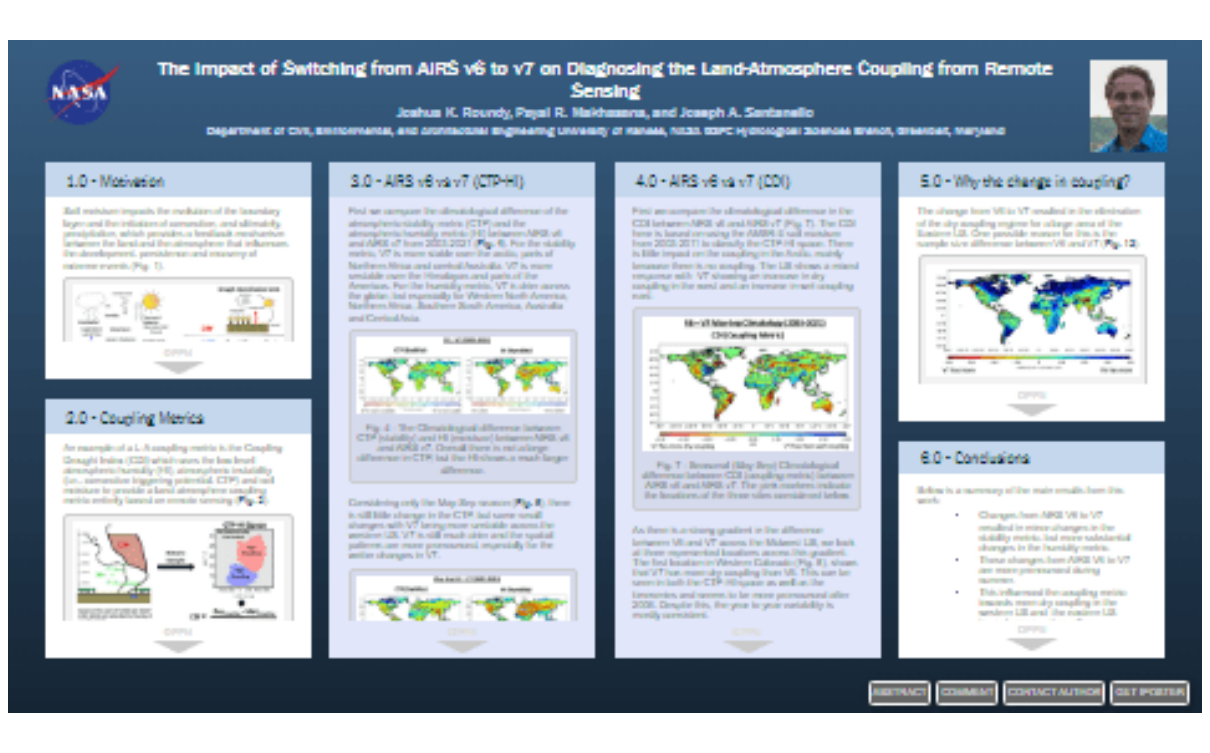
The Impact of Switching from AIRS v6 to v7 on Diagnosing the Land-Atmosphere Coupling from Remote Sensing



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PRESENTED AT:

AMS 2023
103rd ANNUAL MEETING
DENVER & ONLINE
AMERICAN METEOROLOGICAL SOCIETY

1.0 - MOTIVATION

Soil moisture impacts the evolution of the boundary layer and the initiation of convection, and ultimately, precipitation, which provides a feedback mechanism between the land and the atmosphere that influences the development, persistence and recovery of extreme events (Fig. 1).

