Dear Dr. Erickson,

Thank you very much for your review and insight, as addressing these miscommunications will greatly benefit understanding of this work for future researchers referencing this work. Your comments were greatly appreciated and taken into account. Please find our clarifications and responses below, with fixes we intend to make to the paper. We feel these comments will greatly improve the quality of the manuscript

- **Comment:** It is suggested that an approach that follows from this work be employed for a full data sweep of climate model Big Data output on the order of a Peta-byte.
    - We toned down the language that gives this representation such that the conclusions are clearer and expectations are properly set, as such larger scale implementations have not been tested. In a new future work section, we also mention future applications to other climate problems.
- Sahel rainfall was studied here and many other climate process could be examined. Perhaps different climate variable time series and spatial series could be optimized for each of the Bayesian, CHARM and LASSO. Perhaps depending on the spatial temporal characteristics of a variety of climate variables one may find that different of the 3 approaches work better under different circumstances...ie Sahel rainfall may be better characterized by LASSO and Siberian drought better characterized by CHARM.
    - We have added language in a future work section as follows:
        - In this work, we used the same set of climate indices for all the individual methodologies employed, to facilitate the comparison and fusion of results. It is possible that using different datasets or different time/spatial series for each methodology can improve their individual results, and in turn the overall outcome of the models. However, additional considerations would be needed for interpreting which models provide evidence of particular relationships between individual climate indices.
- p. 480 What are the 'promising discoveries' mentioned in the abstract. These should be specifically stated in the abstract.

- o The language in the abstract has been made more precise by explicitly specifying our findings.
  - Using this fusion of approaches, we identified relationships among climate factors that modulate Sahel rainfall. These relationships fall into two categories; well-known associations from prior climate knowledge, such as the relationship with the El Niño Southern Oscillation (ENSO) and putative links, such as North Atlantic Oscillation, that invite further research.
- p. 481 Not sure that the Sahel rainfall, or anomaly thereof, is a 'functional response'. It could be a driver not a response.
  - o We have corrected this as follows by adjusting page 481 to state:
    - For example, the rainfall anomaly in the Sahel region of western Africa, which is the focus of this study, represents a "functional response" for the climate system, which is in actuality the predictant of a model (such as Lasso, DBN, etc.).
- p. 481 Why does meningitis epidemic occur when dry? What about wet season epidemics? Could this manuscript take this thread further and make some predictions/e of how meningitis may evolve as the climate variables and modes of variability?
  - o Understanding meningitis variability, while highly important, is a complicated problem that falls outside the scope the primary focus of this paper, which is to discover climate relationships associated with Sahel rainfall. The introduction has been clarified, and some additional information has been added to provide a more coherent motivational statement.
    - Comprehending these mechanisms is particularly important due to the influence of rainfall variability in the region. Severe drought occurred throughout the 1970's and 1980's, leading to severe disruption of agriculture and major food shortages (Mortimore and Adams., 2001). Dry conditions (low rainfall anomaly) also lead to the spread of meningitis, as in wet conditions, higher humidity during both the spring and summer seasons strongly reduce disease risk by decreasing the

transmission capacity of the bacteria (Sultan et al., 2005). These issues make the Sahel particularly vulnerable to fluctuations in rainfall, and provide motivation to improve domain scientist's knowledge of the contributing factors

- p. 482 The ECI score is mentioned here but does not seem central to this manuscript
    - o We removed mentioning ECI score.
- p. 483 The use of italics is over done, and seems in indicate a desire to come up with some new 'term' for a variability model in statistics and/or climate, p. 486 Every before and relationships in lines 14-15 do not to be italicized. P. 488 Possibly does not need italics:
    - o We have corrected the italics throughout the paper to restrict its use specifically to defining new terms.
- p. 483 Well, on line 1-14, what are those previously-undiscovered relationships???
    - o Text has been added to the abstract, results and conclusions to make it clearer what these relationships are. Here, we have altered the language to make it clearer that this method is a framework which could be applied elsewhere.
        - ▪ Furthermore, the application of this unified result to the climate network may allow the identification of previously-undiscovered relationships, which can then be analyzed from a traditional climate perspective. In the Section 3 (specifically Table 3), we present the application of such a method to the climate indices affecting Sahel rainfall.
- p. 484 So, is there support of a climate relationship with antecedent climate variables?
    - o In our work, we capture a climate relationship as being such itemsets of climate variables that co-occurs at least twice in our data, where in our case climate variables are climate indices, as discussed in Section 2.1.2. Literature support for such available relationships is available in Section 3, and captured in Table 3.
- Lines 26-27 are an understatement.
    - o The lines have been clarified as follows:

- Due to the complexity of the climate system, building comprehensive models over climate data is not trivial, due in part to the interactions between its subsystems, the dimensionality and structure of its underlying data, and the quality of such data.

