFTs adopt a constant phenological factor, with frost hardening applied to reduce V_{cmax} for needleleaf forests in cold seasons. Cropland phenology is prescribed from planting and harvest calendars. LAI is updated at 10-day intervals based on total leaf carbon and vegetation phenology:

$$LAI = f \times LAI_b \quad (3)$$

Here, LAI_b is related to vegetation carbon, which is the sum of leaf (C_l), root (C_r), and stem pools (C_w):

$$C_{veg} = C_l + C_r + C_w \quad (4)$$

[As a result, carbon assimilation determines the total carbon available for allocation, whereas carbon allocation dynamically regulates vegetation development \(Cox, 2001; Clark et al., 2011\).](#)” (Lines 149-167)

For JSBACH, the photosynthetic parameterizations differ from those in iMAPLE. In addition, key parameters such as V_{cmax} have not undergone global calibration. Furthermore, although LAI is dynamically simulated, it is decoupled from carbon allocation processes. We clarified in Section 2.2.1 with following key points:

“In JSBACH, photosynthesis of C_3 plants is represented using the Farquhar model (Farquhar et al., 1980), consistent with iMAPLE. For C_4 plants, JSBACH utilizes the Collatz model (Collatz et al., 1992). The primary difference between the Collatz and Farquhar formulations lies in their parameterization of the carboxylation rate (J_c) and the electron transport rate (J_e)” (Lines 240-244)

“LAI is dynamically simulated using the phenological model of LoGro-P, which does not feed carbon allocation back into leaf phenology (Dalmonech and Zaehle, 2013; Dalmonech et al., 2015).” (Lines 262-264)

4) *Benchmark datasets, particularly MERRA-2, need to be described in more detail. For example, how is soil moisture calculated in MERRA-2 and what assumptions are made? In addition, details on the simulation setup is required to ensure reproducibility*

of the analysis.

- In the revised manuscript, we have expanded Section 2.4 to clarify the MERRA-2 soil-moisture definition and conversion, and we have added further details of the simulation setup in Section 2.3 for reproducibility:

“Near-surface soil moisture was derived from the MERRA-2 surface wetness variable GWETTOP, which represents relative saturation in the topmost soil layer. GWETTOP was converted to volumetric water content ($\text{m}^3 \text{m}^{-3}$) by multiplying it by the grid-cell soil porosity.” (Lines 360-363)

“The experiments were driven by observed sea surface temperature and sea ice fraction without atmospheric nudging. The interactive HAM/MOZ chemistry and aerosol modules were disabled. Greenhouse gas concentrations followed the CMIP6 historical pathway. Both ECHAM6-iMAPLE and ECHAM6-JSBACH simulations used identical atmospheric settings at T63L47 resolution for the period of 2000-2014. The first five years were used for model spin-up, and the remaining ten years were averaged for analysis and performance assessment.” (Lines 342-348)

Reviewer #2

Review for Development and evaluation of the ECHAM6-iMAPLE v1.0 coupled atmosphere-ecosystem model

In their manuscript “Development and evaluation of the ECHAM6-iMAPLE v1.0 coupled atmosphere-ecosystem model”, the authors describe and present some benchmarking analysis of the ECHAM6 atmospheric model coupled to the iMAPLE v1.0 land model, in place of the JSBACH land model.

The manuscript is overall well written, and the benchmarking analysis is fairly clear. Following minor revisions, this study would be suitable for publication in the EGU family of journals.

My largest point of confusion was that it was unclear until fairly late in the manuscript if iMAPLE was being imposed alongside JSBACH to handle certain specific aspects of the land surface, or if JSBACH was being entirely removed and replaced by iMAPLE. Specific comments are listed line by line below.

- Thank you for your positive evaluations. In this revision, we have made these major changes following your comments:
 - (1) We clarified the relationship between iMAPLE and JSBACH: iMAPLE replaces the carbon and water cycle components of JSBACH, rather than the entire JSBACH module, and these improved land-surface processes can further influence climate simulations in ECHAM6.
 - (2) We expanded the descriptions of the differences in carbon and water cycle processes represented in iMAPLE and JSBACH.
 - (3) We revised Figures 5 and 6 to more clearly demonstrate how ECHAM6-iMAPLE reduces the simulation biases present in ECHAM6-JSBACH.

