Responses to Referee #2

We appreciate the detailed and constructive feedback provided by the anonymous reviewer, which has been valuable in enhancing the manuscript. The reviewer's comments are categorized into main comments and those directly on the manuscript. We respond to both categories, with reviewer comments in shaded text and our responses in black.

General comment:

This manuscript conducts a set of WRF-Noah simulations to examine the impacts of historical land use and land cover change (LULCC) and potential agriculture expansion in the future. By comparing historical, control, and future cases, this work illustrates the drying climatology and land conditions (e.g., warming surface temperature and decreased precipitation and soil moisture). However, several problems and limitations exist; thus, a major point-to-point revision is needed. For example, at least several months of spin-up are needed to initialize the soil moisture and allow the surface fluxes to respond to LULCCs; however, the manuscript doesn't mention if the authors spin up the WRF-Noah before the formal runs. Also, the authors haven't confirmed if WRF-Noah can simulate the specific mechanisms discussed. For example, the authors should confirm if WRF-Noah can resolve the remote effects of LULCC.

We acknowledge the reviewer's comment. First, we should clarify that our experiments do have an 11-month spin-up period that was dismissed from the analysis, ensuring the stabilization of all variables. Our simulations span from Jan 2014 to July 2016, with a specific focus on the austral summer season (DJF), encompassing the 2014/2015 and 2015/2016 summers. The validation of the CONTROL ensemble involves a comparison of simulated and observed variables for the entire period, including the spin-up months. The updated version of this section's plots will incorporate the ensemble member dispersion. This addition provides a clear illustration of how our model simulations rapidly stabilize their values within the first month of simulation, particularly notable for soil variables that traditionally take longer to reach equilibrium. Further details on this aspect can be found in our response to comment 3 of Data, model, and experiments.

Unlike typical land surface or hydrologic models, climate models do simulate non-local effects of LULCC. Land surface models (LSMs), in our case Noah-MP, solve equations in isolated columns. However, they play a crucial role by providing the boundary conditions in all time-steps to the atmospheric component of the climate model, where the grid volumes are completely connected. Thus, LULCCs have a direct and immediate local impact on the soil, modifying the surface fluxes, which in turn, are able to alter the local and non-local atmospheric variables, influenced by the atmospheric dynamics.

In summary, climate models stand as the ideal and singular tool capable of unraveling the intricate chain of processes affected by changes in initial and boundary conditions, an analysis that cannot be replicated using observed data or reanalysis.

This is explained in more detail in our response to comment 7 of “Data, model, and experiments”.

Comments about Introduction:

1) The introduction lacks enough paper review. For example, Georgescu et al. (2013) also use WRF to simulate the LULCC over South America.

We will enhance the entire literature review in the introduction section by incorporating relevant publications, such as:

Barros, V. R., Boninsegna, J. A., Camilloni, I. A., Chidiak, M., Magrín, G. O., and Rusticucci, M. (2015). Climate change in Argentina: trends, projections, impacts and adaptation. *WIREs Clim. Change*, *6*(2), 151-169.

Bulacio, E.M., Romagnoli, M., Otegui, M.E., Chan, R.L., and Portapila, M. (2023). OSTRICH-CROPGRO multi-objective optimization methodology for calibration of the growing dynamics of a second-generation transgenic soybean tolerant to high temperatures and dry growing conditions. *Agric. Syst.*, *205*, 103583.

De Sy, V., Herold, M., Achard, F., Beuchle, R., Clevers, J.G., Lindquist, E., and Verchot, L. (2015). Land use patterns and related carbon losses following deforestation in South America. *Environ. Res. Lett.*, *10*(12), 124004.

Georgescu, M., Lobell, D.B., Field, C. B., and Mahalov, A. (2013). Simulated hydroclimatic impacts of projected Brazilian sugarcane expansion. *Geophys. Res. Lett.*, 40(5), 972-977.

Li, D., Bou-Zeid, E., Barlage, M., Chen, F., and Smith, J. A. (2013). Development and evaluation of a mosaic approach in the WRF-Noah framework. *J. Geophys. Res. Atmos.*, 118(21):11–918.

Maertens, M., De Lannoy, G.J.M., Apers, S., Kumar, S.V., and Mahanama, S.P.P. (2021). Land surface modeling over the Dry Chaco: the impact of model structures, and soil, vegetation and land cover parameters. *Hydrol. Earth Syst. Sci.*, 25, 4099–4125.

Mosciaro, M.J., Calamari, N.C., Peri, P.L., Flores Montes, N., Seghezzo, L., Ortiz, E., Rejalaga, L., Barral, P., Villarino, S., Mastrangelo, M., Volante, J. (2022). Future scenarios of land use change in the Gran Chaco: how far is zero-deforestation?. *Reg. Environ. Change.,* 22, 115.