- p. 485 Miss-aligned is not the correct term. Parts of the globe are not miss-aligned. Algorithms used to examine different parts of the globe may be miss-aligned for the climate domain usage. Figure 3 and the associated caption pretty much sums it up.
    - p. 485 Line 6 has been changed as follows:
        - …such diversity of spatiotemporal alignment between the system's features…
    - p. 485 Line 14 has been changed as follows:
        - However, these climate indices that capture data for climate subsystems are located in different parts of the globe (see Fig.3).
    - p. 485 Line 20 has been changed as follows
        - … they are often still not perfectly aligned…
    - P.499 Line 6 has been changed as follows:
        - …given spatial alignment issues…

- p. 487 The definitions attributed to NOAA are arbitrary. Not set in stone or convention defined.
    - The lines have been changed to be as follows:
        - As suggested by NOAA (2014) and based on our interactions with climate scientists, we identify anomalies as any set of values below the 33.33rd percentile or above the 66.67th percentile for any given variable.

- But multiple inciters is exactly what geophysically is going on.
    - We have added language in a future work section as follows:
        - Furthermore, the present CHARM approach studies rules heterogeneously, which is for the benefit of understanding rules with significant support within particular coupling inciters. However, we intend to address rules across multiple inciters in future work, given the geophysical nature of the underlying data and

understanding that climate relationships are in reality affected by multiple inciters.

- p. 489 Itemsets, inciters and should be defined.
  - These terms will be formally defined in section 2.1.2 and reminded in subsequent sections.
- Many things are embarrassingly parallel.
  - We are clarifying this in lines 9-10 on pg 488
    - Thus, the method operates in smaller parallel executions with low overhead.
- p. 490 Stronger physical rationale of what???
  - The lines have been clarified as follows:
    - These results complement the existing physical models and may help climate scientists categorize the correct season for the response of interest (e.g. Sahel rainfall variability).
- p. 491 Lines 17-23 are only temporal issues? No space component?
  - Spatial and temporal contexts for DBN have been clarified as follows:
    - DBNs are a very popular means with which to mine and represent modulatory relationships in spatial and temporal data, given that the conditional probability distribution of each node can be estimated independently (Friedman et al., 1998; Murphy, 2002; de Kock 2008). The model's dynamicity is obtained by combining a traditional Bayesian network with a temporal Bayesian network that allows for capturing behaviors of the Bayesian network over the temporal space, and is not to be confused with the idea that the model changes over time (Murphy, 2002).
- p. 492 What is temporally-infeasible edges?
  - The lines have been clarified as follows:
    - Given our utilization of the toolkit, we abide by this complexity for our estimation, only restricting the execution by disallowing temporally-infeasible edges (i.e. edges are only allowed between two nodes if the originating node occurs temporally before the destination node). In doing so, we ensure that the

directionality of the network is temporally sound and fits proper modulatory relationships.

- p. 493 Is there an example of a DAG?
  - The lines have been clarified as follows:
    - Such graph includes a set of vertices and directed edges, which in the context of this study represent the climate factors and the relationships between them, respectively. Furthermore, there are no cycles in the graph (i.e. following a path originating at a given node will never lead back to that node)
- p. 494 Lines 1-21 could be recast so a domain scientist could move forward and understand the specific methodology implied.
  - The inherently statistical by nature description of the methodology will be recasted and we will check with domain scientists for ease of comprehension.
- p. 495 Not sure what was not available from NCAR. I bet it is there in some form or manner but immersed in a vast amount of other data.
  - The lines have been clarified as follows:
    - Hence, where climate literature suggested a teleconnection between a given climate variable and Sahel rainfall, but a representative climate index for it was not readily available from NCAR, an EOF analysis of the 850mb height field was created instead, using reanalysis data.
- p. 496 A further, detailed definition of an 'EATL8 coupling inciter' would be useful.
  - The lines have been clarified as follows :
    - Table 3 captures the relationships known from reference material in contrast to the findings of the evaluated methods for the $EATL_8$ coupling inciter, which implies that for the given data couplings, the coupling inciter used was Atlantic ENSO in the temporal phase of August-September-October.
- p. 497 So, Sahel Rainfall variability is correlated, or related to the NAO. Thus has been reported. So, these new CHARM techniques reproduce and confirm earlier studies. What is the new Geophysical Insight??

