Author response in red font, original editor/reviewer comments in black font.

This study develops, documents, and demonstrates a reproducible workflow for enabling fully interactive land–atmosphere coupling in both E3SM SCM and DP-SCREAM. The authors performed multi-year offline-forced E3SM/ELM integrations and developed an offline Python preprocessing script to generate DP-SCREAM-compatible land restart files without modifying ELM's core I/O infrastructure, thereby obtaining realistic spun-up land initial conditions. Using long-term hindcast simulations over the GOAmazon and SGP campaigns, and short-term process-level case studies of shallow and deep convections, this paper find that interactive land coupling is essential for reproducing near-surface thermodynamic biases characteristic of global simulations, including warm 2-m temperature biases. Prominent cloud and convection biases (insufficient deepening of shallow convection, deficits of mid-level congestus, weak convective organization) are largely insensitive to the choice between prescribed fluxes and interactive land treatments, suggesting that they arise primarily from atmospheric model physics and dynamics.

The study provides practical guidance for the community on when interactive versus prescribed surface fluxes are appropriate for process-level model evaluation. The results are scientifically important and offer valuable insights for future process-level studies using E3SM SCM and DP-SCREAM. The technical workflow for generating spun-up land initial conditions is well documented and will be of value to the broader community. The manuscript is generally well-written, logically organized, and supported by extensive simulations. I have only minor comments for the authors to consider.

The authors thank the reviewer for their time spent in evaluating this article. Please see below for our response to each point raised.

The first comment is about the comparison with interactive land options in other SCMs. As the authors mentioned, technical option for interactive land has existed in E3SM SCM. Also, I remember SCAM6 uses interactive land as its default settings. However, the current introduction gives the impression that all existing single-column models rely on prescribed surface fluxes. I would strongly recommend adding discussions of interactive land options in other SCMs within the introduction, along with a clear explanation of how the approach presented here differs from those existing implementations.

We thank the reviewer for highlighting the need to distinguish existing interactive-land capabilities from the contribution of this study. We agree that the introduction needed to acknowledge previous coupled land–atmosphere SCM configurations more clearly.

We have revised the introduction to clarify that prescribed surface fluxes characterize the previous E3SM process-level applications discussed here, rather than all SCM implementations. We added the following text:

"Previous applications of the E3SM SCM and DP-SCREAM considered here have used prescribed surface fluxes for continental cases. Although useful for isolating atmospheric processes under observational constraints, this treatment suppresses feedbacks between the evolving atmosphere and land surface and can complicate comparison with the coupled parent global model."

We also added the following discussion of existing implementations and the specific contribution of this study:

"Interactive land–atmosphere coupling is already available in several SCM frameworks. SCAM6 supports an active CLM5 land component and configurable prescribed or model-calculated surface fluxes (Gettelman et al., 2019), while the E3SM SCM likewise supports interactive land, with prescribed fluxes used by default when supplied in the case forcing file (Bogenschutz et al., 2020). Coupled SCM applications include the GABLS3 intercomparison, which examined the influence of land-surface coupling on the diurnal boundary layer (Bosveld et al., 2014), and the ARPEGE–SURFEX configuration of CNRM-CM6-1, used to evaluate land–atmosphere interactions across contrasting land covers (Bernard et al., 2025). Building on this established capability, the present study develops and documents a reproducible initialization and simulation workflow for both E3SM SCM and DP-SCREAM. This includes preparing spun-up ELM states and mapping the land subgrid hierarchy onto the doubly periodic domain. We then use paired prescribed-flux and interactive-land experiments to assess the influence of coupling on multi-year hindcast statistics and targeted cloud and convection processes."

Finally, we revised the opening sentence of the subsequent paragraph to describe our contribution as "developing and documenting the initialization and simulation workflow needed to use interactive land coupling in the SCM and DP-SCREAM configurations." These changes distinguish the existing coupling capability from the initialization workflow and systematic evaluation presented here.

