We would like to thank all of the reviewers for the thorough and insightful suggestions and comments. We made substantial changes to the manuscript, replaced one figure, and completed an additional model simulation in response to the feedback we received. We feel that the manuscript has improved significantly as a result of these thoughtful reviews. Please find our detailed responses to the reviewer's comments below.

Please note that the reviewer comments are shown in black and our author responses are in blue. Where changes have been made in the manuscript, the page and line number(s) are given. In some cases, to highlight changes to passages in the manuscript, these sections are copied and pasted from the manuscript.

Reviewer #1: Oliver Lopez

Summary:

The manuscript presents a study of the impacts that a sprinkler irrigation scheme in a land surface model have on the latent and sensible heat fluxes, and more substantially in the soil moisture state on a small, high resolution domain containing center-pivot sprinkler irrigation systems. The study explores the sensitivity of the results to two parameters: the irrigation intensity as prescribed by an input data set (GRIPC), and the greenness vegetation factor (GVF) used to scale the irrigation amount depending on the growth stage of the crops. The soil moisture state is compared to fixed soil moisture probes and a gridded soil moisture product, both using Cosmic Ray Neutron Probes. Including irrigation in land surface models is becoming more important to properly characterize the state and fluxes in agricultural regions, and thus efforts to evaluate the impact that either the choice of irrigation scheme or their input datasets have on the model results is certainly relevant to HESS. The study introduced modifications to the irrigation scheme such as using a real-time greenness vegetation factor data (as opposed to a climatological one) and also introduced a modification in the method to develop a soil moisture gridded product.

Overall, the manuscript is well written and the conclusions reached are sufficiently supported by the results. However, there are some few comments that I think would improve the readability of the manuscript, particularly with the description of some of the input datasets (GRIPC and in situ irrigation) as well as part of the methodology. Therefore, my recommendation is acceptance with minor revision.

General comments

1. The title refers to *"non-traditional"* and *"human-practice"* datasets. However, it is not clear what the authors mean by these two concepts. It might be the case that *"non-traditional"* is referring to the use of Cosmic Ray Neutron probes, but this is not obvious. In contrast, "human-practice" data is defined in Page 6, line 13 to be the irrigation amount. However, it is not clear if this term is referring to the GRIPC dataset used throughout the study (which is

based not only on human data, but also on remote sensing data), or to the amount of irrigation applied at two sites, as mentioned in Page 6, line 10.

We consider the 'human-practice' dataset to be the information on irrigation amounts and timing and the 'non-traditional' dataset to be the Cosmic Ray Neutron Probe datasets, both stationary and gridded. To clarify this, as well as to provide more details about the evaluation data in response to General Comment 3 below and several of Reviewer 4's comments, a new section has been added to the Methods called 3.2 Evaluation Data.

This new section begins (Page 8, Lines 19-20):

> "The non-traditional, CRNP soil moisture data products and human-practice data gathered in Franz et al., (2015) are used to evaluate the sprinkler irrigation algorithm in LIS."

In this new section, with respect to the human-practice data and irrigation amount description (comment 3 below), the manuscript now reads (Page 8, Line 20-21):

> "Human-practice data in the form of the irrigation amount and dates of irrigation application at one irrigated soybean and one irrigated maize site were reported via personal communication to Franz et al., (2015)."

Also with respect to the non-traditional dataset clarification, this section now reads (Page 9, Line 1):

> "Additional non-traditional data from Franz et al., (2015) include a soil moisture product that uses the spatiotemporal statistics of the observed soil moisture fields…"

2. Related to the previous comment: although a reference is given for the GRIPC dataset, a brief description of this dataset would benefit the manuscript. An estimate of the uncertainties related to this dataset would also be helpful.

The following sentences describing the GRIPC have been added to Page 7 Lines 17-23:

> "The GRIPC dataset integrates remote sensing, gridded climate datasets, and responses from national and sub-national surveys to estimate global irrigated area. The dataset closely agrees (96% at 500 m) with the USGS MIrAD-US2007 dataset (Pervez and Brown, 2010) and assessment of GRIPC against field level inventory data showed an 84% agreement in Nebraska (Salmon et al. 2015). This dataset represents a significant improvement in defining irrigated areas as compared to previous configurations of this model and scheme (Lawston et al. 2015) in which irrigated areas were defined using the 24-category USGS landcover classification, based on data from the 1990's. However, the GRIPC dataset overestimates irrigation intensity in the study area,…"

3. Also related to the first comment: a description of the irrigation data from the study in Franz et al. (2015) is also worth including. This is especially important in Figure 7, where irrigation at the maize site is shown, as well as in the text (Page 12, lines 14-16).