Line 108 – surely JSBACH was already doing this, was it not? (a process-based simulation of soil temperature and moisture, even if it was different than the approach used by NOAH-MP)

- Yes, JSBACH also employs process-based simulations of soil temperature and moisture. Therefore, this sentence highlights the key improvements introduced by iMAPLE relative to YIBs (the carbon module in iMAPLE), rather than serving as a comparison with JSBACH. In the revised paper, we clarified as follows:
 “This enables dynamical simulation of soil temperature and moisture and facilitates tight coupling between the carbon (simulated by YIBs) and water (simulated by Noah-MP) cycles (Niu et al., 2011).” (Lines 113-115)

Section 2.1 – clearly delineating what JSBACH did not do that required replacement with iMAPLE would be valuable. Or, if it is just a different approach to the land model (but covering the same processes as JSBACH), that is still valuable – the entire premiss of CMIP is “have more models/model combos” – but make it clear that that is the case.

- Thank you for this helpful suggestion. The main reasons for replacing JSBACH in ECHAM6 with iMAPLE are twofold. First, iMAPLE demonstrates improved performance in simulating carbon and water fluxes compared with JSBACH, which is expected to improve climate simulations when coupled with ECHAM6. Second, iMAPLE incorporates a broader range of biogeochemical processes, providing greater potential for extending land-atmosphere coupling to atmospheric chemistry in future applications. We have clarified in Section 2.3 as follows:

“Although both JSBACH and iMAPLE participated in the multi-model intercomparison project for Global Carbon Budget, iMAPLE demonstrated superior performance relative to JSBACH in simulating key carbon (e.g., GPP) and water (e.g., ET) fluxes (Friedlingstein et al., 2025). In addition, iMAPLE incorporates a more comprehensive representation of biogeochemical processes, providing greater potential for extending land-atmosphere coupling to atmospheric chemistry in future applications.” (Lines 285-291)

Section 2.1 – clearly delineating what the difference between NOAH-MP and iMAPLE is --- does iMAPLE add layers of complexity to NOAH-MP, or does it use parts of NOAH-MP’s code (eg solving the soil energy budget) and not other parts?

- Thank you for this helpful suggestion. iMAPLE does not introduce additional layers of complexity to Noah-MP. Instead, the hydrological and soil-physics components of Noah-MP have been fully incorporated into iMAPLE, enabling the

dynamic calculation of soil parameters required for carbon cycle simulations in iMAPLE (based on YIBs) and facilitating the coupling between carbon and water fluxes. In the revised manuscript, we have clarified this relationship in Section 2.1 as follows:

“Furthermore, iMAPLE integrates the process-based hydrological scheme Noah-MP, including precipitation partitioning, infiltration, soil moisture redistribution, evapotranspiration, runoff generation, and groundwater-related processes. This enables dynamical simulation of soil temperature and moisture and facilitates tight coupling between the carbon (simulated by YIBs) and water (simulated by Noah-MP) cycles (Niu et al., 2011).” (Lines 110-115)

Line 183-185: was not clear here if ECHAM (JSBACH) or MAPLE is handling the land. Which component of the model is responsible for what? Does MAPLE just do the vegetation, or all land surface properties? How does that interact with the physical surface like feedbacks between leaf area and albedo?

➤ Thank you for pointing out this ambiguity. We have revised this part to enhance the clarity:

“In the default ECHAM6 configuration, land surface processes are handled by JSBACH. After coupling with iMAPLE, JSBACH remains responsible for most land surface calculations in ECHAM6, whereas iMAPLE is used for vegetation processes. Details of the exchanged variables are given in Section 2.3.” (Lines 207-210)

iMAPLE feeds back only soil temperature, soil moisture and evapotranspiration to ECHAM6 in the present coupling. Physical surface processes of this type, including leaf-area–albedo interactions, therefore continue to be handled by JSBACH. We have acknowledged this incomplete coupling as a limitation in the Conclusion and Discussion, and it is also a priority for future model development: “... not all vegetation properties simulated by iMAPLE are fully coupled to ECHAM6. For instance, dynamically simulated LAI is not consistently used by ECHAM6 to update land surface parameters or ecosystem emissions.” (Lines 495-498)

Line 197-198: not clear if iMAPLE is replace JSBACH, or replacing only parts of it,

OR only adding new functionality, and stuff that iMAPLE did that JSBACH was already doing doesn't get incorporated and the JSBACH processes are used.