Ribichich, K.F., Chiozza, M., Ávalos-Britez, S., Cabello, J.V., Arce, A.L., Watson, G., Arias, C., Portapila, M., Trucco, F., Otegui, M.E., and Chan, R.L. (2020). Successful field performance in warm and dry environments of soybean expressing the sunflower transcription factor HB4. *J. Exp. Bot.*, *71*(10), 3142-3156.

Richards, P.D., Myers, R.J., Swinton, S.M., and Walker, R.T. (2012). Exchange rates, soybean supply response, and deforestation in South America. *Glob. Environ. Change*, *22*(2), 454-462.

Stanimirova, R., Graesser, J., Olofsson, P., and Friedl, M. A. (2022). Widespread changes in 21st century vegetation cover in Argentina, Paraguay, and Uruguay. *Remote Sens. Environ.*, *282*, 113277.

This revision will improve the context and provide a more comprehensive overview of the relevant research.

2) The impacts of LULCCs have been widely studied in WRF. For example, Lee et al. (2012) had a similar experiment design, study region, and results. Therefore, the authors should emphasize their novelty and new insights compared with previous studies.

We appreciate the reviewer's observation and acknowledge the antecedent work of Lee and Berbery (2012). Indeed our work advances on those results, now providing new insights into a specific ecoregion. It's essential to highlight the distinctiveness and advancements offered by the current study in comparison. Specifically:

Study Region and temporal scope: Our focus extends beyond the La Plata Basin to the Gran Chaco, which is recognized as one of the most threatened ecoregions in South America concerning agricultural expansion rates. Moreover, our study spans a comprehensive 30-month period (2014-2016), providing a more extensive analysis of the impacts of land use and land cover changes (LULCCs) over time compared to the 3-month simulations in 2002 by Lee and Berbery (2012).

Experiment Design: While Lee et al. considered extreme LULCCs (all natural vegetation, all crops), our study considers both observed and realistic expansions of LULCCs, offering a nuanced understanding of the actual and potential impacts on regional climate.

Novel Insights: By considering more realistic scenarios, it is possible to hypothesize how agricultural expansion in one region influences the hydroclimate of another, which is crucial for effective regional land use planning on a topic prone to developing socio-ecological conflicts associated with LULCCs. This focus on uncovering the processes behind such remote effects is a relatively unexplored aspect in existing literature, making our study particularly novel and relevant.

In summary, our study contributes valuable insights into the hydroclimate patterns arising from LULCCs, providing a clearer perspective on the potential outcomes of agricultural expansion in Dry Chaco over the entire Gran Chaco. We believe these distinctions underscore the significance and originality of our work in advancing the current understanding of regional climate dynamics impacted by land use changes.

3) Because the results are all derived from WRF-Noah, the author should introduce how WRF-Noah simulates land-use changes and discuss its limitations. For example, which processes can be resolved, and which cannot.

The Noah-MP LSM assigns a dominant land cover type to each grid point, and this assignment remains constant over time (Li et al., 2013). In turn, each land cover is associated with a set of 15 biophysical properties. The properties can either be values fixed on time or can vary seasonally or dynamically when vegetation dynamics is activated. Our simulations enable vegetation dynamics, i.e., the model simulates changes in vegetation properties, such as leaf area index (LAI), surface roughness, and other land surface characteristics, as they naturally evolve over the simulated period due to seasonal changes and vegetation growth cycles. These dynamic properties allow the model to capture the seasonality of vegetation and its impact on land-atmosphere interactions. By default, the model employs the land cover map derived from the Moderate Resolution Imaging Spectroradiometer (MODIS), which classifies the land cover following the 20 categories proposed by the International Geosphere-Biosphere Programme (IGBP). **Then, the land cover changes in our experiments are implicitly imposed by the**

change of land cover map among the various ensembles. It is worth noting that other studies for different regions of the world have applied a similar approach with WRF to assess the impact of LULCCs on the overlying atmosphere (e.g. Lal et al. 2021, Flanagan et al. 2021).

Noah-MP comprises four soil layers with a thickness from top to bottom of 10, 30, 60 and 100 cm (2 m total depth), and includes representations of the root zone, vegetation categories, monthly vegetation fraction, soil texture, among others. It simulates soil moisture, soil temperature, skin temperature, canopy water content, and the energy flux and water flux terms of the surface energy balance and surface water balance. Different options of schemes for various physical processes that are key in the soil-atmosphere interaction, are available in Noah-MP. These processes include dynamic vegetation; canopy interception; soil moisture factor controlling stomatal resistance, *b* Factor; runoff and groundwater; surface exchange coefficient for heat; and radiation transfer. The vegetation and soil components are closely coupled and interact with each other via complex energy, water, and biochemical processes. The recent publication of He et al. (2023) describes in detail the above processes, including equations and schematic diagrams.