Another topic which may be outside the primary scope of this paper but I believe worth a brief discussion is air-sea interactions. The present study addresses land–atmosphere coupling for continental cases only. For oceanic cases, current SCMs similarly rely on prescribed surface fluxes. Some coupled atmosphere–ocean single-column models have been developed (e.g., EC-Earth; Hartung et al., 2018). What are the similarities and

differences between air–sea interactions in oceanic cases and land–atmosphere interactions discussed here? Are there plans to extend this framework to include air–sea coupling in E3SM SCM in future work?

We agree that air–sea coupling provides a useful comparison with the land–atmosphere interactions examined here. We clarify that oceanic cases in E3SM SCM and DP-SCREAM can use either prescribed surface fluxes or fluxes calculated from the evolving atmospheric state and prescribed SSTs. For example, the MAGIC and COMBLE simulations in Bogenschutz et al. (2025) use calculated sensible and latent heat fluxes with prescribed, time-varying SSTs. These configurations allow surface fluxes to respond to atmospheric changes, but do not permit SST to respond to the simulated surface energy budget.

There are currently no plans to couple E3SM SCM or DP-SCREAM to a full ocean model. A slab ocean could provide a comparatively simple future extension for studying thermodynamic feedbacks, although this is not a committed development plan.

We have added the following paragraph to the Summary and Discussion section to explain the similarities and differences between land and ocean coupling and clarify this possible extension:

“Although this study focuses on continental cases, analogous questions arise for air–sea interactions. Oceanic cases in E3SM SCM and DP-SCREAM support either prescribed surface fluxes or fluxes calculated from the evolving atmospheric state and prescribed SSTs, as demonstrated for MAGIC and COMBLE by Bogenschutz et al. (2025). The latter permits atmospheric control of surface exchange but excludes feedbacks of the simulated surface energy budget on SST. Interactive land and ocean coupling share the objective of allowing the surface and atmosphere to evolve together; however, land feedbacks depend on soil moisture, soil temperature, and vegetation, whereas ocean feedbacks depend on heat storage and upper-ocean mixing. Coupled atmosphere–ocean SCMs, such as that of Hartung et al. (2018), explicitly represent these ocean responses. We currently have no plans to couple E3SM SCM or DP-SCREAM to a full ocean model, although a slab ocean could provide a comparatively simple future extension for examining thermodynamic feedbacks, subject to assumptions about mixed-layer depth and unresolved ocean heat transport.”

Some other minor comments:

A few abbreviations are used without their full names being provided, such as SHOC and SNICAR-AD. Please define these at first use.

We have defined SHOC (Simplified Higher-Order Closure) and SNICAR-AD (Snow, Ice, and Aerosol Radiative model with Adding-Doubling solver) at their first occurrence in the manuscript.

Figure 5: The late-afternoon peak is not clearly illustrated in Figure 5. I recommend specifying that this late-afternoon peak corresponds to the 02 UTC time step, which represents approximately 20:00 LST.

We have revised the text discussing Figure 5 to specify that the late-afternoon/early-evening precipitation peak occurs at 02 UTC, corresponding to approximately 20:00 local standard time.

Line 312-314: I don't quite understand this logical chain. why excessive boundary layer mixing may maintain overly warm near-surface temperature? Would the higher sensible heat flux and excessive mixing be associated with a stronger land-air temperature gradient, which would imply colder air temperature?

The reviewer was right to question this explanation. We agree that the original wording implied a causal connection that is not established by the diagnostics presented. Although nighttime mixing can transport warmer air downward under stable conditions, the coexistence of temperature and surface flux biases does not establish excessive mixing as their cause. Likewise, our analysis does not demonstrate that nighttime warmth causes daytime stabilization or a compensating sensible heat flux deficit.

We have modified the text so it now reads:

“During nighttime hours, both model configurations exhibit a positive sensible heat flux bias, whereas a negative bias occurs during daylight hours. These flux biases coexist with warm near-surface air temperature biases in the interactive-land simulations, but the diurnal composites alone do not establish their underlying mechanisms or a causal connection between the nighttime and daytime errors. Attribution of these biases requires further analysis of surface–air temperature differences, atmospheric temperature profiles, turbulent heat transport, and the surface energy budget.”

