Response to Reviewer Comments

General comments:

This manuscript attempted to map the future afforestation distribution in China. This future afforestation distribution plays an important role in land-atmosphere interactions and carbon cycle research, but it hardly been obtained so far. The authors provided a technological roadmap to deal with it. Compared to previous idealistic and hypothetical afforestation scenarios, this study designed a plausible afforestation scenario due to considering the national afforestation plan. The study also did a relatively good job at dynamical downscaling of GCM outputs in terms of future climate projection. Overall, the study adopted a novel perspective and robust technique for identifying future potential afforestation domains.

I find that this paper is very intriguing and important and lots of additional work behind this study is worth further exploring. The manuscript could be accepted as I believe. On the other hand, I also have several minor comments. I hope that these comments can improve the manuscript. My comments are given below.

Response: We thank you for your interest in our study. These comments are valuable and very helpful for revising and improving our paper. We have studied the comments carefully and have made revisions to the revised version. I hope these major revisions meet with approval. The point-by-point responses to the reviewer's comments are as follows:

Specific comments:

Why is the SSP2–4.5 scenario selected? There are several shared socioeconomic pathways (SSPs) for future climate projections in the CMIP6. The study results may be dependent on the selection of SSPs. Why is the SSP2–4.5 scenario suitable for your studies?

Response: CMIP6 used a new scenario projection framework combined with the SSPs (i.e., SSP1-2.6, SSP2-4.5, SSP5-8.5). It is indeed that projected precipitation and temperature vary across the SSPs. Thus, the future forests suitable lands may be divergent. It is reported that the middle-of-the-road development (SSP2–4.5 scenario) represented the most likely development path to occur in China. Therefore, this study used the SSP2–4.5 scenario. In future, we can further compare the effects of different SSPs on the distribution of potential afforestation regions.

By comparing potential vegetation domain simulation with observation, some disagreement could be found. For example, in southern China, the observed subtropical forest expands northward up to 32°N. However, the simulation results reduce the extent. Given the bias in the WRF model simulation, why does this simulation still make sense?

Response: In this study, the main role of the WRF simulation is to identify the extent of forest suitable land. In order to reduce the effect of the WRF simulation, this study has corrected the bias of the lateral boundary conditions. Compared with the actual forest pattern, the WRF simulation could reproduce the distribution of potential forest regions in China well. Compared to the national afforestation plan, the bias in the extent of forest suitable land due to WRF simulation has a small impact on the results of this study.

This study only used an MPI–ESM1–2–HR model as the lateral boundary of WRF model. It may fail to obtain robust future climate projections. The NEX-GDDP-CMIP6 (NASA Earth eXchange Global Daily Downscaled Projections CMIP6 Data) datasets contain multiple GCMs and SSPs with a spatial resolution of 0.25° × 0.25°, which is approximate same with this study of 25- by 25-km. Why not use this dataset? The relevant reference is "Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., & Nemani, R. (2022). NASA global daily downscaled projections, CMIP6. Scientific Data, 9(1), 262."

Response: Thank you for bringing this recent study to our attention. The NEX-GDDP-CMIP6 datasets are developed by the statistical downscaling algorithm. Compared to the NEX-GDDP-CMIP6 datasets, the dynamic downscaling climate data (i.e., WRF model output) has the advantage of keeping physical consistency constraints between variables such as the hydrostatic equilibrium and geostrophic wind balance. Thus, dynamical downscaling climate data is used in this study. The discussion on the statistical downscaling was included in the revision, as follows:

Although the resolution of our dynamical downscaled simulation (25 km) is finer than raw GCMs (~100 km), it is difficult to meet the needs of afforestation planning in areas with complex topography. Convection-permitting climate modelling at the kilometre-scale has recently been developed to reproduce better mesoscale atmospheric processes (Prein et al., 2015; Lucas-Picher et al., 2021), and obviously improve the WRF simulation, especially precipitation (Knist et al., 2020).

However, increasing the resolution of the simulation implies higher computational costs. In contrast, statistical downscaling methods are also known to obtain high-resolution climate data with fewer computational resources (Tang et al., 2016). It assumes that the historical relationship between local climate variables and the large-scale circulation remains fixed in the future term (Wilby and Dawson, 2013). The multi-model ensemble means from the CMIP6 statistical downscaling can significantly reduce the biases compared to individual models (Gebrechorkos et al., 2019). Thus, some statistical downscaled CMIP6 datasets (Gebrechorkos et al., 2023; Lin et al., 2023; Thrasher et al., 2022), with a resolution of 0.1°-0.25° covering the global land, can be applied to explore the future global potential afforestation area in following work. However, it is noted that the statistically downscaling data may have a limitation, as the covariance among the variables may not align with physical laws.

References

Prein, A. F., Langhans, W., Fosser, G., Ferrone, A., Ban, N., Goergen, K., et al. (2015). A review on regional convection-permitting climate modeling: Demonstrations, prospects, and challenges. Reviews of Geophysics, 53(2), 323-361.

