Note: All revisions are highlighted in red, while the text that was originally part of the manuscript is highlighted in green. The review comments are presented in black, and our justifications and explanations are written in blue.

This study combines different soil moisture and atmospheric data products to evaluate land-atmosphere coupling within the classical CTP-HI framework. The scientific approach and methods used are sound, and the results will be of interest to the land-atmosphere interactions community. Although the scientific elements are strong, it was at times difficult to clearly grasp what they authors were trying to achieve and communicate. I believe that the paper could benefit from some minor revisions that would help strengthen the narrative and better highlight its key points. These are summarized by my comments on the abstract but extend to the rest of the paper's discussion as well:

Thank you for your detailed review and constructive feedback on our manuscript. We understand your concerns regarding the clarity and structure. Your comments have helped us revise and reorganized the manuscript for better coherence and readability.

Abstract Revisions

The abstract is rather long and fails to adequately set up the study's main goals. Many elements are introduced rather haphazardly and readers may struggle to connect the dots. Some sentences are also repetitive, leading to greater confusion. For example, the abstract begins by stating that "this research assesses the impact of different soil moisture datasets on the classification and distribution of L-A coupling regimes." Then, the following sentence states that the goal is to "examine the persistence of dry and wet coupling regimes… exploring how soil moisture influences coupling classification." Although these sentences are certainly related, it's not clear then whether the main goal is to assess differences between the SMAP data products or to more broadly evaluate soil moisture coupling. The term "persistence of dry and wet coupling regimes" is also introduced without much context, though it seems like "persistence" is a central concept to the study and how the authors are thinking about coupling. Despite the title and first few sentences of the abstract setting up soil moisture and the different SMAP data products as the main focus of the study, the bulk of the abstract is spent discussing the need for consistent and unbiased observations of the atmospheric state and the merged reanalysis product the authors created.

After rereading the abstract a few times and digesting the rest of the manuscript, here are my suggestions for restructuring:

Thank you for your detailed comments about the abstract. We agree that the original abstract was disconnected and failed to convey the work in the paper. We apologize for the inconvenience. We have taken your suggestions and completely revised the abstract to better reflect the goals, work and conclusions of the paper. The detailed revised abstract is presented below.

1. Start off with: "In recent years, there has been a growing recognition of the significance of Land-Atmosphere (L-A) interactions and feedback mechanisms and their importance for weather and climate prediction." (no change)

   Revision (no change):

2. Lead into a sentence explaining why L-A coupling regimes are useful/important/of interest: e.g., "L-A coupling regimes are a useful framework for understanding..."

   Revision - Lines (9-11)

3. Then set up the study's focus and contribution with respect to data products: e.g., "Characterizing and studying L-A coupling regimes requires consistent and unbiased observations of surface conditions and the atmosphere..."

   Revision - Lines (12-18)

4. Now state the main goal of the study, succintly in one sentence: e.g., "We compare the classification and distribution of L-A coupling regimes across different soil moisture datasets by computing the lag correlation between the SMAP Level 3 and Level 4 soil moisture products and Convective Triggering Potential (CTP) and Humidity Index (HI) from a merged reanlaysis product we develop."

   Revision - Lines (11-12)
   We are stating the main goal of the study before explaining the study's focus and contribution with respect to the dataset. This approach ensures that the reader understands the primary objective before delving into how the study contributes to the understanding and analysis of L-A coupling regimes through consistent and unbiased observations.

5. 1-3 sentences for findings: e.g., "We find that the persitence of dry and wet coupling regimes during the time period of the study can be understood through..."

