Reviewer #2: The paper "Implementation of Multi-layer Snow Scheme in Seasonal Forecast System and Its Impact on Model Climatological Bias" evaluated the retrospective seasonal forecast performance of the Global Seasonal Forecast System (GloSea) version 5 (GloSea5, with a single-layer snow scheme) and version 6 (GloSea6, with a multi-layer snow scheme) over a 24-year period (1993-2016), focusing on the impacts of multi-layer snow scheme (GloSea6) versus single layer snow scheme (GloSea5) on the climatological biases of the seasonal forecast system. Results revealed that GloSea6 more accurately captures the snow phenology, elongating the snow melting season by two weeks, which improves the simulations of soil moisture, surface temperature, surface evaporation and subsequent land-atmosphere coupling regime in mid-to-high latitudes. This enhancement mitigates near-surface warming bias and improves precipitation simulation over snow-covered regions during late spring to summer. The authors attributed this improvement to the multi-layer snow scheme in GloSea6, yet more analyses are necessary to exclude other model physics updates (including atmosphere, ocean and sea ice) to support this conclusion.

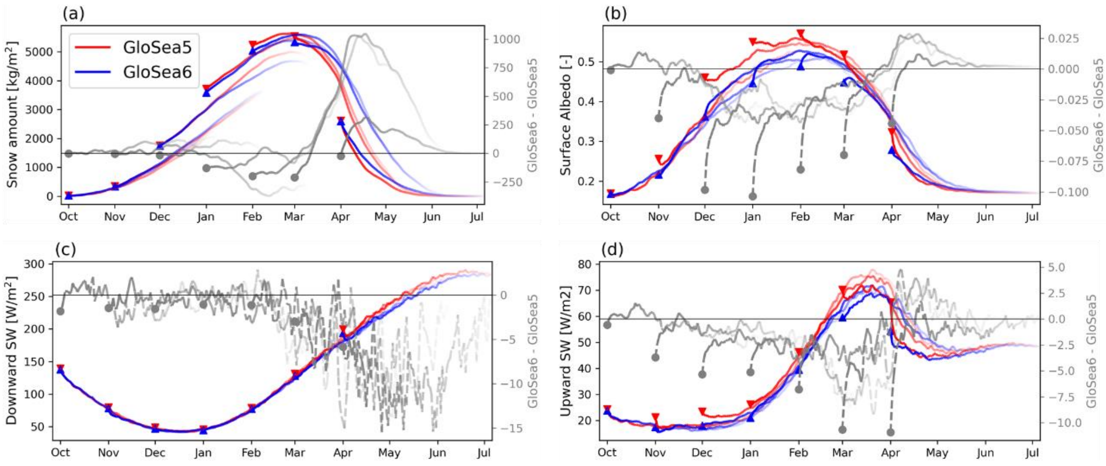
➔ *We thank the reviewer for the comments. We hope we have adequately clarified our descriptions and addressed the points raised.*

Major points:

Snow cover is important in land surface modeling, besides the treatment of snowpack in single layer or multi-layer scheme, snow surface albedo and snow cover fraction (the percentage of a model grid that is covered by snow) are pivotal factors that influence the accumulation and melting of snow cover in climate models. How about the difference in these two factors in GloSea5 and GloSea6?

➔ *As reviewer pointed out, snow cover fraction is also a pivotal factor that balances energy budgets at the land surface by influencing snow surface albedo. However, snow fraction is not included in the list of standard model output, so that it is alternatively estimated by the surface albedo calculated by upward and downward shortwave radiation at the surface. Below, figures (added to the supplementary figure 1) show that GloSea6 simulates more snow in early March, and surface albedo increases around the end of March, compared with the GloSea5. It results from upward shortwave radiation rather than downward component. In other words, increasing snow amount leads to an increase of surface albedo due to higher fractional snow cover at the land surface about 10 days later. The description about surface albedo has been added in Lines 265-267 with updated Fig. 1.*

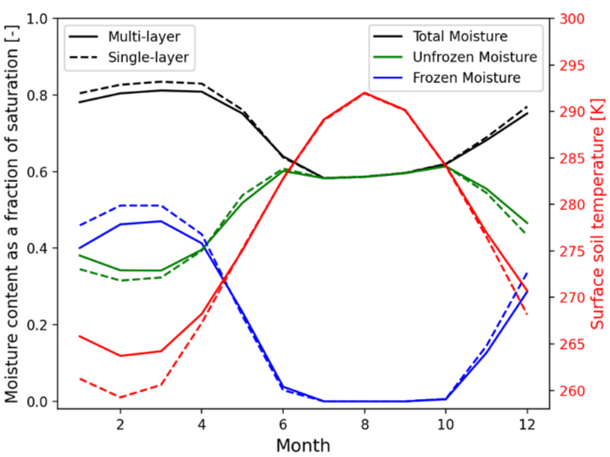
➔ ***"The multi-layer snowpack also extends the area of snow cover, which leads to the increased surface albedo, where increasing snow amount leads to an increase of surface albedo at the land surface about 10 days later (SFs. 1a,b)."***