To enhance clarity, we will provide a concise overview of the WRF/Noah-MP representation of land cover, simulated processes, and associated limitations in the revised section “The WRF model and its configuration”. The description of observed and imposed LULCCs is already detailed in the experiments’ description.

Flanagan, P.X., Mahmood, R., Sohl, T., Svoboda, M., Wardlow, B., Hayes, M., and Rappin, E. (2021). Simulated Atmospheric Response to Four Projected Land-Use Land-Cover Change Scenarios for 2050 in the North-Central United States. *Earth Interact.*, *25*(1), 177-194.

Lal, P., Shekhar, A., and Kumar, A. (2021). Quantifying temperature and precipitation change caused by land cover change: a case study of India using the WRF model. *Front. Environ. Sci.*, *9*, 766328.

Li, D., Bou-Zeid, E., Barlage, M., Chen, F., and Smith, J. A. (2013). Development and evaluation of a mosaic approach in the WRF-Noah framework. *J. Geophys. Res. Atmos.*, 118(21):11–918.

He, C., Valayamkunnath, P., Barlage, M., Chen, F., Gochis, D., Cabell, R., Schneider, T., Rasmussen, R., Niu, G.-Y., Yang, Z.-L., Niyogi, D., and Ek, M. (2023). Modernizing the open-source community Noah with multi-parameterization options (Noah-MP) land surface model (version 5.0) with enhanced modularity, interoperability, and applicability. *Geosci. Model Dev.*, 16(17), 5131-5151.

Comments about Data, model, and experiments:

1) Ln 130, the authors should explain why this change is unreasonable instead of simply providing two references without elaboration.

The identification of a change as being unreasonable or illogical derives from Cai et al. (2014)’s study. In that article, a land cover transition is defined as illogical if it contradicts ecological rules and is therefore unlikely to be observed. (For example, if you have bare soil, you would not expect to have a full-grown tree the following year.)

In our case, the statement about the changes from savanna and woody savanna to deciduous broadleaf forests in a short period (14 years) being unthinkable in the real world is based on ecological understanding. Savanna and woody savanna ecosystems typically undergo gradual transitions over extended time frames due to ecological processes. The rapid and natural conversion to deciduous broadleaf forests contradicts established ecological dynamics and is likely an artifact of the computation algorithms of land cover maps. Following the cited references (Liang and Gong, 2010; Cai et al., 2014) support our skepticism about the observed changes. Moreover, Cai et al. (2014) identify Gran Chaco as a region with a high frequency of illogic transitions. To provide a more detailed explanation, we will further elaborate on the ecological implausibility of such rapid transformations in the revised manuscript.

Cai, S., Liu, D., Sulla-Menashe, D., and Friedl, M.A. (2014). Enhancing MODIS land cover product with a spatial–temporal modeling algorithm, *Remote Sens. Environ.*, 147, 243-255.

Liang L, and Gong, P.: An assessment of MODIS Collection 5 global land cover product for biological conservation studies (2010). In: 2010 18th international conference on geoinformatics, Beijing, China, 18–20 June 2010, pp 1–6.

2) Ln 133, for a 1-year WRF simulation or longer simulations, nudging is often needed to constrain the simulation; however, the authors didn't discuss their choice of nudging.

A lateral boundary relaxation zone spanning ten grid-points was implemented, and spectral nudging within the domain was intentionally omitted to allow the atmosphere more freedom in responding to surface forcing (Pohl and Crétat, 2014). We recognize the significance of nudging in studies aiming to mitigate regional model drifts from the spatial scales of the forcing global reanalysis, thereby enhancing downscaled climate outcomes and constraining internal variability within the regional model (e.g., Miguez-Macho et al. 2005; Radu et al., 2008; Alexandru et al. 2009). In our case, nudging was not considered to allow the free evolution of variables, as impacted by surface processes. Despite the absence of nudging in our simulations, it is noteworthy that minimal internal variability is observed in the simulated variables, as demonstrated in the updated Figs. 5d, 6g, 7d, which now include a surrounding band illustrating the spread of ensemble members around the mean. This will be clarified in the revised manuscript.