   Revision - Lines (19-22)

6. End with sentence on significance: "These findings lay the groundwork for understanding the sensitivity of drought evolution to soil moisture variations by gaining insight into the quantification of coupling strength, thereby providing critical insights for future drought modelling and prediction efforts." (second part of the sentence is repetitive and can be removed)

   Revision - Lines (22-24)

“Abstract. In recent years, there has been a growing recognition of the significance of Land-Atmosphere (L-A) interactions and feedback mechanisms in understanding and predicting Earth’s water and energy cycles. Soil moisture plays a critical role in mediating the strength of L-A interactions and is important for understanding the complex and governing processes across this interface. This study aims to identify the significance of

soil moisture in identifying L-A coupling strength within the Convective Triggering Potential (CTP) and Humidity Index (HI) framework. To address this, a consistent and reliable dataset of atmospheric profiles is created by merging CTP and HI using Triple Collocation (TC) with three reanalysis datasets. The merged CTP and HI product demonstrates enhanced performance globally as compared to the individual datasets when validated with radiosonde and satellite observations. This merged product of CTP and HI is then used to compare the L-A coupling strength based on Soil Moisture Active Passive Level 3 (SMAPL3) and SMAP Level 4 (SMAPL4) over two decades (2003-2022) where L-A coupling strength is defined as the persistence probability within the dry and wet coupling regimes. Results indicate that the persistency-based coupling strength is related to the ability of soil moisture to predict future atmospheric humidity and dry vs. wet coupling state. The coupling strength in SMAPL4 is consistently stronger than in SMAPL3 and is likely due to its reliance on a land surface model and reduced susceptibility to random noise. The difference in coupling strength based on the same CTP-HI underscores the importance of soil moisture data in estimating coupling strength within the CTP-HI framework. These findings lay the groundwork for understanding the role of L-A interactions and drought evolution due to soil moisture variations, by providing insight into the quantification of coupling strength and its role in drought monitoring and forecast efforts."

Other Clarifications

1. **Timescales of Coupling (L393-394):** My understanding is that the CTP-HI framework is typically used to evaluate land-atmosphere coupling on diurnal timescales. In particular, the original Findell and Eltahir papers focus on how soil conditions influence the evolution of the early morning atmosphere. In this study, the authors evaluate coupling between soil moisture and the CTP-HI metrics by computing the lagged correlation over a 10-day average. In lines 393-394 the authors state this is because "reliable weather predictability is generally limited to 10 days." While this is true for numerical weather prediction, this argument seems less relevant for a LA study. I think this is an interesting aspect of the paper that could be expanded on. Please provide more context and justifiation for the timescale of coupling and maybe highlight some other works that have evaluated coupling over this timescale. I believe some of the cited works are relevant here; a review paper some of the authors were involved in (Santanello et al., 2018) also has an excellent discussion of this.

   Thank you for your insightful comment regarding the timescales of coupling. We recognize the need to provide a clearer justification for using a 10-day average in lag-correlation study. The primary reason behind our use of a 10-day average is to capture the persistence of soil moisture influences beyond a single diurnal cycle. Soil moisture anomalies can have prolonged impacts on atmospheric processes, and this extended timescale helps us understand the cumulative effects of soil moisture on land-atmosphere interactions. We have revised the manuscript to better articulate this rationale, highlighting the relevance of a 10-day period in capturing the persistence of soil moisture influence.

Lines (430-442): “To delve deeper into the noted differences in coupling strength, the lagged correlation between the three sets of soil moisture and the CTP and HI over 2015-2022 are analyzed. Lag correlation is employed to identify the relationship between soil moisture and future CTP and HI and vice versa. While previous work has discussed the potential for soil moisture predictability out to 60 days (Dirmeyer et al., 2018), this analysis uses a 10-day lag to capture the role of soil moisture in predicting the atmospheric state (CTP and HI) and the atmospheric state in predicting soil moisture on time scales relative to typical weather predictability. Within this setup, the ability of soil moisture to predict future CTP and HI is given as a positive lag correlation and the ability of the CTP and HI to predict future soil moisture is given as a negative lag. For both the CTP and HI, the correlation with soil moisture is negative due to the relationship between SM-CTP and SM-HI. Wet soil typically results in surface cooling when solar radiation is limited, leading to a more stable temperature profile in the lower atmosphere. This stability restricts vertical movement and consequently leads to a lower CTP, thus creating a negative correlation. HI, on the other hand, measures atmospheric moisture content. Higher HI values signify drier air, while lower values indicate moisture-rich air closer to saturation. High soil moisture enhances evaporation, which adds water vapor to the atmosphere, reducing the gap between temperature and dew point and thus lowering the HI, resulting in a negative correlation.”