Line 356-357: This explanation provided here focuses on the contrast between interactive land and prescribed fluxes. How does this extend to the comparison between SCM and DP-SCREAM? Specifically, why does DP-SCREAM with interactive land fail to represent shallow cumulus as well as the SCM configuration?

We agree that this is a very interesting difference. Our analysis does not establish why DP-SCREAM with interactive land represents the observed shallow cumulus less accurately than the SCM with interactive land. We agree that this warrants further investigation and have added the following sentence:

“The reason that DP-SCREAM represents the observed shallow cumulus less accurately than the E3SM SCM even when both use interactive land remains unresolved and warrants targeted investigation in future work.”

Author response in red font, original editor/reviewer comments in black font.

The authors thank the reviewer for their time spent in evaluating this article. Please see below for our response to each point raised.

This manuscript presents a useful workflow for initializing interactive land simulations in E3SM SCM and DP-SCREAM and evaluates how surface coupling affects the reproduction of global-model biases. The comparison across two observational sites and several process-level cases is valuable. I just have some minor comments.

1. Section 3 states that ELM runs in the background while its outputs are overwritten by prescribed fluxes, but it remains unclear exactly which quantities are overwritten. In particular, I am interested in how ground heat flux is treated. It would help to explain the excessive nighttime cooling and fog in the prescribed flux simulation. Right now it is difficult to explain what causes the nighttime cooling.

We thank the reviewer for identifying this ambiguity. The overwritten quantities are the surface sensible and latent heat fluxes supplied to the atmosphere. We agree that specifying these quantities does not, by itself, establish the mechanism responsible for excessive nighttime cooling. We have replaced the original statement in Section 3 with the following text:

"In the prescribed-flux configuration, ELM continues to run, but the surface sensible and latent heat fluxes supplied to the atmosphere are overwritten by the prescribed values. This replacement applies to turbulent heat and moisture exchange with the atmosphere, rather than prescribing the ground heat flux, which represents conductive heat exchange within the land surface. The imposed turbulent fluxes cannot adjust to the evolving simulated near-surface temperature and humidity, so their consistency with the simulated surface and atmospheric energy budgets is not guaranteed. However, the present analysis does not isolate the contributions of ground heat exchange, radiative cooling, and turbulent heat transport to the nighttime cold bias and associated fog; establishing their relative roles requires a dedicated energy-budget analysis."

2. The study includes SCM, several DP-SCREAM resolution setups, an offline ELM integration, and SAM LES reference simulations. Although Section 4.2 lists the DP-SCREAM resolutions, the configuration information is scattered, and SAM is introduced only in the results. Maybe add a table summarizing each experiment's model, case or period, resolution, domain size, and purpose. Also, please use "E3SM SCM" consistently in the results section where single-column configuration is intended.

We thank the reviewer for these suggestions. We have addressed all three points.

First, we added a paragraph introducing the System for Atmospheric Modeling (SAM) in the Model Descriptions section. It describes its role as the large-eddy simulation reference, the turbulence and microphysics treatments used, and the case-specific configurations, with references to the original case studies and Bogenschutz et al. (2025). We removed the redundant introduction of SAM from the results section.

Second, we added Table 1 in the Experiment Design section to consolidate the models, cases or periods, horizontal resolutions, domain sizes, and purposes of the experiments. The table includes the offline ELM integration, E3SM SCM and DP-SCREAM long-term hindcasts, the standard and higher-resolution DP-SCREAM process cases, and the SAM LES references. Its caption also identifies the paired prescribed-flux and interactive-land experiments and explains the daily hindcast protocol.

Finally, we revised the manuscript, including the results text and figure captions, to use “E3SM SCM” consistently when referring to the single-column configuration, while retaining “E3SM” for the broader modeling system.

3. The discussion provides useful guidance on reproducing near-surface biases versus diagnosing cloud and convection errors. It would be great if a more detailed discussion of when and where interactive land-atmosphere coupling is expected to matter and which scientific questions this capability can potentially address. Examples include soil moisture or vegetation controls on boundary-layer growth, cloud-radiation and surface-flux feedbacks, or nocturnal land surface and boundary-layer exchange. This would help generate broader interest in the study, particularly given its focus on model development.