   A description of the irrigation data has been included in the new 'Evaluation Data' section (3.2). Please see comment #1.

4. The methodology for defining the growing season was not included in the Methods section. It is however mentioned later in the Discussion section on Page 15, lines 13-14 *"The method for determining the start and end of the growing season, based on the 40% annual range in climatological GVF, proved to be reliable for this study area and climate"*.

   The details of the determination of the irrigation season have been added to the Methods section when first introduced. Page 10, Line 3 now reads:

   > "The growing season, addressed in question three, is a function of the gridcell GVF (i.e., 40% annual range in climatological GVF; Ozdogan et al. 2010)…"

Minor comments

1. Page 2, line 9: (referring to observational data) *"are generally not obtainable at the scale of LSMS" and Page 5, lines 19-21: "available at the same spatial scale as LSMs"*

   What do the authors mean by scale of LSMs? land surface models can be run at a great range of scales. Perhaps the authors are talking specifically about high-resolution LSMs such as in this study? If so, please specify this.

   Yes, we mean high-resolution but also are referring to the fact that observation data are often not available in spatially continuous/gridded fashion. This has been clarified:

   > Page 2, Line 9-10: "…are generally not obtainable in a spatially continuous format at the scale of high-resolution LSMs..."
   >
   > Page 5, Line 23: "...area average soil water content…available at the same spatial scale as high-resolution LSMs"

2. Page 4, line 1: *"For example, a flood irrigation parameterization. . . "*

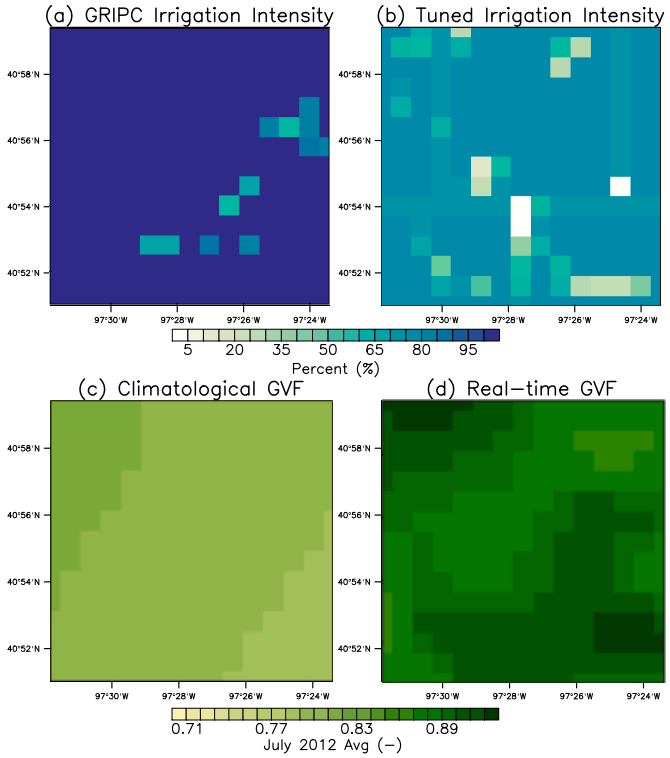
   It is not clear if this is referring to scheme number 1 or 2 defined above in Page 3, lines 19-22. The text would benefit if this term ("flood irrigation parameterization") would be included in Page 3, lines 19-22 where applicable.

   A sentence has been added to clarify here. The sentence at Page 3 Line 20 now reads:

"This need has been addressed via irrigation parameterizations in LSMs that largely fall into three types of schemes: 1) defined increases to soil moisture in one or more soil layers (Kueppers and Snyder, 2011; de Vrese et al. 2016), **sometimes referred to as flood (Evans and Zaitchik 2008),…"**

3. Figure 1: The titles in each sub-figure are confusing. Perhaps the titles could read (top left, top right, bottom left, bottom right): "GRIPC irrigation intensity", "Tuned irrigation intensity", "Climatological GVF", and "Real-time GVF" to better identify what is being shown. Furthermore, the figure would improve by the inclusion of labels "a", "b", "c" and "d". Finally, the colorbar for the top figures (which is the same for both) could be shown in the center as it was done for the bottom figures.

   All of the suggested changes have been made to Figure 1:



4. Page 11, line 2: *"the SPoRT GVF is greater than climatology in June"*
   Please clarify: do the authors mean "greater than climatological GVF"?

   Yes, this has been changed in the manuscript to 'greater than climatological GVF.'