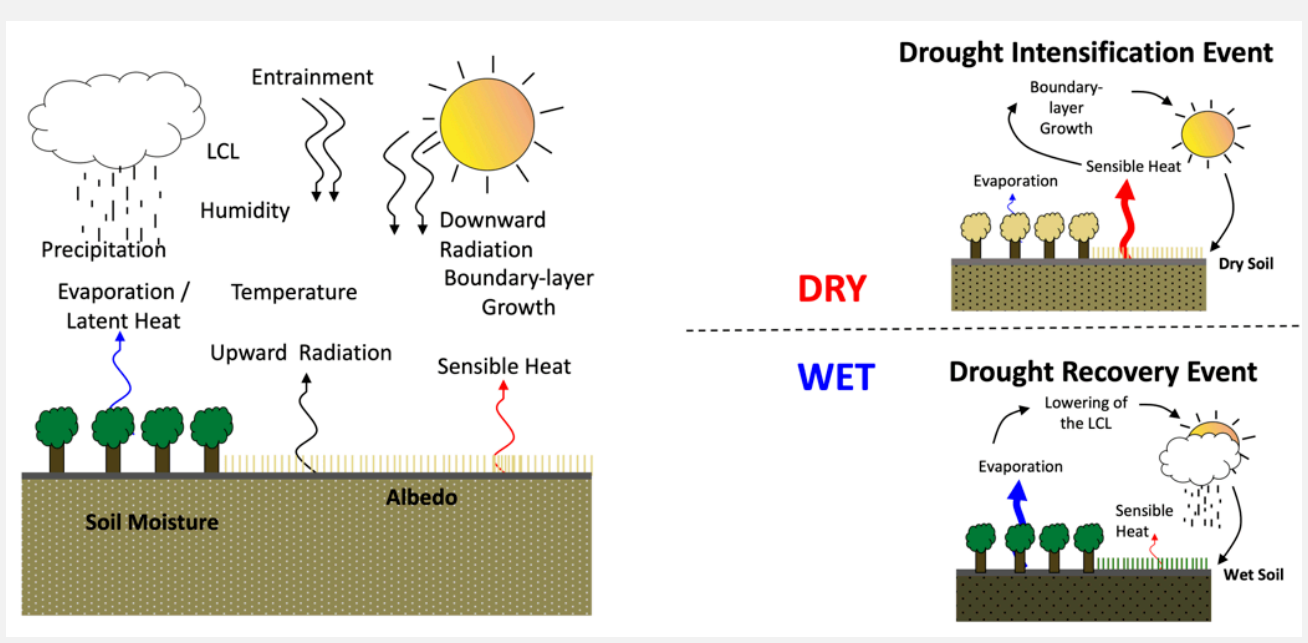
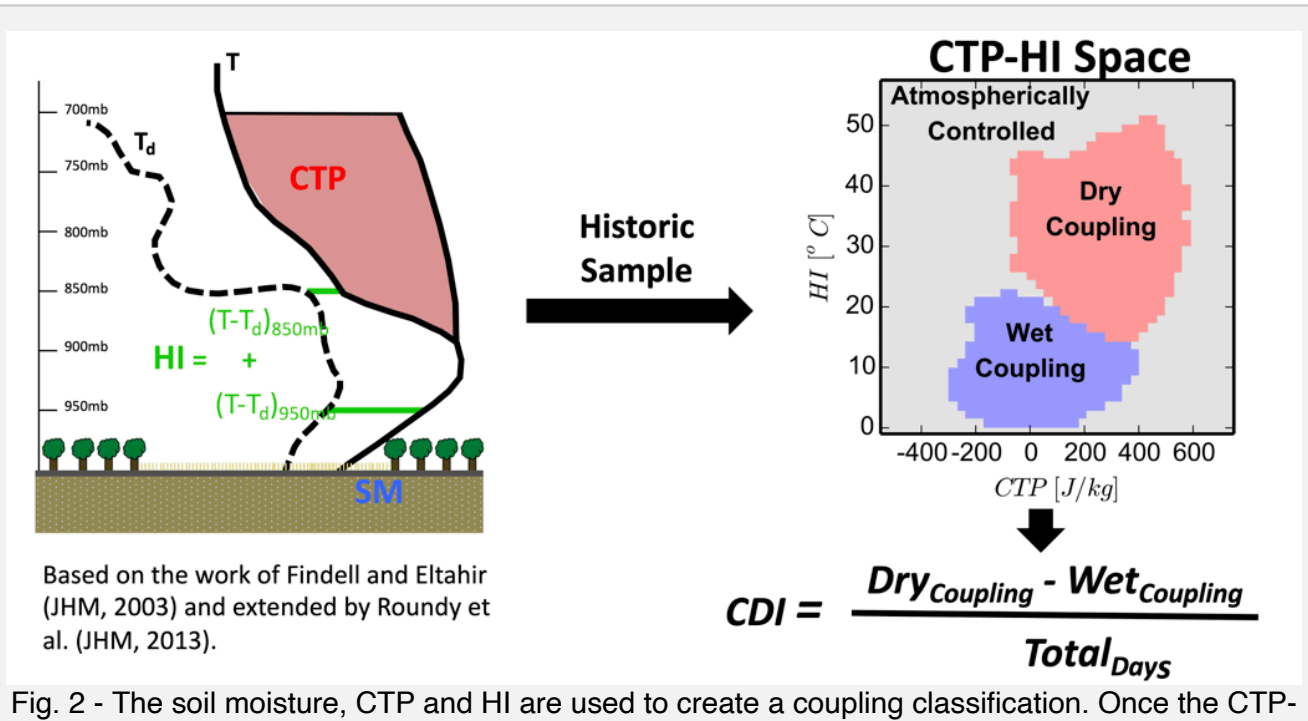