- We are sorry for this misunderstanding. When iMAPLE is coupled with ECHAM6, JSBACH remains the default land component of ECHAM6 and continues to perform most land-surface calculations. The iMAPLE model is used to replace the carbon and water cycle in the JSBACH, which could further affect the climate simulations in ECHAM6. In the revised paper, we clarified as follows:

“In the default ECHAM6 configuration, land-surface processes are handled by JSBACH. After coupling with iMAPLE, JSBACH remains responsible for most land-surface calculations in ECHAM6, whereas iMAPLE is used for vegetation processes.” (Lines 207-210)

“In return, iMAPLE feeds back simulated soil temperature, soil moisture, and *ET* to ECHAM6. These variables further change the surface energy and water balance, thereby altering heat and moisture fluxes that define the atmospheric lower boundary conditions and regulate near-surface climate.” (Lines 300-303)

“The replacement of near-surface soil moisture updates the land hydrological state, thereby modifying available soil water and regulating subsequent land-atmosphere moisture exchange. The resulting surface heat and moisture fluxes provide the lower boundary conditions for vertical turbulent transport of dry static energy and specific humidity in ECHAM6. Specifically, an implicit surface-atmosphere coupling scheme uses surface dry static energy and saturated surface humidity, constrained by the surface energy balance, as lower boundary conditions, after which the atmospheric column is updated upward from the lowest model level. Consequently, changes in land surface states, including soil temperature, soil moisture, and *ET*, propagate to near-surface air temperature and humidity, and further influence the atmospheric column through turbulent diffusion.” (Lines 318-328)

Line 271-274: implies JSBACH is entirely removed/bypassed. Is that correct?

- Please see our responses in the above.

Figure 1 / related text: no discussion about representation of aerodynamic properties or turbulence - are they static, time evolving, using Monin Obukhov similarity

theory/something else?

- In the revised paper, we provided a more detailed description of the aerodynamic characteristics and turbulence:
“Turbulent mixing in the atmosphere is represented by a turbulent kinetic energy (TKE) scheme, and surface fluxes are computed using bulk transfer coefficients with Louis-type stability functions based on the bulk Richardson number (Louis, 1979; Brinkop and Roeckner, 1995). Land roughness lengths are provided by JSBACH and evolve with the surface state.” (Lines 198-202)

Figure 1: What component of the model is dealing with the entire centre column?

- The centre column of Figure 1 represents the coupling interface between ECHAM6 and iMAPLE, rather than a separate physical component. Atmospheric forcing is passed to iMAPLE through newly added interface code. Selected variables simulated by iMAPLE are then fed back to ECHAM6 along the existing JSBACH land-surface feedback pathway. In the revised paper, we have clarified in the caption of Figure 1 as follows:
“The integrated modeling framework for ECHAM6-iMAPLE v1.0: Atmosphere-Ecosystem Coupled Model. Left: ECHAM6 atmospheric processes. Centre: land–atmosphere coupling interface. Right: iMAPLE vegetation and hydrology.” (Lines 874-876)

Figure 5: Is this full column soil moisture, or near surface, or root zone, or something else? How does each model handle ground water (if at all – and is it included in this figure?)

- Thank you for this important clarification. Figure 5 shows near-surface soil moisture only. iMAPLE and JSBACH treat groundwater differently. In iMAPLE, Noah-MP uses the simple groundwater model (SIMGM). In JSBACH, deep groundwater components below bedrock are not considered as a separate store and the related subsurface outflows are represented in a simplified way through drainage (Hagemann and Stacke, 2015). In the revised paper, we have clarified this in Sections 2.1.2 and 2.2.2:

For iMAPLE: “Groundwater is treated explicitly in Noah-MP through the simple groundwater model (SIMGM) (Niu et al., 2007). An unconfined aquifer is placed

beneath the soil column; aquifer water storage (W_a) evolves through recharge and discharge, and the water-table depth is diagnosed from W_a .” (Lines 184-187)

For JSBACH: “Deep groundwater components such as aquifers below the bedrock are not considered. These flows are conceptually simplified and included in the drainage.” (Lines 270-272)

Figure 6 (and also figure 5, but especially true in 6): this is quite hard to compare. Perhaps show MERRA-2, then the difference of iMAPLE-MERRA or JSBACH-MERRA in the middle and right columns?

➤ We have modified Figure 5 and Figure 6 as suggested.