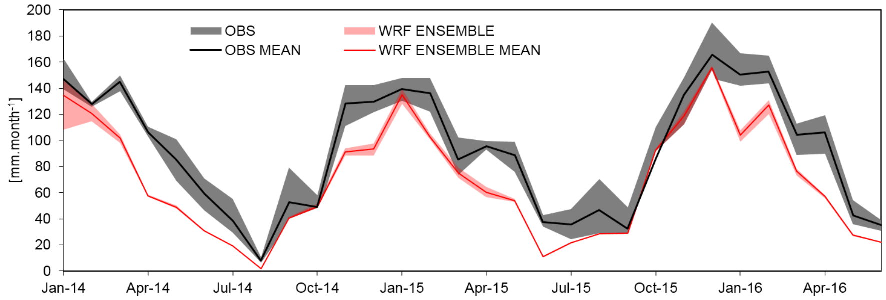

Figure 5d. Precipitation time-series averaged in the Gran Chaco region.

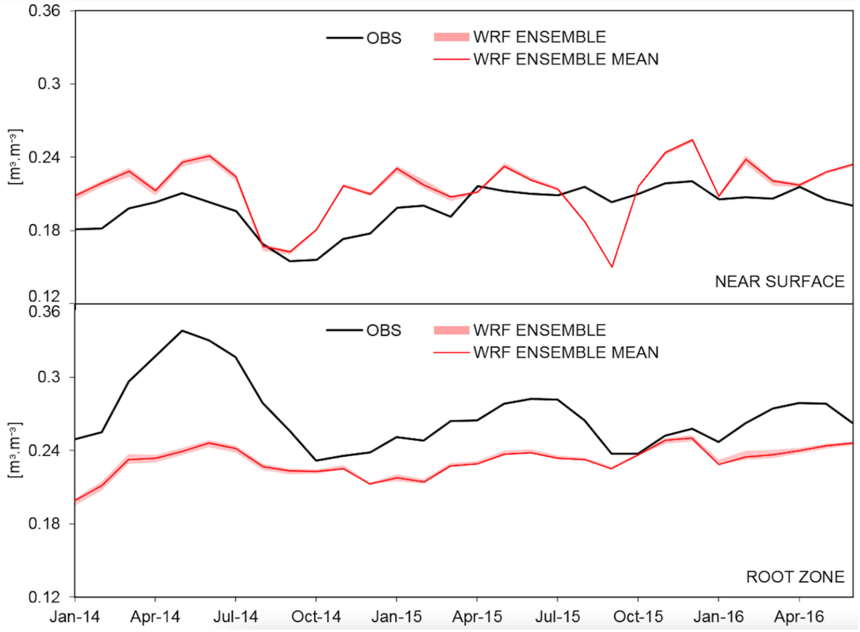

Figure 6g. Soil moisture time-series averaged in the Gran Chaco region.

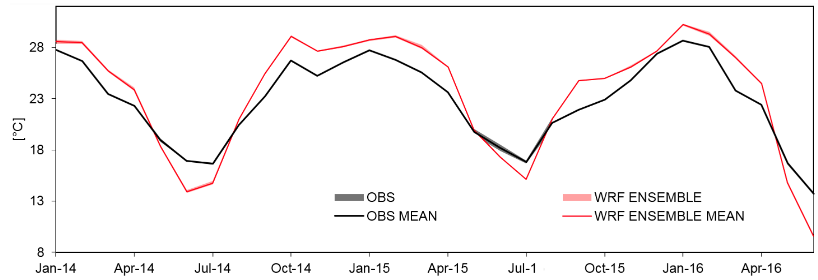

Figure 7d. Near-surface temperature time-series averaged in the Gran Chaco region.

Alexandru, A., de Elía, R. Laprise, R. Separovic, L. and Biner, S. (2009). Sensitivity study of regional climate model simulations to large-scale nudging parameters. *Mon. Wea. Rev.*, 137, 1666– 1686.

Pohl, B., and Crétat, J. (2014). On the use of nudging techniques for regional climate modeling: Application for tropical convection. *Climate Dyn.*, 43, 1693–1714.

Miguez-Macho, G., Stenchikov, G.L. and Robock, A. (2005). Regional climate simulations over North America: Interaction of local processes with improved large-scale flow. *J. Climate*, 18, 1227–1246

Radu, R., Déqué, M. and Somot, S. (2008). Spectral nudging in a spectral regional climate model. *Tellus*, 60A, 898–910.

3) Ln 133, to initialize the land processes, at least six months of spin-up is needed, and the soil system usually takes longer (Jerez et al. 2019). It seems the authors did not use any spin-up periods.

Regarding the initialization of land processes, we appreciate the reviewer's concern. As clarified in our response to the general comment, a spin-up period of 11 months was employed for the evaluation of summer seasons, ensuring the attainment of equilibrium for soil variables. The validation of the CONTROL ensemble encompasses the entire simulation period, including the spin-up months. The updated Figures 5d, 6g, and 7d illustrate that simulated variables quickly stabilize within the first month of simulation, a noteworthy observation, especially for soil variables that conventionally require more time to reach equilibrium. The rapid stabilization of soil moisture can be attributed to our simulations starting during the wet season, where differences between the initial soil moisture state and the equilibrium state are minimal. A comparable approach was undertaken in a prior study (Sörensson and Berbery, 2015), specifically examining soil moisture stabilization by initializing simulations in all months of the year. The spin-up period will be clarified in the revised "Experimental Design" section, while the stabilization time shown by our simulations will be discussed in the new "Discussion" section.