Fig. 1 - A simple schematic representing how the land-atmosphere feedbacks impact the development, persistence and recovery of extreme events.

The development of satellite-based land-atmosphere coupling metrics has great potential for providing a global reference data set of land atmosphere interactions that can be used for evaluating and improving earth system models. One such product is the Atmospheric Infrared Sounder (AIRS) that provides the needed atmospheric variables to quantify the atmospheric state on a global domain. The AIRS data set was recently updated from version 6 to version 7, which included improvements in the retrievals and calculations of the atmospheric profile variables. In this work we compare differences in atmospheric state and coupling metrics on a global scale between AIRSv6 and AIRSv7.

2.0 - COUPLING METRICS

An example of a L-A coupling metric is the Coupling Drought Index (CDI) which uses the low-level atmospheric humidity (HI), atmospheric instability (i.e., convective triggering potential, CTP) and soil moisture to provide a land-atmosphere coupling metric entirely based on remote sensing (**Fig. 2**).



Based on the work of Findell and Eltahir (JHM, 2003) and extended by Roundy et al. (JHM, 2013).

$$CDI = \frac{Dry_{Coupling} - Wet_{Coupling}}{Total_{Days}}$$

Fig. 2 - The soil moisture, CTP and HI are used to create a coupling classification. Once the CTP-HI space is classified, only CTP-HI is needed for daily classification. The daily coupling classification is then used to create the CDI metric.

For this work we are using the AMSR-E soil moisture from 2003-2011 to classify the CTP-Hi space and produce the CDI for both AIRSv6 and AIRSv7. The combination of AMSR-E and AIRS provides remotely sensed observations of both the land and the atmosphere that when combined in the CDI provide a good representation of drought intensification and recovery (**Fig. 3**.).