Lines (447-458): “Fig. 6(b) and 6(c) show the average lag correlation out to 10 days over the contiguous US and indicate that soil moisture has a stronger predictive influence on CTP and HI as shown by the larger magnitudes of correlations over positive lag. This is particularly noticeable for shorter lags, suggesting a more immediate impact of soil moisture on atmospheric stability and humidity. Conversely, the decrease in correlation magnitude with longer lags highlights the diminishing influence of L-A interaction over time. For the different datasets, SMAPL4 consistently shows higher correlations at all lag intervals for both CTP and HI. However, the sample size does play a role in this assessment as noticed by a decrease in the magnitude of correlation for the SMAPL4_L3. Despite this, the SMAPL4_L3 dataset still shows a higher magnitude in lag correlation as compared SMAPL3, particularly for CTP. This suggests that the assimilation of SMAP observations into a model, as in SMAPL4, may yield a stronger relationship in the temporal dynamics between the land surface and the atmosphere. In contrast, the pattern of a stronger L-A connection for SMAPL4 is less evident for HI.”

Also, the outcome of the lag correlation analysis is already well mentioned in the conclusion section (lines 600-604)

2. **Time Period of Study (L290-292)**: The abstract states that the study "examine the persistence of dry and wet coupling regimes over two decades (2003–2022), exploring how soil moisture influences coupling classification." This seems a little misleading given that SMAP is only available for the last eight years of that time period. I was a little confused by what "Since soil moisture measurements are only needed for the classification period, the

time series of coupling classiciation can still cover the entire time series of CTP-HI from 2003 to 2022." in Lines 290-292 meant. Should this instead say "Since soil moisture measurements are only needed for the lagged correlations?" Please explain and also be more careful about stating the time period of the results in the rest of the study.

Thank you for your insightful comment. The nuance of how soil moisture is used within the classification of the CTP-HI space is often a point of confusion. We have revised methodology section to better detail the role of soil moisture in the classification of the CTP-HI space and the development of the daily coupling classification. The methodology is now divided into three subsections: 2.1.1 Classification Input Variables, 2.1.2 Classification of the CTP-HI Space, and 2.1.3 L-A Coupling Strength. This includes adding a middle panel to Figure 1 that shows how soil moisture is utilized within the classification of the CTP-HI space.

Lines (116-123): Section 2.1.2 - "The classification process relies on daily values of the early morning estimates of CTP, HI and SM over a classification period. In this work, the classification period was selected as April 2015 to December 2022, to be consistent with the SMAP observational record. An example of the joint probability space, with the CTP in the x-axis, the HI in the y-axis, and the SM averaged over bins in the CTP-HI space is given in the middle panel of Fig. 1. This joint probability space is then used to define L-A coupling regimes within the 2-dimensional CTP-HI space based on the distribution of soil moisture. This is done by comparing the soil moisture in each bin to the climatological soil moisture using the two-sample Kolmogorov-Smirnov test. Bins with soil moisture distributions significantly wetter than the climatological distribution are classified as a wet regime bin, while those with significantly drier soil moisture distributions are classified as a dry regime bin."

Line (95):