Sörensson, A.A., and Berbery, E.H. (2015). A note on soil moisture memory and interactions with surface climate for different vegetation types in the La Plata basin. *J. Hydrometeorol.*, 16(2), 716-729.

4) Ln 150, the simulation period (less than two years) is not long enough to sample the impacts of modes of variability such as MJO, thus preventing this work from getting more robust conclusions.

Note that the simulation period is 30 months long (2.5 years). This should suffice for assessing the land-atmosphere processes, which occur on shorter time scales. Conducting simulations spanning 10 years or more would provide information on large-scale modulations but would not provide new understanding of the surface processes. On the other hand, it is important to note that the Gran Chaco region, our focus of interest, exhibits minimal sensitivity to large-scale phenomena such as the Madden Julian Oscillation (MJO) and the El Niño Southern Oscillation (ENSO). In particular, Grimm (2019) demonstrates that the various MJO modes strengthen precipitation anomalies in central east and southeast South America summers, while non-significant small anomalies are found in our region of interest. Regarding ENSO, the simulation period includes an El Niño event, developed between Sep 2014 and March 2016. However, Cai et al. (2020) shows the insensitivity of Gran Chaco to ENSO phases. Moreover, Vera and Osman (2018) reported that the impact of the El Niño 2015 event has been weakened by the Southern Annular Mode (SAM). In light of these findings, the revised manuscript will explicitly specify the prevalent atmospheric conditions (ENSO, SAM, MJO) during the simulation period, emphasizing their minimal influence on the Gran Chaco region.

Cai, W., McPhaden, M.J., Grimm, A.M., Rodrigues, R.R., Taschetto, A.S., Garreaud, R.D., Dewitte, B., Poveda, G., Ham, Y.-G., Santoso, A., Ng, B., Anderson, W., Wang, G., Geng, T., Jo, H.-S., Marengo, J.A., Alves, L.M., Osman, M., Li, S., Karamperidou, C., Takahashi, K., and Vera, C. (2020). Climate impacts of the El Niño–southern oscillation on South America. *Nat. Rev. Earth Environ.*, *1*(4), 215-231.

Grimm, A.M. (2019). Madden–Julian Oscillation impacts on South American summer monsoon season: precipitation anomalies, extreme events, teleconnections, and role in the MJO cycle. *Clim. Dyn.*, 53(1-2), 907-932.

Vera, C.S., and Osman, M. (2018). Activity of the Southern Annular Mode during 2015–2016 El Niño event and its impact on Southern Hemisphere climate anomalies. *Int. J. of Climatol.*, *38*, e1288-e1295.

5) Ln 171, more widely used datasets such as ERA5 (precipitation, temperature, and soil moisture) and GLDAS (soil moisture) are worth using in evaluation.

We appreciate the reviewer's suggestion. For atmospheric variables (precipitation and temperature), we have chosen gridded observation datasets such as CPC and CRU, widely utilized in the literature. In response to the recommendation, we will replace WFDEI with ERA5 in the updated plots, as ERA5 is a well-recognized reanalysis dataset.

Regarding soil moisture, GLDAS ingests various observational data sources into land surface models to generate its datasets, with most products focusing on meteorological fields. Notably, it lacks an assimilation of soil moisture data. Thus, the comparison between soil moisture from WRF/Noah-MP simulations and GLDAS remains limited to a comparison of two models. For this reason and considering the lack of in-situ soil moisture measurements in Gran Chaco, we consider that the use of satellite-based products, like SMOPS and HSAF, is more adequate for validation purposes.

Comments about Experiments' results:

We provide a specific response to each comment in this section. We would like to note that:

a) in this section, we focus on the description of the experiments' results, while plausible interpretation of the processes behind the changes is offered in the Discussion section;

b) it is always a challenge to elucidate the processes that explain a specific change in a given variable due to the several factors acting together, as shown in the Fig. R2.1,

c) thus, our goal is to identify the most relevant mechanisms that explain the effects of LULCCs in Gran Chaco hydroclimate, while acknowledging that other processes may also have certain impact on our results.