Lucas-Picher, P., Argüeso, D., Brisson, E., Tramblay, Y., Berg, P., Lemonsu, A., et al. (2021). Convection-permitting modeling with regional climate models: Latest developments and next steps. Wiley Interdisciplinary Reviews: Climate Change, 12(6), e731.

Knist, S., Goergen, K., & Simmer, C. (2020). Evaluation and projected changes of precipitation statistics in convection-permitting WRF climate simulations over Central Europe. Climate Dynamics, 55(1-2), 325-341.

Tang, J., Niu, X., Wang, S., Gao, H., Wang, X., & Wu, J. (2016). Statistical downscaling and dynamical downscaling of regional climate in China: Present climate evaluations and future climate projections. Journal of Geophysical Research: Atmospheres, 121(5), 2110-2129.

Wilby, R. L., & Dawson, C. W. (2013). The statistical downscaling model: insights from one decade of application. International Journal of Climatology, 33(7), 1707-1719.

Gebrechorkos, S., Hülsmann, S., & Bernhofer, C. (2019). Regional climate projections for impact assessment studies in East Africa. Environmental Research Letters, 14(4), 044031.

Gebrechorkos, S., Leyland, J., Slater, L., Wortmann, M., Ashworth, P. J., Bennett, G. L., et al. (2023). A high-resolution daily global dataset of statistically downscaled CMIP6 models for climate impact analyses. Scientific Data, 10(1), 611.

Lin, H., Tang, J., Wang, S., Wang, S., & Dong, G. (2023). Deep learning downscaled high-resolution daily near surface meteorological datasets over East Asia. Scientific Data, 10(1), 890.

Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., & Nemani, R. (2022). NASA global daily downscaled projections, CMIP6. Scientific Data, 9(1), 262.

From Figure 6c to Figure 7, you further constrained the afforestation area through the total precipitation. Precipitation is important but not the only determinant of afforestation allocation. More other factors may be needed to be considered.

Response: We agree with this comment. In the revised manuscript, the HLZ value as a comprehensive indicator has been used to quantify the climatology suitability for afforestation. Areas with a low HLZ value are allowed priority afforestation. Because a low HLZ value means a greater opportunity to be potential forestlands. Following this new method, we find that the probable locations for future potential afforestation areas in China are around and to the east of the Hu Line.

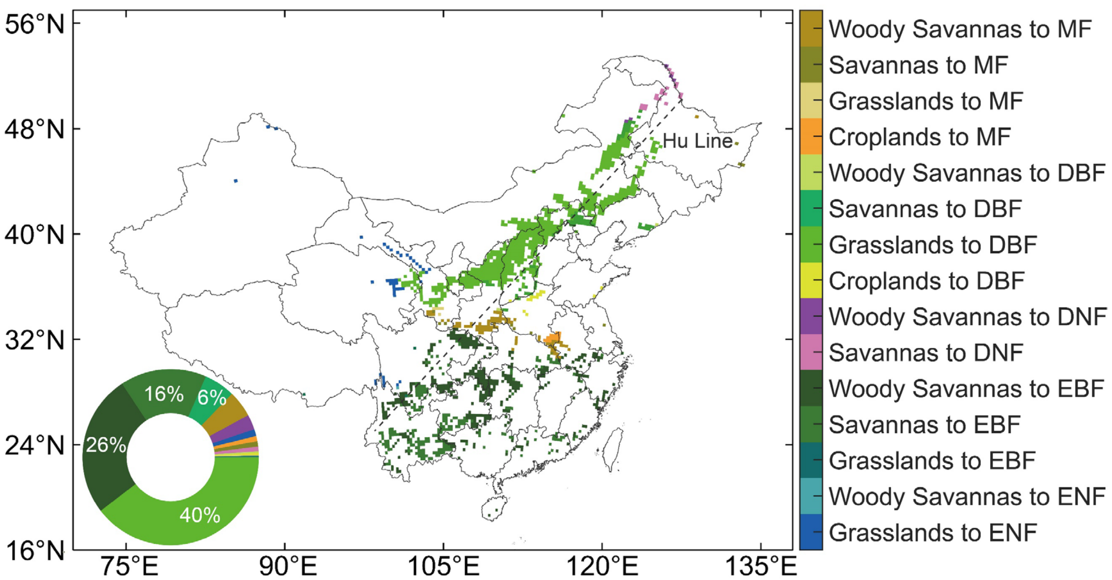

Figure 1: Map of future potential afforestation distribution under constraining of national afforestation planning total area and future climate changes and the afforestation-induced vegetation types conversions. Forest types from IGBP include Evergreen Needleleaf Forests (ENF), Evergreen Broadleaf Forests (EBF), Deciduous Needleleaf Forests (DNF), Deciduous Broadleaf Forests (DBF), and Mixed Forests (MF). The black dotted line indicates the Hu Line.

It's not clear that "This bias-corrected approach was applied to the variables such as air temperature, specific humidity, zonal wind, meridional wind, geopotential height, etc." in Line 121. In addition to these five meteorological variables, were there other variables bias-corrected? More detail please.