5. Page 11, lines 3-4. *"However, in September, the SPoRT GVF detects the (negative) vegetation response to the July drought and irrigation amount and flux impacts are reduced"*.

What do you mean by "the sport GVF detects the negative vegetation response to the July drought?" is it because it is a real-time product as opposed to the climatological product and the fact that 2012 was particularly dry?

Yes, exactly. This has been rephrased to clarify:

> "…the SPoRT GVF detects vegetation stress caused by a July flash drought, resulting in reduced GVF, irrigation amounts, and flux changes."

6. Page 11, lines 4-7. *"These seasonal scale impacts illustrate that the NLDAS-2 forcing (e.g. precipitation) data, via changes to soil moisture, drives the irrigation timing during the growing season and that the behavior of the irrigation scheme is consistent with expectations of human triggering of irrigation during dry and wet periods"*.
I am not sure I follow completely what is meant here. Is this saying that we expect irrigation triggering when there is no (or small amounts of) precipitation and no triggering when there is? If so, then this is already phrased better in the next lines (page 11, lines 9-10): *"At the interannual and seasonal scale, irrigation amounts and impacts are driven primarily by background rainfall regime, given by the forcing precipitation, with only small changes evident between the methods"*.

   Yes, the first sentence is meant to convey that irrigation is being triggered when there is little precipitation, as we would expect farmers to do. The second sentence is meant to re-iterate the triggering but also to point out that all three irrigation simulations had very similar results at the interannual and seasonal scales. This is set up as a contrast to the forthcoming daily scale results that show much larger differences in fluxes between irrigation experiments.

   The first sentence has been re-worded to clarify:

   > "These seasonal scale impacts illustrate that the NLDAS-2 forcing (i.e., precipitation) data, via changes to soil moisture, constrains the irrigation timing during the growing season, and that the soil moisture threshold is sufficient in triggering irrigation during rain-free periods"

7. In Figure 7, why not include the soil moisture from the CRNP gridded soil moisture product as well for comparison with the fixed probes?

   We compared the CRNP gridded soil moisture time series to the CRNP stationary probes at the three sites and noticed that the gridded product had a small dry bias. This is confirmed by the Franz et al. (2015) paper that also notes a small dry bias in the gridded product that is likely a result of the rover driving on and sensing drier, gravel roads. This is in contrast to the CRNP stationary probes that are "painstakingly calibrated." Since the goal of this figure was to illustrate the impact of irrigation on the soil moisture time series and how well those changes are reproduced by the model, we show only the best available observations at these two sites, which are the CRNP stationary probes. The utility of the gridded product lies in the

areas where we don't have the probe data and as such, we use it to get a better understanding of how the model performs over the larger area (rather than at the individual sites).

8. Page 13, lines 11-12 *"In this study, we modify the spatial regression technique to treat irrigated and non-irrigated areas differently by using the CRNP (irrigated) rainfed data in the regression for (irrigated) non-irrigated gridcells"*.
I am not sure I follow the last part with the parentheses "by using the CRNP (irrigated) rainfed data in the regresion for (irrigated) non-irrigated gridcells". Could you please clarify this?