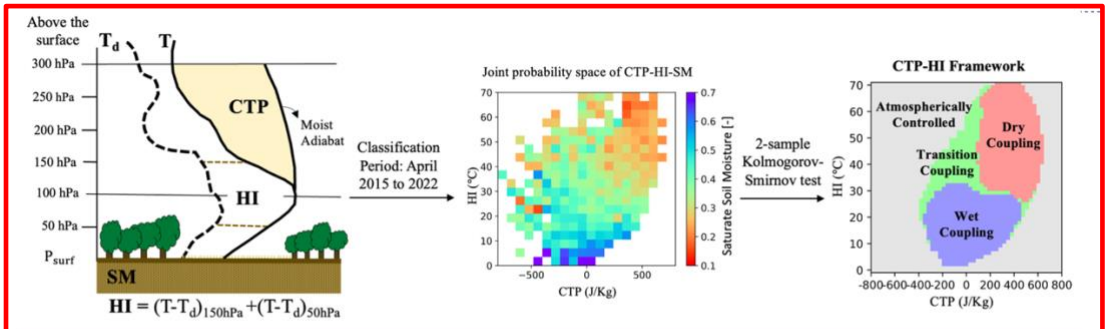


Figure 1: A visual representation of the Soil Moisture (SM), Convective Triggering Potential (CTP), and Humidity Index (HI) on a thermodynamic diagram, along with a joint probability space of CTP-HI-SM at a specific grid location (38.89, -115.59). The CTP-HI framework is depicted after applying a two-sample Kolmogorov-Smirnov test on the joint probability space of CTP-HI-SM for the classification period from April 2015 to 2022.

Lines (143-150): Section 2.1.3 – "Once the CTP-HI space is classified based on estimates of morning observations of CTP, HI, and SM, a daily coupling timeseries can be generated. The daily coupling is determined by mapping the CTP and HI values for a day onto the classified CTP-HI space (right panel Fig. 1). For example, if the CTP and HI

for a particular day map to a wet coupling regime, then that day is classified as a wet coupling regime day. This process is repeated for every day where there is an estimate of CTP and HI. Since the process for determining the daily coupling regime does not require the SM variable, the coupling timeseries can extend beyond the availability of SM data if there are CTP and HI data. Therefore, even though the CTP-HI space was classified on data from 2015-2022, the time series of daily coupling was extended to 2003 based on the availability of CTP and HI data from remote sensing."

Time of CTP-HI "Measurements" vs. AIRS (375-381): I think that some of this discussion about the time taken from the reanalysis datasets for CTP and HI metrics should go earlier in Methods (Section 3.1). Given that readers are told the AIRS instrument overpass is for 1:30 AM local time, this naturally raises questions about when CTP and HI are being evaluated since it wouldn't make sense to analyze CTP and HI at 1:30 AM. It would be better to not have to wait so long to have those questions answered and mention the sunrise time earlier.

Thank you for your insightful comment. We have revised Section 3 to clarify the timing of the CTP-HI measurements and the rationale for using the AIRS overpass time for validation and the sunrise overpass time for coupling classification. This information is now placed earlier in Methods (Section 3.1).

Revision:
Lines (226-233) - "The merged product is validated using the AIRS overpass time (~1:30 AM local time) to leverage the benefits of remote sensing data (i.e., global coverage). However, the theoretical basis for the CTP-HI framework relies on early morning observations of CTP and HI (Findell and Eltair, 2003; Roundy et al. 2013), which more closely align with the SMAP overpass time (~6 AM local time). Estimates of CTP and HI calculated from reanalysis at 1:30 AM and 6:30 AM reveal variations that suggest that the timing of data acquisition may influence these measurements. Therefore, the merged product is created at two different times, the AIRS overpass time (~1:30AM) and at sunrise. The validation of the merged product is based on CTP and HI calculated at the AIRS overpass time so that it can be directly compared to AIRS, while the merged sunrise CTP and HI is used for the analysis on coupling strength to be consistent with previous L-A coupling work."

3. **Defining Persistency (L125-126):** The quantity "persistency" is central to the study but, since its only described conceptually, it can be hard to understand and remember what exactly it represents and how it is computed. Given that the quantity is not defined with an equation, it maybe be helpful to readers to refer to it as a probability (if I'm understanding it correctly) in some of the figures and when it is first discussed in the results. Perhaps representing it as a probability (%) in Figure 6 could make that more clear?

   Thank you for your insightful comment. We recognize that our initial explanation of coupling strength was insufficient. Therefore, we have revised Section 2.2, now section 2.1.3 to ensure that the concept of coupling strength is clearly explained.