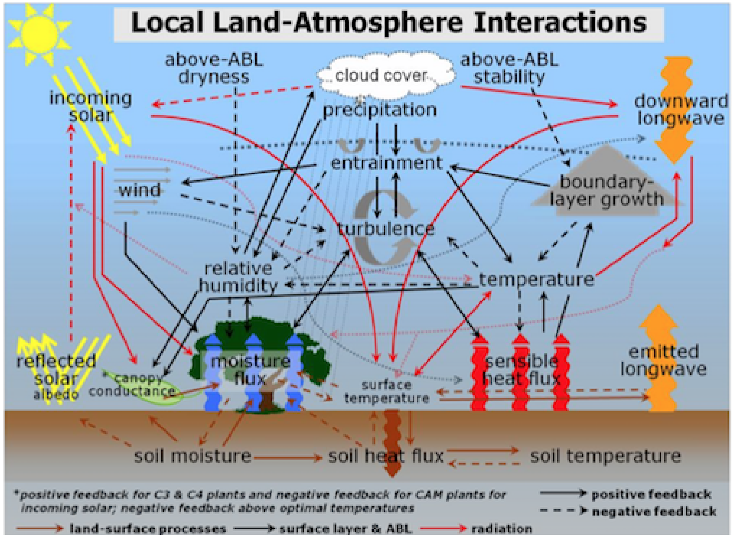

Figure R2.1. Schematic diagram of land-atmosphere interactions (from Santanello et al. 2018).

Santanello, J.A., Dirmeyer, P.A., Ferguson, C.R., Findell, K.L., Tawfik, A.B., Berg, A., Ek, M., Gentine, P., Guillod, B., van Heerwaarden, C., Roundy, J., and Wulfmeyer, V. (2018). Land–atmosphere interactions: The LoCo perspective. *BAMS*, 99(6), 1253-1272.

1) Ln 246, how does WRF-Noah adjust LAI and stomatal resistance responding to LULCCs?

The adjustment in LAI, stomatal resistance, and other biophysical properties, in response to land use and land cover changes (LULCCs) is governed by the association of each land cover type with specific biophysical properties in WRF/Noah-MP. Changing the land cover map implies a modification of these associated properties. Further clarification on how Noah-MP handles land cover information will be provided in the revised manuscript, as mentioned in our response to the main comment #3 of the Introduction.

2) Ln 260, it's true that the warming in the north and cooling in the south accord with the radiation changes. However, further explanations and evidence are needed to illustrate how regional LULCCs impact radiation changes, thus altering the temperature fields.

LULCCs modify biophysical properties that are key for the radiation balance like albedo, emissivity, or leaf area index. In particular, deforestation reduces vegetation cover, leading to lower latent heat flux and increased sensible heat flux. This, coupled with higher surface albedo, intensifies net shortwave radiation warming the surface, and this warmth is transferred to the adjacent air through sensible heat exchange. We will elaborate on these dynamics in the revised manuscript to better explain the relationship between land use changes, radiation and energy balance, and soil-atmospheric warming.

3) Ln 267 and Ln 308, what processes and mechanisms determine the decreased precipitation to LULCCs?

The processes governing decreased precipitation due to LULCCs, detailed in the Discussion section, highlight the impact of agriculture intensification in the Dry Chaco. The resulting reduced LAI increases surface temperature, diminishing vegetation sheltering and enhancing outgoing longwave radiation. Simultaneously, the increased albedo reduces net shortwave radiation. These changes contribute to a reduction in net surface radiation and energy, which implies less energetic conditions in the boundary layer. This, in turn, impacts the dynamics of the planetary boundary layer, diminishing the generation of convective precipitation. This precipitation reduction contributes to declining soil moisture, creating a feedback loop as dry soil absorbs significantly less solar radiation than moist soil.

4) Ln 270 and Ln 274, the author should elaborate on the explicit processes governing the decreases in runoff and soil moisture in WRF-Noah.

Following the previous explanation, the overall reduction of precipitation is the main driver for the decreases in runoff and soil moisture. The soil moisture variations in Noah-MP are estimated with a surface water balance fed by precipitation. Thus, the reduced precipitation has a direct and immediate impact on soils, reducing their water content. The runoff in Noah-MP is constituted by surface and groundwater runoff. Surface runoff is mainly saturation-excess, while groundwater runoff mainly depends on the depth of the water table. Thus, drier soils disfavor the runoff generation in both forms. Different is the analysis for evapotranspiration, given that the removal of vegetation exposes the soil directly to sunlight, increasing the direct evaporation from bare soil. However, transpiration from plants counterbalances the changes, as it is reduced due to the lack of vegetation cover. A complete formulation of the model hydrology is found in Chen et and Dudhia 2001 and Niu et al. 2011.

Chen, F., and Dudhia, J. (2001). Coupling an advanced land surface–hydrology model with the Penn State–NCAR MM5 modeling system. Part I: Model implementation and sensitivity. *Mon. Weather Rev.*, 129(4), 569-585.