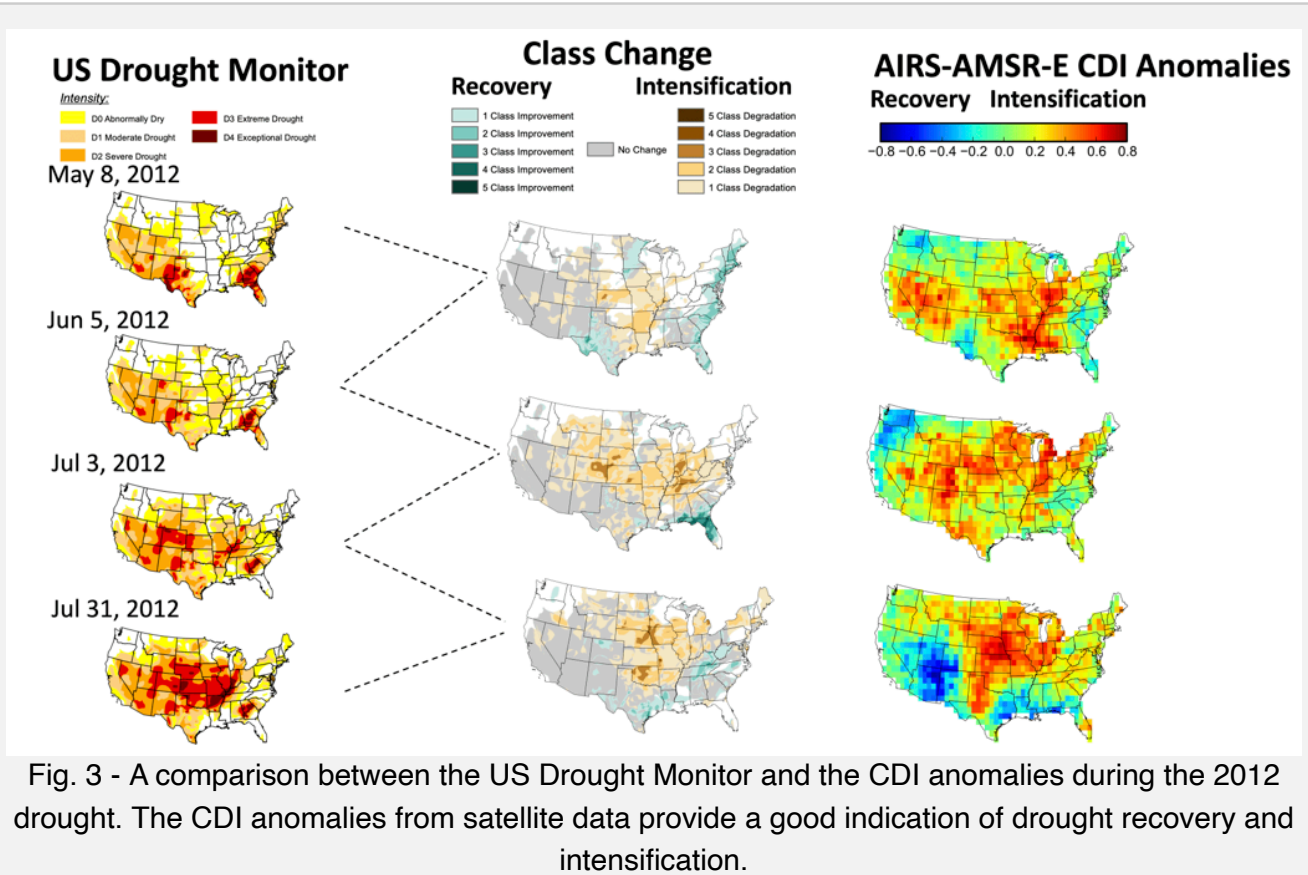


Fig. 3 - A comparison between the US Drought Monitor and the CDI anomalies during the 2012 drought. The CDI anomalies from satellite data provide a good indication of drought recovery and intensification.

3.0 - AIRS V6 VS V7 (CTP-HI)

First we compare the climatological difference of the atmospheric stability metric (CTP) and the atmospheric humidity metric (HI) between AIRS v6 and AIRS v7 from 2003-2021 (**Fig. 4**). For the stability metric, V7 is more stable over the arctic, parts of Northern Africa and central Australia. V7 is more unstable over the Himalayas and parts of the Americas. For the humidity metric, V7 is drier across the globe, but especially for Western North America, Northern Africa, Southern South America, Australia and Central Asia.