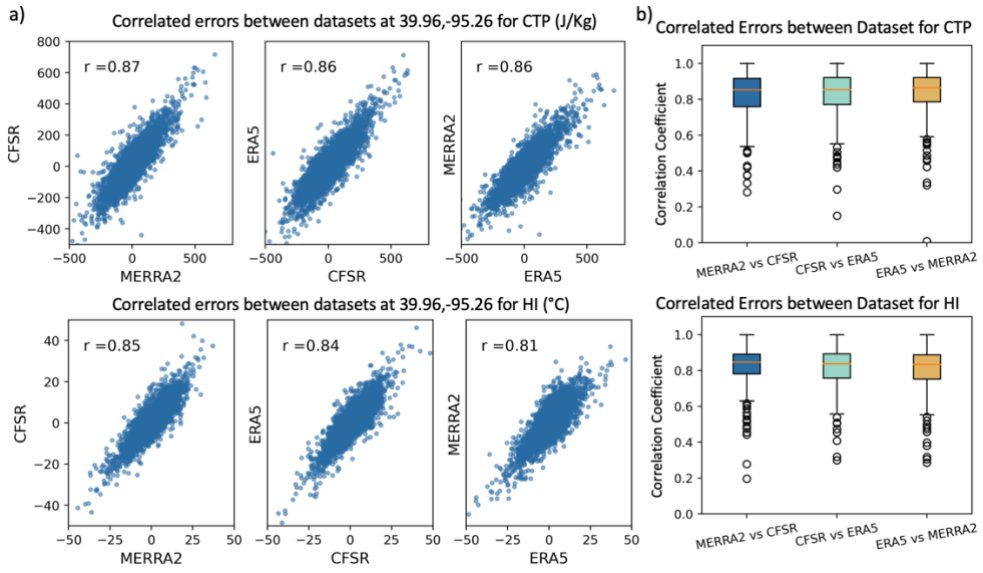
Lines (151-159): - “The coupling strength is calculated by applying a first order three-state (dry, wet, and atmospherically controlled) Markov Chain model to the timeseries. A first order three state Markov Chain describes the evolution of the coupling state through three persistence probabilities and six transitional probabilities based on a one-day lag (i.e. tomorrows coupling state is only dependent on the current coupling state). Of the nine probabilities calculated, only the two persistence probabilities for the dry and wet regimes are used to define the coupling strength (i.e. the probability that it remains in its current state). Since coupling strength is a probability expressed as a percentage (ranging from 0% to 100%, with 100% indicating strong coupling or persistence), higher percentages signify a stable interaction between the land and the atmosphere that can impact weather patterns and short-term climate variability. In contrast, low values of coupling strength indicate weaker L-A interactions.”

As suggested, we also added (%) to all the figures that showed coupling strength to remind the reader that coupling strength is a probability as described in section 2.1.3. This included revising Figures 6 (line : 457), 8 (line : 504),and 9 (line : 517).

Minor Edits

1. Figure 3a: Not sure having all the scatterplots displayed here is useful, given that there are so many and requires careful consideration of the axes. Perhaps this figure would be more readable as a table?

   We understand your concern about the readability of the scatterplots. The scatterplots provide a visual representation of the correlated errors between the datasets across the 529 global sites, offering insights into relationships and correlations that might be less intuitive in a tabular format. To improve readability, we revised the scatterplots to box plots, which will make the information clearer and easier to interpret.
   Revision:
   Line (349)



2. Line 36: Maybe a citation for ECV for those who are unfamiliar?

   We have added an appropriate citation to provide context for readers who may be unfamiliar with Essential Climate Variables.

   Revision:

   Lines (33-35)

   It serves as a vital component in the climate system and represents an essential climate variable (ECV) (Liu et al., 2020; Miranda Espinosa et al., 2020; Pratola et al., 2015).

Overall, this was a well-performed study, and I am looking forward to the publication of this work. Some minor improvements on the readability of the manuscript would go a long way in helping the paper better reach its intended audience.

Thank you for your feedback and encouragement. We appreciate your acknowledgment of the study's quality and your anticipation of its publication. We believe these changes will help the paper better reach and engage its intended audience. Thank you again for your valuable input.