Niu, G.Y., Yang, Z.L., Mitchell, K. E., Chen, F., Ek, M.B., Barlage, M., Kumar, A., Manning, K., Niyogi, D., Rosero, E., Tewari, M., and Xia, Y. (2011). The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements. *J. Geophys. Res. Atmos.*, 116(D12).

5) Ln 294 and Ln 334, I wonder if the WRF-Noah can simulate the diminished shading associated with decreased LAI. If so, corresponding equations or mechanisms need to be provided.

Effectively, Noah-MP addresses the diminished shading associated with decreased LAI through a "semitile" subgrid scheme representing vegetation (see Fig. 1 of Niu et al. 2011 attached below). The model employs a modified two-stream radiation transfer scheme considering canopy gaps to compute fractions of sunlit and shaded leaves and their absorbed solar radiation. Additionally, it incorporates a Ball-Berry type stomatal resistance scheme relating stomatal resistance to photosynthesis of sunlit and shaded leaves, along with a short-term dynamic vegetation model.

Noah-MP's thermodynamics manages the surface energy balance by separating the canopy layer from the ground surface using the semitile subgrid scheme. Within this scheme, shortwave radiation transfer considers gap probabilities across the entire grid cell, avoiding the overlap of shadows. Longwave radiation, latent heat, sensible heat, and ground heat fluxes are independently calculated over two tiles: a fractional vegetated area ($Fveg$) and a fractional bare ground area ($1 - Fveg$), where $Fveg = 1 - e^{-0.52LAI}$.

The key flux equations for net longwave radiation (La), latent heat (LE), sensible heat (H), and ground heat (G) fluxes over a model grid cell are as follows:

$$La = (1 - Fveg)Lag,b + Fveg(Lav + Lag,v)$$
$$LE = (1 - Fveg)LEg,b + Fveg(LEv + LEg,v)$$
$$H = (1 - Fveg)Hg,b + Fveg(Hv + Hg,v)$$
$$G = (1 - Fveg)Gg,b + Fveg(Gv + Gg,v)$$

Finally, the surface energy balance equation over a grid cell is:

$$Sav + Sag = La + LE + H + G.$$

For additional details, please refer to Niu et al. (2011), sections 3.1 and 3.5.

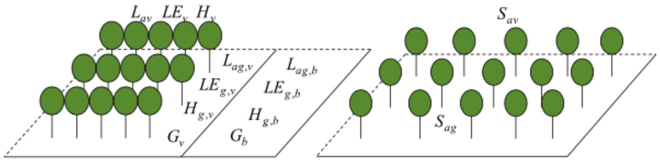

Figure 1. Schematic diagram for the "semitile" subgrid scheme. (left) Net longwave (L_a), latent heat (LE), sensible heat (H), and ground heat (G) fluxes are computed separately for bare soil (subscript "b") and vegetated (subscript "v") tiles following the "tile" approach, while (right) short-wave radiation fluxes (S_{av} and S_{ag}) are computed over the entire grid cell considering gap probabilities.

Niu, G.Y., Yang, Z.L., Mitchell, K. E., Chen, F., Ek, M.B., Barlage, M., Kumar, A., Manning, K., Niyogi, D., Rosero, E., Tewari, M., and Xia, Y. (2011). The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements. *J. Geophys. Res. Atmos.*, 116(D12).

6) Ln 297, considering the regional average signals are limited, how could you conclude that the temperature change extremes (0.6 degreeC here) is not a result of model uncertainties?

Temperature changes of 0.6 °C in magnitude are only observed at grid cell level, where the radiation and energy budget components present large differences (>10%). This alignment supports our assertion that the magnitude of warming or cooling is a result of the observed variations in these influencing factors. Additionally, the analysis of the model dispersion among members indicates negligible internal variability, as demonstrated in our response to comment #2 in the "Data, Model, and Experiments" section.

7) Ln 301 and Ln 315, the land grids in WRF-Noah are isolated and thus cannot impact surrounding grids. Explicit mechanisms are needed to confirm that WRF- Noah can resolve the remote effects of LULCC.

Uncoupled land surface models (LSMs) operate on isolated grid cells and **cannot directly alter surrounding grids**. However, when a LSM is **coupled** to a climate model, as in our case with WRF/Noah-MP, they **inevitably impact surrounding grids** since (a) grid volumes in the atmosphere are fully connected, and (b) the land interacts with the atmosphere in each time-step. This interaction involves setting the forcings for each other.