Why are surface soil moisture (SSM) simulated in GloSea5 are more than those in GloSea6 from October to March but the situation reversed (i.e., GloSea5 SSM less than GloSea6) after April, although the initial snow amount are close to each other on April 1st (Figure1a,b)?

➔ *Multi-layer snowpack, which has a role of soil insulator, increases the soil temperature during winter season due to inhibiting thermal energy exchange between land and atmosphere, which results in the reduction of energy transport from land to the atmosphere. The warm soil temperature increases the ratio of unfrozen soil – this liquid water is mobile in the soil matrix, unlike soil ice, so that less soil moisture is simulated in GloSea6 from October to March. To demonstrate this process, we carried out two sets of JULES offline simulation using single or multi-layer snow scheme for 24 years (2000-2023), where near-surface atmospheric forcing variables are utilized by ERA5 reanalysis, but the precipitation is used from IMERG data. The bottom figure represents the climatological annual cycle of surface soil temperature and frozen and unfrozen moisture contents over the Eurasian continent (0–130E, 45–55N). The result exhibits the multi-layer snow scheme leads to increased soil temperature and the larger partitioning of unfrozen soil moisture along with more total content of soil moisture. The description is added in Lines 274-277*

"In contrast, GloSea6 simulates less soil moisture throughout the snow-covered season, although the initial soil moisture condition is similar in both simulations. The warmer soil temperature in GloSea6, induced by the snow insulation effect, increases the fraction of unfrozen soil moisture. Unlike soil ice, liquid water in the soil remains mobile, contributing to subsurface runoff and potentially evaporation, resulting in drier soil."



In line 270-271, the author claimed that the weaker insulating effect of the single-layer snow scheme leads to warmer surface temperature during thin (snow melting or freezing season) snow cover (figure 1c), in fact, during the freezing season from October to January when the air is colder than land surface, if the single-layer snow scheme provides a weaker insulating effect, it should lead to colder rather than warmer surface temperature. How to understand this contradiction?

➔ *Simply notating surface temperature confuses classifying surface soil and air temperature, so we add both results in Fig. 1c and 1d, respectively. During snow melting season, soil and air temperature in GloSea6 commonly become colder because the later onset of snow melting leads to abundant soil moisture. For the snow season, GloSea6 simulates warmer soil temperature and colder air temperature, which refers to that the multi-layer snow scheme hinders energy transport between near-surface atmosphere and the soil. During the snow peak season, the snow insulating effect also contributes to the increase of surface air temperature, but the direction is opposite. The warmer air during early spring cannot lose its heat to the soil due to insulation by the snowpack, allowing the air to remain warm. The main text has been modified to clarify the soil and air temperature responses in GloSea6 throughout snow freezing, peak, and melting seasons. The description is added in Lines 280-285*

"…the multi-layer snow scheme provides a stronger insulating effect, simulating significantly warmer soil temperature from snow cover onset through March, when air is colder than the land surface (Fig. 1c). In GloSea6, the colder surface air temperature during the snow freezing season is attributable to the energy interception between the air and the ground (Fig. 1d). The snow insulating effect also contributes to the higher air temperature during the peak snow season, limiting transfer of heat from air to soil due to the enhanced insulation by the multi-layer snowpack."