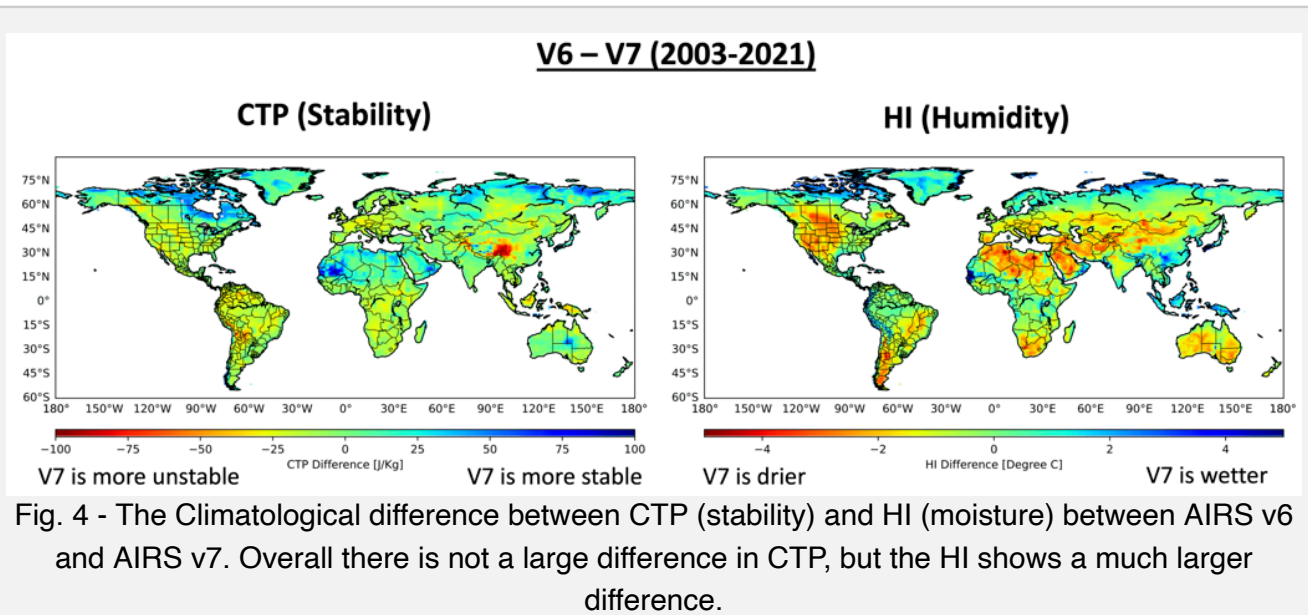


Fig. 4 - The Climatological difference between CTP (stability) and HI (moisture) between AIRS v6 and AIRS v7. Overall there is not a large difference in CTP, but the HI shows a much larger difference.

Considering only the May-Sep season (**Fig. 5**), there is still little change in the CTP, but some small changes with V7 being more unstable across the western US. V7 is still much drier and the spatial patterns are more pronounced, especially for the wetter changes in V7.

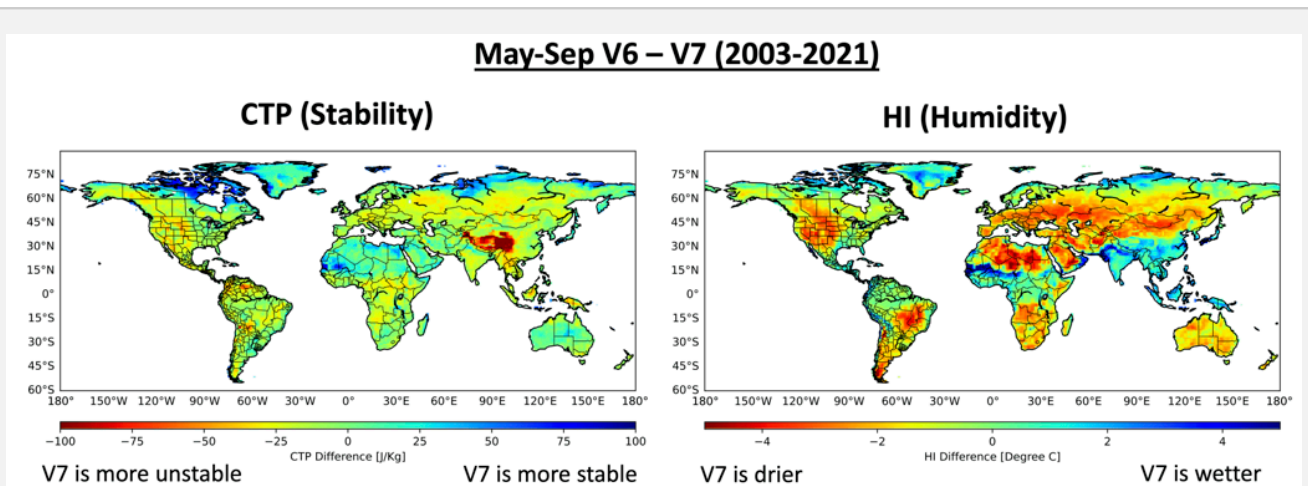


Fig. 5 - Seasonal (May-Sep) Climatological difference between CTP (stability) and HI (moisture) between AIRS v6 and AIRS v7.

Next we compare the correlation between the V6 and V7 for both the CTP and HI (**Fig. 6**). There is less correlation between V6 and V7 in the stability metric over the tropics, arctic and the Himalayas. The humidity metric shows less correlation over the entire globe but especially over the tropics.