- o The lines have been clarified as follows:
  - ▪ Lasso and DBN coincide in capturing extra-tropical NAO forcing. Although the NAO is known to impact Sahel rainfall (Hurrell, 1995), the mechanism by which this occurs is unclear. A link to the tropical Atlantic, particularly through the LLW's, is suggested by the results here. It is possible that the moisture flux from the tropical Atlantic is dependent on the phase of the NAO. On a finer scale, the model also predicts a direct link to the NAO. The association between the NAO and Sahel rainfall may be multifaceted, and our results are being further investigated by the authors based on an NAO-driven hypothesis over the entire West African Sahel (Tetteh, 2012).
- p. 498 So an increase in edges means more cumulative knowledge when the fused technique is used than indvidial models/apporahce. I guess that that is good.
  - o I am clarifying this as I do not believe an increase in edges is necessarily good, instead that Lasso's results are affecting the resulting network
    - ▪ Figure 8 captures the resulting network after the different models are fused into a consensus result, and presents the final set of edges provided by the model. The vast number of edges presented is mostly driven by the high sensitivity of the Lasso methodology, and as mentioned in Section 3.3, such number direct connections can detract from understanding indirect rainfall relationships.
- p. 500 More geophysically germane conclusions and specific climate-related scientific advancement should be high-lighted. This manuscript would have benefited greatly by a more detailed and intense interaction with climate domain scientists.
  - o This paper presents a new method for climate network analysis, providing Sahel rainfall as an example. As such, the emphasis is on the methodology. However, climate scientists at the Climate Laboratory of North Carolina State University

were consulted throughout. The conclusion has been revisited to include more explanation of the findings from this example

- The IOD, ENSO, MSEA and AMO were confirmed as important SST anomalies modulating rainfall in the region, as previously discussed in the climate literature. The relationship with the NAO is found to have both direct and indirect components, and is particularly related to equatorial westerlies (LLWs) in the Atlantic, known to influence the region (Nicholson., 2009). It is hypothesized that the NAO modulates the position and strength of the equatorial westerlies, impacting the Tropical Easterly Jet and therefore Sahel rainfall. This hypothesis is currently under investigation by climate domain scientists (i.e. Tetteh., 2012), based on the results of this study, and serves as an example of a relationship which is not fully understood being highlighted by the framework presented here.

- Are all figures necessary, and of appropriate quality? No. Figs 2, 4 and 8 could be removed.
  - Figure 2 is intended as a description of Association Rule Mining (ARM) for non-computer scientists who have never been exposed to the ARM approach and provides a visual of the approach explained in section 2.1.1.
  - Figure 4 can be removed only if the example in line 3-6 of page 486 is also removed.
  - Figure 8 is representative of the consensus result and Lasso's effect on it. I do not think it should be removed but the caption can be updated to "Resulting combined network for coupling inciter $EATL_8$, capturing relationships between each specific climate variable node. This figure highlights the high number of relationships found by mining approaches, and specifically captures Lasso's adverse effect on the interpretation of such network."

Dear Reviewer,

Thank you very much for your review and insight, as addressing these miscommunications will greatly benefit understanding of this work for future researchers referencing this work. Your comments were greatly appreciated and taken into account. Please find our clarifications and responses below, with fixes we intend to make to the paper. We feel these comments will greatly improve the quality of the manuscript

- 1) Introduction, related to the known and not-so-well-understood relationships summarized in Figure 1: The authors provided one example. It would be very helpful if a more exhaustive description of these relationships can be included, with references to specific studies. This would help improve the credibility of results from this study for those who are not familiar with this body of literature.
  - This section replaces where we currently have "For example…" 481, line 9. We think this is a valid and wanted to address it.
    - These associations have a diverse range of climate mechanisms. For example, warmer temperatures in the Mediterranean Sea region lead to increased evaporation, and southward moisture advection in the lower troposphere toward the Sahel (Rowell, 2003). On a more global scale, the Atlantic Multidecadal Oscillation (AMO) displaces the Intertropical Convergence zone (ITCZ) further northward, bringing more moisture to the Sahel region (Zhang and Delworth.,2006). The North Atlantic Oscillation (NAO) has been linked to the moisture budget in Northern Africa (Hurrell., 1995), through a direct influence on the Sea Level Pressure (SLP), although this mechanism remains underexplored. In the Pacific, a warm ENSO event is associated with enhanced trade winds over the tropical Atlantic and weaker moisture advection over West Africa, consistent with a weaker monsoon system strength (Janicot et al., 2001). Figure 1 illustrates a complete overview of the climate modulatory network, which is a collection of modulatory pathways, with some mechanisms driving

- 2) Section 3: It sees that the figures are not referenced in their order of appearance. Please fix.
    - o This will be corrected in a final scrub
- 3) The results showed a large agreement between ARM and Lasso, and the number of relationships identified by DBN is much much smaller. As a result, the consensus among the three is pretty much determined by DBN. What is the implication of this regarding the usefulness of either (ARM & Lasso vs. DBN)?
    - o It is not intended that the results of DBN determine the consensus. It is instead a valuable piece of evidence. To clarify, a paragraph has been added to section 2.5 as follows:
        - ▪ We use these statistics to determine a consensus in the relationships found by the methods employed and build a network to capture said consensus. Note that the number of relationships in the consensus result will not be restricted by the methodology that identifies the fewest relationships. Instead, each methodology serves as evidence for the consensus result and affects the strength of the evidence provided for a particular relationship. Hence, each method contributes to the consensus result, with no specific methodology acting as a determining factor that would bias the result towards that specific methodology. Determining a bound at which to remove rules from the consensus result based on the amount of evidence provided is a topic of future work.