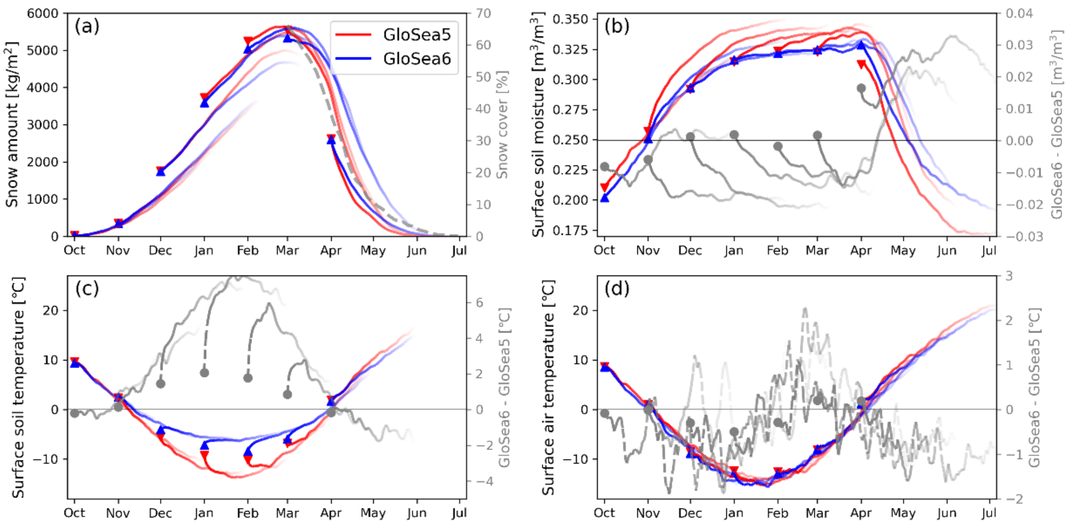


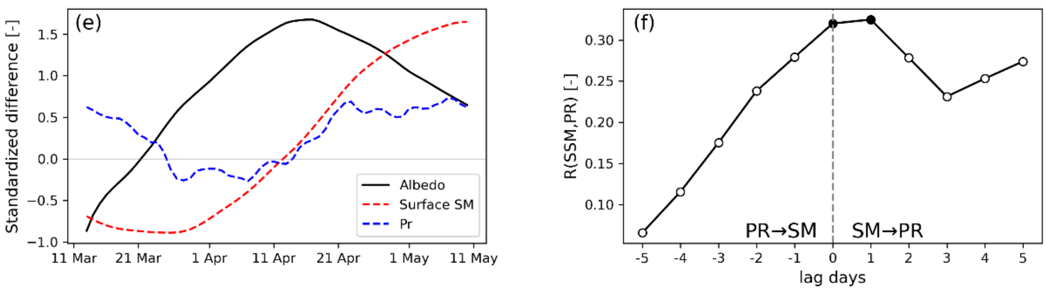
Figure2a shows that GloSea6 provides more surface soil moisture in mid-to-high latitudes of the northern Hemisphere, in addition to the positive evapotranspiration-precipitation feedbacks suggested by the authors (line 355), is it possible that the update in atmospheric physics in GloSea6 rather than the update of snowpack scheme from single layer to multi-layer results in more precipitation than GloSea5 in these regions (Figure 6a,b)?

➔ *To illustrate the physical sequence between land surface variables, we look into the climatology of 25-day running mean (removing high-frequency noises) time series of surface albedo and water budget terms in the runs initiated at each year of 1st March (Fig. 1e). On March 21, the* *surface albedo of GloSea6 becomes larger than that of GloSea5, and the increase in soil moisture due to the decrease in latent heat flux appears about 3 days later, and it can be confirmed that precipitation increases one day after the increase in soil moisture. Therefore, it can be confirmed that the change in snow melting due to the improvement in snow scheme sequentially affects other variables. This further description is added in Lines 287-291*

"To illustrate the physical sequence between land surface variables by the realization of snow physics, the time series of major water budget variables is compared between both simulations (Fig. 1e). The surface albedo of GloSea6 becomes larger than that of GloSea5 at the end of March, which results in increased soil moisture about 3 days after. The increase in soil moisture resulting from the reduction in latent heat flux, with a subsequent rise in precipitation begins after the soil moisture increase."

➔ *Moreover, to demonstrate the causality of the positive evapotranspiration-precipitation feedbacks, lead-lag correlation for the time series of the difference between GloSea5 and GloSea6 for surface soil moisture and precipitation is conducted (Fig. 1f). The highest lead-lag correlation coefficient is observed at +1 lead-lag day with statistically significant at a 99% confidence level. Therefore, the result demonstrates the abundant soil moisture over the mid-latitude areas in GloSea6 enable increasing precipitation. Of course, whether this is a realistic response for a global model with parameterized convection is a separate matter. The description is added in Lines 292-294*