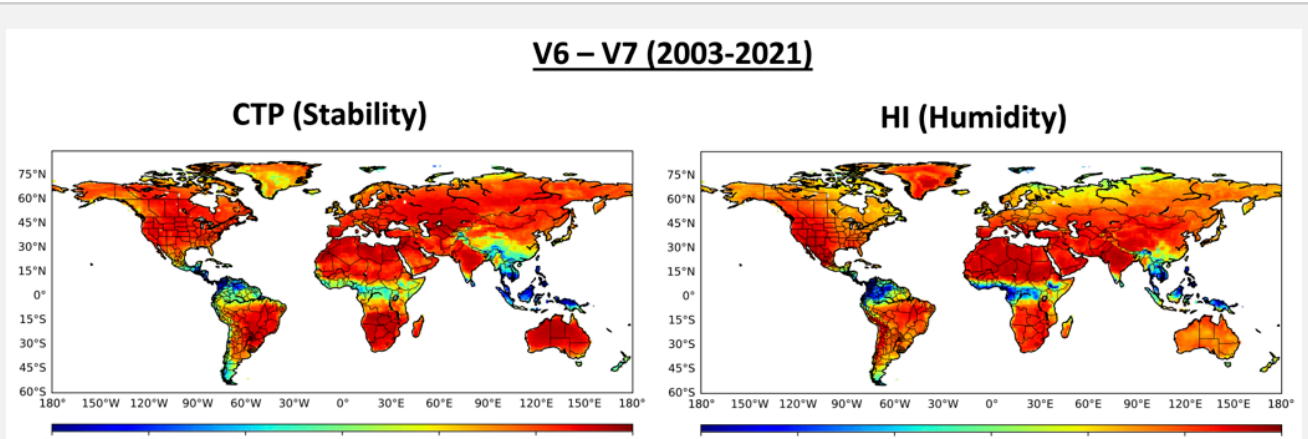


Fig. 6 - Daily Correlation in CTP and HI between AIRS V6 and AIRS V7.Caption

4.0 - AIRS V6 VS V7 (CDI)

First we compare the climatological difference in the CDI between AIRS v6 and AIRS v7 (Fig. 7). The CDI here is based on using the AMSR-E soil moisture from 2003-2011 to classify the CTP-HI space. There is little impact on the coupling in the Arctic, mainly because there is no coupling. The US shows a mixed response with V7 showing an increase in dry coupling in the west and an increase in wet coupling east.