As a proof of concept, consider two adjacent grid points where all surface parameters are the same. Then, you modify the parameters for one of the grid points. As a result, you would have a change in surface fluxes and other variables at one point but not at the other. A change in the surface fluxes implies a change in the surface temperature, evapotranspiration, and atmospheric variables. The resulting horizontal gradients give rise to advective processes, effectively facilitating nonlocal effects of the LCLUCs. In other words, LULCCs exert a direct and immediate local impact on the soil, modifying the surface fluxes, which, in turn, alter the local and non-local atmospheric conditions, influenced by atmospheric dynamics such as moisture and heat transport. Therefore, we emphasize that climate models uniquely serve as the ideal tool to unravel the intricate chain of processes affected by changes in initial and boundary conditions. This analytical capability cannot be replicated using observed data or reanalysis.

8) Ln 341, MSE is not only determined by local processes but also by large-scale circulations; thus, the changes in MSE cannot be solely explained by LULCCs.

We acknowledge the reviewer's point that MSE is influenced by both local and large-scale circulations. The proposed experiments exclusively modify the land cover map while maintaining the same lateral boundary conditions, meaning that the large-scale circulation remains unchanged among simulations. Consequently, any observed changes in variables can be solely attributed to the proposed LULCCs.

9) Ln 348, changes in CAPE should be illustrated in your simulations to draw the conclusion here.

We appreciate the reviewer's feedback. Unfortunately, due to computational constraints, we did not store all WRF output variables for the 12 simulations, including the 3d variables required to estimate CAPE. Instead, we relied on interpreting changes in energy variables and precipitation, supporting our analysis with the precipitable water field (see Fig. R2.2). While we recognize that precipitable water does not replace CAPE, they both contribute to our understanding of atmospheric conditions. The reduced precipitable water in the FUTURE experiment would suggest less moisture available for convection to develop. This point will be clarified in the revised manuscript.

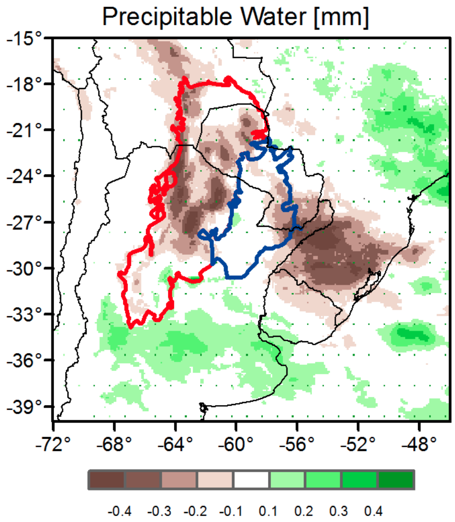

Figure R2.2. Differences in the summer precipitable water in the AG_INT scenario (FUTURE-CONTROL).

10) The main text or the supplement should provide mechanisms in WRF-Noah governing the processes in the land-atmosphere feedback pathway illustrated in Fig. 14. For example, temperature changes seem to result from changes in radiation budget instead of the driver of radiation changes.

The revised manuscript will incorporate additional details elucidating the mechanisms governing the series of processes depicted in the land-atmosphere feedback pathway illustrated in Fig. 14. We appreciate the comment on temperature clarity, acknowledging that the variable refers to surface temperature, which determines the outgoing terrestrial radiation term in the radiation balance. The increased surface temperature is transferred to the adjacent air through sensible heat exchange. Representing this intricate interaction in a schematic diagram poses a challenge, but the purpose of our plot is to synthesize the dominant process pathways.

Lastly, note that due to the HESS journal's guidelines, supplementary material cannot be used to provide additional scientific interpretations or findings beyond the manuscript's contents (see section Supplemnts in https://www.hydrology-and-earth-system-sciences.net/submission.html).

Comments about Discussion and conclusions:

1) Corresponding content should be modified and adjusted based on the comments above.

We are committed to delivering a more comprehensive discussion addressing the various concerns raised by the reviewer in the revised version. Specifically, we will delve into the strengths and limitations of the employed model, and its internal variability, situate the simulated period within the context of large-scale variability, and provide a thorough examination of the involved processes.

2) Some conclusions should be examined (e.g., the remote effect and the mechanisms of decreasing precipitation). The author needs to address whether WRF-Noah can resolve these processes.

In our responses to comments about "Experiments' results," we provide an expanded explanation addressing all the reviewer's concerns about the processes triggered by LULCCs in Gran Chaco and the capability of WRF/Noah-MP as a tool to uncover such processes. The concluding remarks in the revised version will succinctly summarize the main findings resulting from the in-depth analysis of the experiments' results and their discussion.

Technical Comments:

1. The color bars in Fig. 5 to Fig. 12 should be adjusted for more scales. For example, only seven color scales in Fig. 6 make it hard to distinguish the changes. In Fig. 12, lots of areas are saturated.

Thank you for your feedback. We will review the color scales in all figures, including adding more scales to enhance clarity and address saturation issues in our maps.