Response: In fact, there are a total of 16 bias-corrected variables. These include five atmospheric fields, i.e. air temperature, specific humidity, zonal wind, meridional wind, geopotential height, and eleven surface fields, i.e. surface temperature, sea-surface temperature, surface pressure, sea ice cover, sea-level pressure, soil temperature, soil moisture, near-surface temperature, relative humidity, zonal and meridional wind.

The authors need to add more descriptions of the future potential afforestation distribution and shift types (Figure 7). It seems that this part of the manuscript is too short.

Response: We have expanded this description as follows:

The findings show that the probable locations for future potential afforestation areas in China would be around and to the east of the Hu Line. Due to afforestation, the land cover would be modified. In northern China, the dominant conversion is from grasslands to deciduous broadleaf forests. Such conversion is also the most dominant land use change due to afforestation. It accounts for 40 % of the newly afforestation area. In detail, among the provinces in northern China, the largest conversion from grassland to deciduous broadleaf forest may occur in Shanxi and Shaanxi. In southwest China, the dominant conversions are from woody savannas and savannas to evergreen broadleaf forests. These conversions account for 26 % and 16% of the newly afforestation area, respectively. These land use conversions are majorly located in southwest China, such as Yunnan province, Sichuan province, and Guizhou province.

In line 209, here, it is stated that the cropland does not encroach on afforestation. However, Figure 7 shows that the shift types include croplands to MF and croplands to DBF. Is that a contradiction here? This should be commented.

Response: We have revised the manuscript. In the revision, the criteria for identifying potential afforestation areas were changed to minimize encroachment on cropland. If the historical grassland, savannas and woody savannas do not meet the demand of the national afforestation plan, we just consider encroachment on the cropland. The result shows that a small amount of cropland has been scheduled for afforestation to meet the national afforestation requirement. Overall, 1.88 billion mu croplands in China are still available for cultivation. It is also away from the protection 'red line' of 1.865 billion mu, released by the National Land Planning Outline (2016–2030) (State Council of China, 2017).

In line 292, "We exclude some ineligible regions, including present forestland, cropland, urban, wetland, and water bodies based on the 2020 MCD12Q1 land cover data". This sentence is repeated. The definition of "historical open space regions" has been clarified in section 2.2.3.

Response: In the revision we deleted it.

Line 114. The presentation on the ERA5 dataset is too short. Which meteorological variables are used in the study? What is the time scale and spatial extent?

Response: In the revision, we introduced more detail about EAR5 as follows:

The ERA5 reanalysis data is the fifth generation global reanalysis product developed by the European Centre for Medium-range Weather Forecast (ECMWF) (Hersbach et al., 2020). The state-of-the-art reanalysis data assimilates multi-source data including ground-based meteorological measurements data, satellite-observed data, and atmospheric sounding data based on 4D-var ensemble data assimilation system (Hersbach et al., 2020). The 6–hourly ERA5 reanalysis data with a spatial resolution of 1.0°×1.0° from 1994 to 2014 was also used as the lateral boundary conditions. The related meteorological variables for the MPI–ESM1–2–HR model and ERA5 reanalysis data included atmospheric fields (air temperature, specific humidity, zonal wind, meridional wind, geopotential height) and surface fields (i.e., sea-surface temperature, sea ice cover, soil temperature and soil moisture, etc.).

Reference

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., et al. (2020). The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), 1999-2049.

Technical corrections:

Line 100 – “Climate Modelling” replace “Climate modelling”.

Response: It is revised.

Table 1 – Give specific model top pressure.

Response: We have added it. The model top pressure is 50hPa in this study.

Line 125 – Check the Equation (2).

Response: We apologize for this mistake. We have corrected the Equation (2):

$$F_{cor} = D_{GCM\_F} \times \frac{SD_{ERA}}{SD_{GCM}} + M_{ERA} + \left(M_{GCM\_F} - M_{GCM\_H}\right) \quad (2)$$

Line 393– “Woody savannas” -> “woody savannas”

Response: Done.

Line 76 – “The fourth section will be the discussion.”

Response: We have refined it as follows:

The discussion and conclusions are summarized in sections four and five.

Table 1 – This should be “Initial and lateral boundary conditions”

Response: It is revised.

Line 14 – 7. In the abstract section, the abbreviation (WRF) should be the full name. Make sure the reader understandings.

Response: All full name is presented in the captions in revision.

Table 1 – “ERA5 analysis” -> “ERA5 reanalysis”

Response: Done.

Line 102– "CMIP6". Add full name.

Response: The full name is the Coupled Model Intercomparison Project 6 (CMIP6).

Line 17– "SSP". Add full name.

Response: The full name is the shared socioeconomic pathways (SSP).

Line 20– "occur" -> "be located"

Response: It is revised.

Line 54– "employ" -> "employed"

Response: Done.

Line 74– "the total area afforestation" -> "the total afforestation area"

Response: Done.

Line 83– "from 1995–2014" -> "from 1995 to 2014"

Response: It is revised.

Line 89– "features" -> "featured"

Response: Done.

Line 378– "historical periods" -> "historical period"

Response: Done.