   Please see comment #9

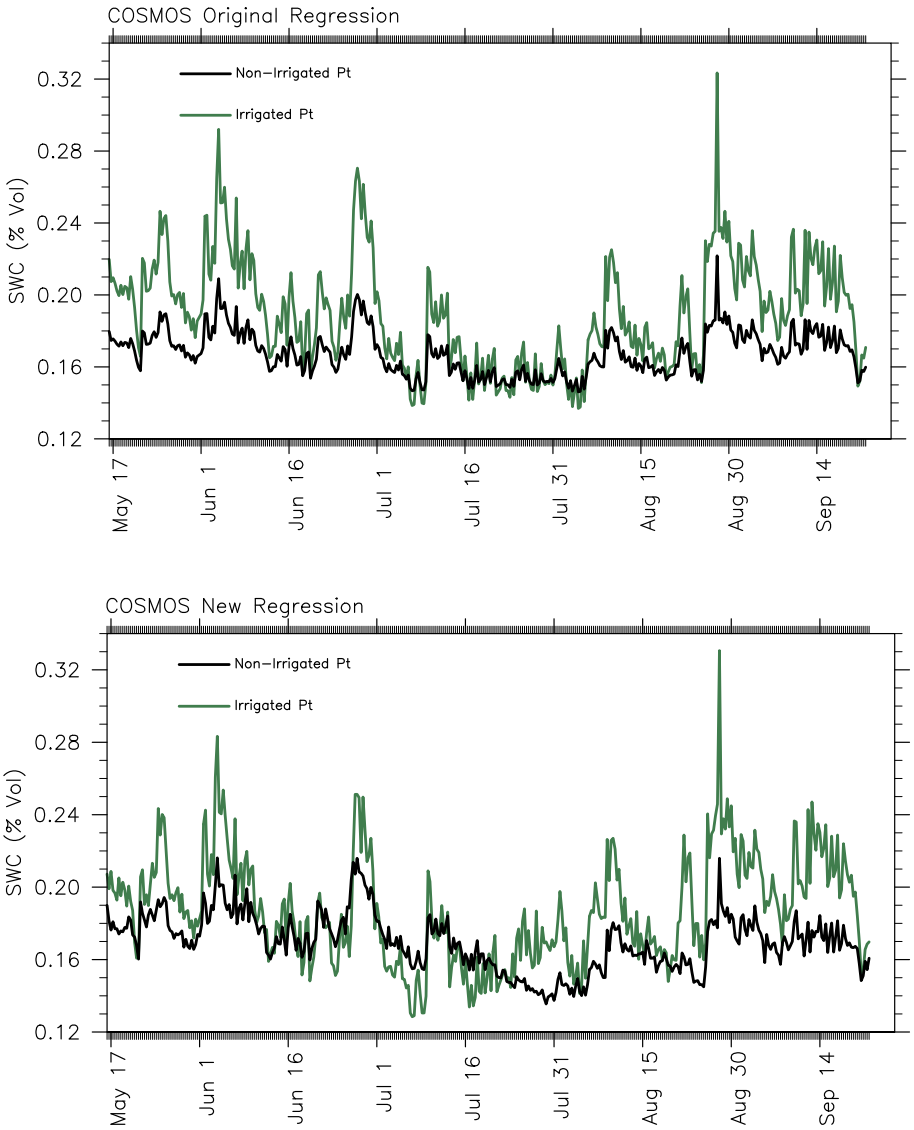
9. Referring to the same text in the last comment, in my opinion, since this is also a novel contribution (the modification of the spatial regression technique for the gridded product), a comparison between the previous and the new product could be included as supplementary material.

   In response to both comments 8 and 9, this section has been rephrased, expanded upon, and relocated to Page 8 Line 19- Page Line 13 in the new Section 3.2 (Evaluation Data). It now reads as follows:

   > "Additional data from Franz et al., (2015) include a gridded soil moisture product that uses the spatiotemporal statistics of the observed soil moisture fields, as obtained via the CRNP rover surveys, and a spatial regression technique to create a 1-km, 8-hour gridded soil moisture product for the growing season (May – Sept, 388 values). Franz et al., (2015) used the average of the three stationary CRNP probes as the regression coefficient, which can smear the spatial differences between irrigated and rainfed areas. In this study, we modified the spatial regression technique to treat irrigated and non-irrigated areas differently by using the CRNP rainfed probe in the regression for non-irrigated gridcells and the average of the two irrigated CRNP probes for the irrigated gridcells. This results in a gridded soil moisture product that retains the spatiotemporal differences of the rainfed and irrigated areas. Irrigated and non-irrigated gridcells are defined by an estimated irrigation mask created using the landcover map of Franz et al. 2015 from ground observations. A comparison of the original and new regression products at an irrigation and non-irrigated point is given in the Supplement.

   As the text states, the following figures have been added to the supplement to show the difference between the new and original regression products. With the original regression technique (a) few differences are seen between the irrigated and rainfed points, especially during the dry-down period in late July to early August. The averaging of the probes results in a levelling off of soil moisture during this time. (b) The new regression technique results in the non-irrigated point showing decreasing SWC during the dry down period, as at the CRNP

rainfed probe, while the irrigated point shows increasing SWC due to irrigation during the dry down. This explanation has been added to the supplement figure caption (below).