We thank the reviewer for encouraging a broader discussion of the scientific applications of this capability. We have added the following paragraph to the Summary and Discussion section:

“Beyond bias diagnosis, this capability provides a controlled framework for investigating local land–atmosphere feedbacks (Santanello et al., 2018). Coupling is expected to be particularly consequential during soil-moisture transitions between wet and dry conditions, when evapotranspiration and surface energy partitioning respond strongly to water availability, and during clear, weak-wind nights when

surface cooling and turbulent exchange jointly govern near-surface stability. Sensitivity experiments perturbing initial soil moisture, prescribed vegetation properties, or land-surface parameters could quantify their effects on boundary-layer growth, entrainment, cloud-base height, and convective initiation. Paired experiments could also examine how cloud-induced changes in surface radiation modify turbulent fluxes and subsequent cloud development, and how soil heat storage and atmospheric mixing influence nocturnal cooling, dew or fog formation, and the morning transition. Comparing these responses between E3SM SCM and DP-SCREAM would help assess how parameterized versus explicitly represented convection interacts with land feedbacks, while recognizing that the models also differ in other physical parameterizations. These applications are prospective and were not systematically tested here. The present homogeneous land initialization and prescribed large-scale atmospheric forcing support studies of local feedbacks, whereas questions involving imposed land-surface heterogeneity, regional circulation responses, or accumulated drought feedbacks would require additional experimental design, spatially varying land initialization, or longer continuous integrations."

4. In general, figure captions could be little more specific and give more details. Figure 7, it's hard to see the red lines that identify surface fog.

We have expanded the figure captions to clarify panel arrangements, averaging periods, model configurations, surface-flux treatments, and time conventions. We have also revised Figure 7 to make the surface-fog indicators easier to see.

5. Some acronyms are difficult to follow for readers unfamiliar with E3SM, for example, "IELM compset" and "ne30pg2". Please try to spell some acronym throughout the manuscript.

We have clarified the terminology in the Land Model Spin-Up section. "IELM compset" is now explained as a component set for an offline configuration with an active E3SM Land Model and prescribed atmospheric forcing supplied through a data atmosphere. We also explain that "ne30pg2" identifies a cubed-sphere grid with 30 × 30 spectral elements on each of the six cube faces and 2 × 2 finite-volume physics cells per element; which corresponds to a 100 x 100 km resolution in the horizontal.

In addition, we expanded EAMv3, ELM, CLUBB, ERA5, GPU, CPU, NERSC, PIO, and SSTs where introduced in the relevant text, improving accessibility for readers unfamiliar with E3SM terminology.

6. In the introduction, please briefly review how other SCMs treat the land surface, including prescribed fluxes and interactive land coupling. This would help readers understand what is already available and what this study adds, particularly since the authors note that interactive coupling was already possible in E3SM.

   This is a nice suggestion. We have revised the introduction to review existing land-surface treatments in SCMs and clarify the contribution of this study. Specifically, we now describe SCAM6's support for an active CLM5 land component and either prescribed or model-calculated surface fluxes (Gettelman et al., 2019), as well as E3SM SCM's existing interactive-land capability and its default use of prescribed fluxes when supplied in the case forcing file (Bogenschutz et al., 2020). We also discuss coupled land–atmosphere applications in the GABLS3 intercomparison (Bosveld et al., 2014) and the ARPEGE–SURFEX configuration of CNRM-CM6-1 (Bernard et al., 2025).

   We have clarified that our contribution is a reproducible initialization and simulation workflow for using interactive land coupling across both E3SM SCM and DP-SCREAM. This includes preparing spun-up ELM states and mapping the land subgrid hierarchy onto the doubly periodic domain, followed by paired prescribed-flux and interactive-land evaluations across multi-year hindcasts and targeted cloud and convection cases. We also revised wording that could imply that the underlying coupling capability itself is new.