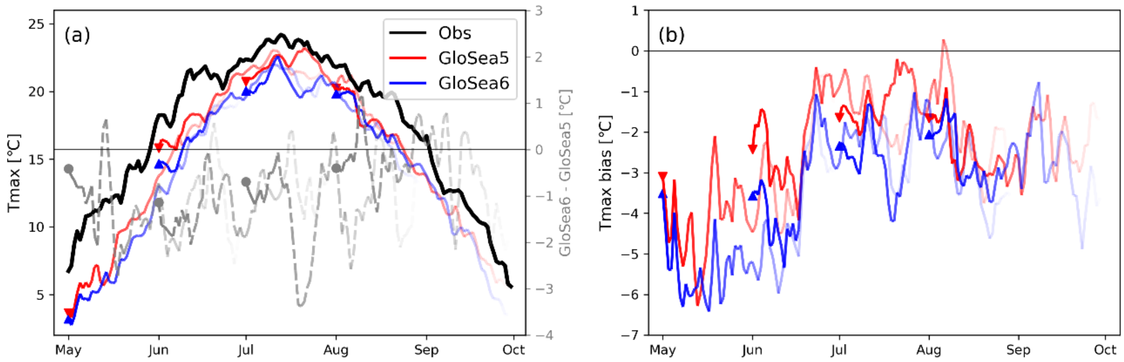
"The lead-lag correlation between soil moisture and precipitation shows statistically significant values at 0 and +1 lead-lag day and the 1-day lagged value is the highest (Fig. 1f). In other words, the increased soil moisture in mid-latitude regions due to snowmelt likely leads precipitation based on the positive evapotranspiration-precipitation feedback."



How to explain the deterioration of both bias and RMSE of Tmax and precipitation in GloSea6 with improved snow scheme in northeastern Eurasian continent (Figures 4e, 5f, 6f)?

➔ *In northeastern Eurasia, low Tmax and wet precipitation biases are observed in GloSea6. Although the positive bias of precipitation exists, as abundant soil moisture supplies enough moisture triggering convective rainfall, it does not significantly increase the RMSE of the modeled precipitation, however. On the other hand, the multi-layer snowpack has a cooling effect compared to the past zero-layer snow scheme, which further aggravates the cold bias observed in Glosea5 and significantly increases its RMSE. Thus, we look into the climatological seasonal cycle of Tmax over northeastern Eurasia (100-120E, 50-65N) (figure below). Comparing the observed seasonal cycle, GloSea5 and GloSea6 commonly represent systematic cold bias which is attributed by the initial condition problem. In particular, the colder initial states prescribed in GloSea6 exacerbate the cold bias. The description is added in Lines 374-376*

"However, some errors are aggravated in GloSea6. For instance, in northeastern Eurasia, Tmax RMSE is significantly increased by an exacerbated cold bias, which is related to a cold bias in initial condition (not shown). The multi-layer snowpack reinforces this bias in GloSea6."



Minor points:

Line 14 of the abstract, "permafrost extent" is not addressed in this study.

➔ *The permafrost extent is not covered in this study. It is not expressly quantified based on our research results, so that it is removed in the revised text and revised in Lines 13-15*

"In GloSea6, the snow melting season shifts two weeks later, delaying the onset of evaporation in the spring season. This slows soil moisture drying, resulting in the improvement in its climatology and memory."

Line 114, "single-layer snow scheme allows the surface layer of the atmosphere to directly access the heat in the soil" is not true when the snowpack is thick.

➔ *GL6, which is the LSM used in GloSea5, employs zero-layer scheme in which a single thermal store was used for snow and the first soil level, and an insulating factor was applied to represent the lower thermal conductivity of snow. The snow scheme itself included no representation of the thermal evolution of the snowpack. Because the past snow scheme has the single thermal store, we express it as "single-layer", but it has clearly led to some confusion. Thus, "single-layer" is replaced by "zero-layer" throughout the manuscript to avoid the confusion. Further description is added in Lines 114-117*

"In GloSea5, a zero-layer snow scheme permitted direct heat exchange between the surface layer of the atmosphere and the soil, utilizing a single thermal store for both the snow and the uppermost soil layer, with an insulating factor to account for the reduced thermal conductivity of snow. This scheme lacked a dynamic representation of snowpack evolution with the inadequate depiction of the snowpack's insulating properties."

Line 395, "(f)" should be "(c)".

➔ *Thanks for pointing out this typo. We correct it in the caption of Fig. 8.*

Line 412, “winch” should be “which”.

➔ *It is also corrected in the updated manuscript.*

The title of this paper can be modified to be more appropriate for its content.

➔ *This study mainly demonstrates the improvement of model’s climatological fidelity with the realization of land-atmosphere interactions by implementing multi-layer snow scheme. Based on reviewer’s suggestion, we modify the title of this paper to* ***“Improving land-atmosphere coupling in seasonal forecast system by implementing a multi-layer snow scheme”****.*