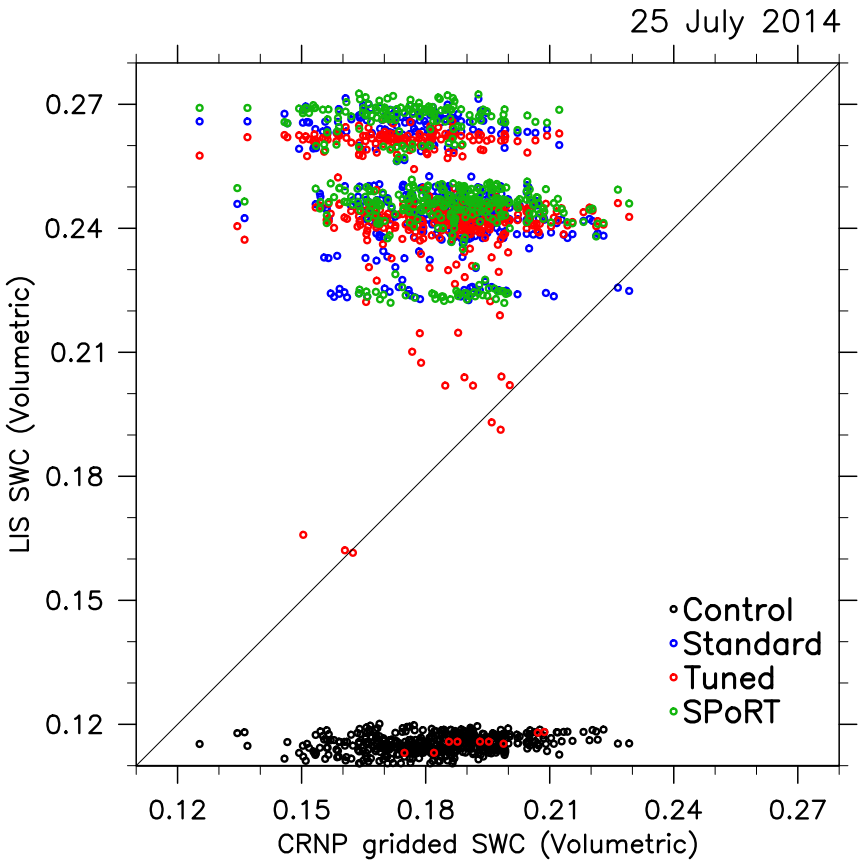
Supplement 1. Time series of soil water content at an irrigated and non-irrigated point given by the gridded CRNP product using (a) the original regression from Franz et al., 2015 (b) the new regression used in this study that treats irrigated and non-irrigated areas differently. With the original regression technique (a) few differences are seen between the irrigated and rainfed points, especially during the dry-down period in late July to early August. The averaging of the probes results in a levelling off of soil moisture during this time. (b) The new regression technique results in the non-irrigated point showing decreasing SWC during the dry down period, as at the CRNP rainfed probe, while the irrigated point shows increasing SWC due to irrigation during the dry down.

10. Page 13, lines 17: *"during which irrigation was applied at the irrigated maize site"*

Only at the maize site? or the whole domain shown in Figure 1? The caption reads *"when irrigation was applied at the irrigated maize and soybean sites"*. To my under- standing, the maize site and soybean sites are only parts of the whole domain, and this figure (Figure 8) is showing a spatial comparison of the whole domain.

Yes, the reviewer is correct. The figure showed the whole domain, which includes the irrigated sites, but is not exclusively the irrigated sites. The intention for that statement was to emphasize that the CRNP gridded observations are at least partially impacted by the irrigation that we know is occurring in at least some areas on that day. This figure has been changed from a CDF to a scatterplot as per Reviewer 3's comments and the caption has been reworded to that below with the reviewer's comments in mind:

> "Figure 8. Scatterplot of the gridcell soil moisture content (volumetric) given by the irrigation simulations as compared to the CRNP gridded soil moisture product."



11. Figure 8: In the legend, consider changing "CoSMOS" to "CNRP" to be consistent with the rest of the paper.

The legend has been updated in the new Figure 8. Please see previous comment (#10).

12. Page 14, lines 9-10 *"Furthermore, when irrigated and non-irrigated areas are averaged separately, the irrigated (Control) simulations match the distribution of irrigated (non-irrigated) areas well"*.
Again, I do not understand the use of the parenthesis here "irrigated (non-irrigated)".

This sentence has been rephrased:

> "Furthermore, when irrigated and non-irrigated areas are averaged separately, the irrigated and control simulations match well the distribution of irrigated and non-irrigated areas, respectively (Fig. 9b)"

4 Technical corrections

All of the following technical corrections have been made.

1. Page 7, line 19 *"as evidenced by only 5% of the gridcells having intensity less than 100% (Fig 1)"*
I think this should be "Fig 1a" instead of "Fig 1".
2. Page 7, line 22 *"(i.e. observationally tuned: Fig 1)"*
I think this should be "Fig 1b" instead of "Fig 1".
3. Page 7, lines 19 and 22 and Page 8, line 4.
Check consistent use of either "(Fig X)" or "(Figure X)".
4. Figure 6: Label in Y-axis "Change in Domain Avg Qle" instead of "Doman"
5. There is a dot missing in Page 13, line 24 before "The model distributions do not match the CRNP CDF, which instead shows. . . "