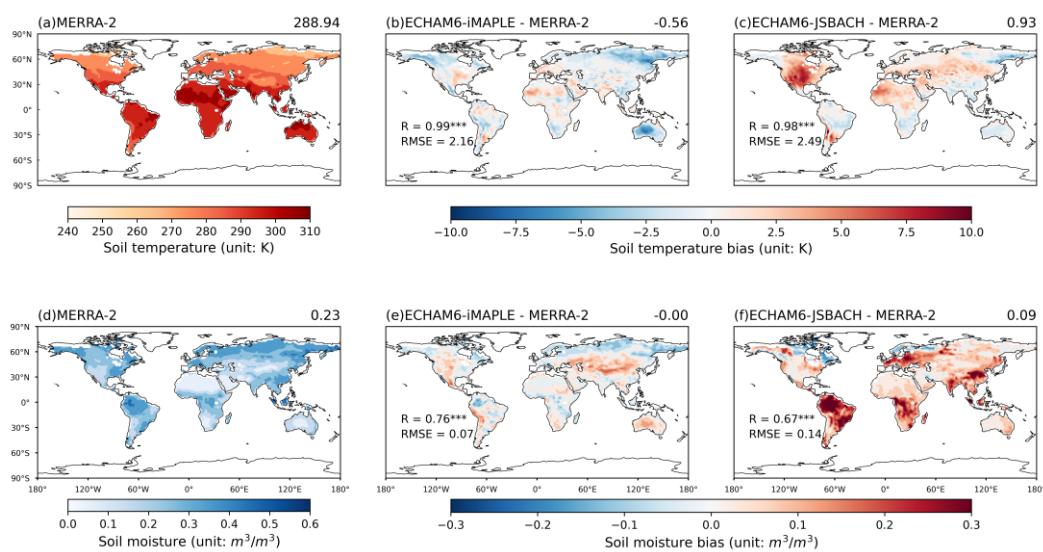


Figure 5. Spatial distributions of (a) soil temperature (ST, K) and (d) near-surface soil moisture (SM, m^3/m^3) from MERRA-2 reanalyses, biases of (b, e) ECHAM6-iMAPLE and (c, f) ECHAM6-JSBACH relative to MERRA-2. Both model simulations and MERRA-2 reanalyses are averaged for the period of 2005-2014. The spatial R and RMSE between simulations and reanalyses are shown in the lower left corner of simulation panels. The area-weighted mean (or mean biases) ST and SM are indicated at the top of each panel.

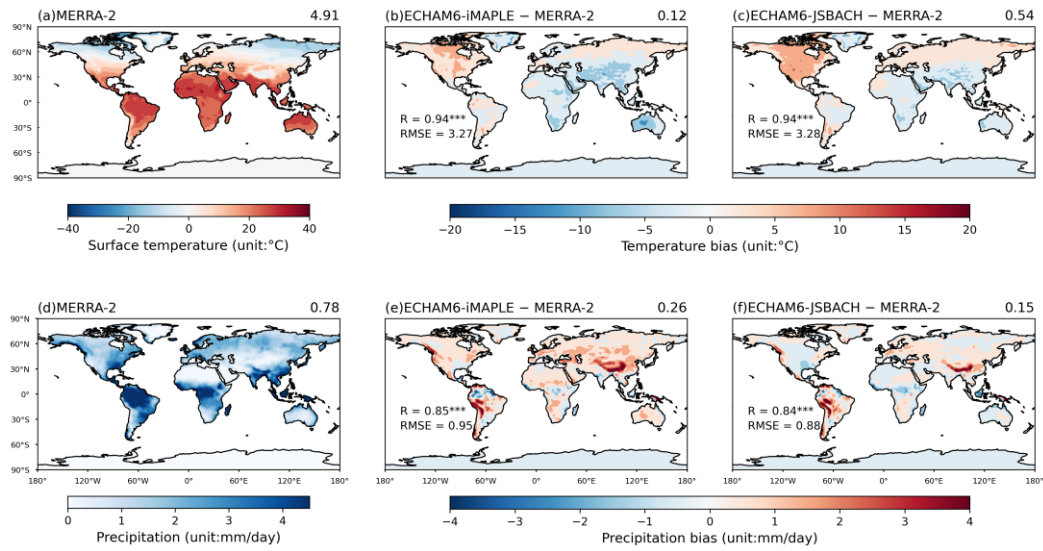


Figure 6. Spatial distributions of (a) surface temperature (T , °C) and (d) precipitation (PREC, mm/day) from MERRA-2 reanalyses, biases of (b, e) ECHAM6-iMAPLE and (c, f) ECHAM6-JSBACH relative to MERRA-2. Both model simulations and MERRA-2 reanalyses are averaged for the period of 2005-2014. The spatial R and RMSE between simulations and observations are shown in the lower left corner of simulation panels. The area-weighted mean (or mean biases) T and PREC are indicated at the top of each panel.

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