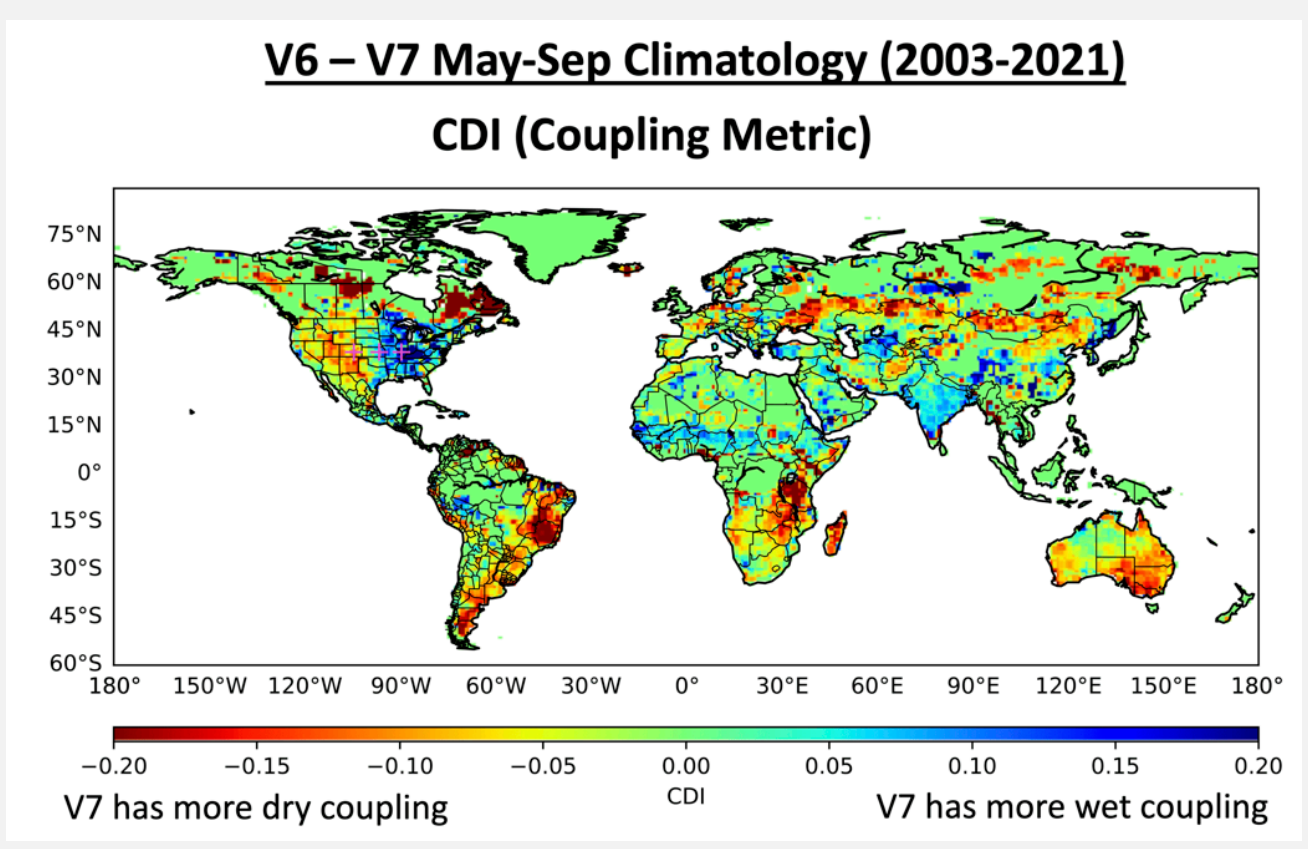


Fig. 7 - Seasonal (May-Sep) Climatological difference between CDI (coupling metric) between AIRS v6 and AIRS v7. The pink markers indicate the locations of the three sites considered below.

As there is a strong gradient in the difference between V6 and V7 across the Midwest US, we look at three represented locations across this gradient. The first location in Western Colorado (Fig. 8), shows that V7 has more dry coupling than V6. This can be seen in both the CTP-HI space as well as the timeseries and seems to be more pronounced after 2006. Despite this, the year to year variability is mostly consistent.

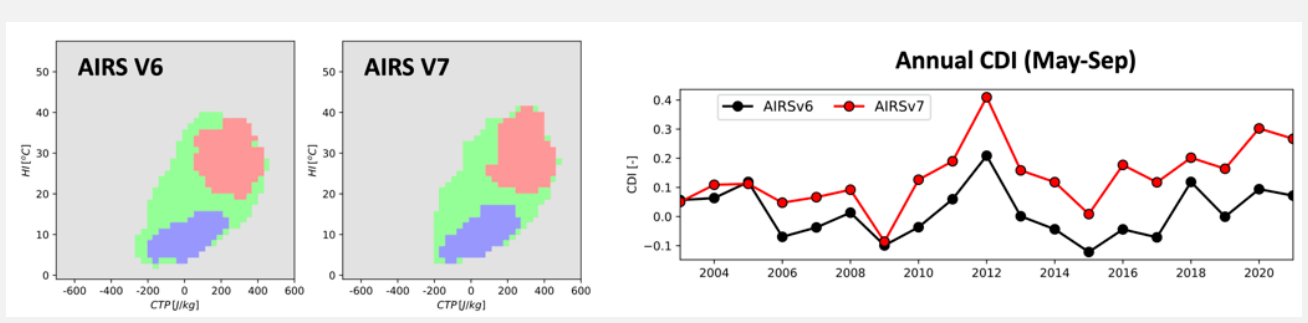


Fig. 8 - Difference in CDI Climatology May-Sep (-0.123) for a location in Western Colorado (38.5, -104.5).

Next we consider a grid cell over Eastern Kansas (Fig. 9), which shows little difference between the V6 and V7 in terms of the climatological CDI. While there are some minor differences, for the most part the two versions are mostly consistent in both the CTP-HI space and timeseries.

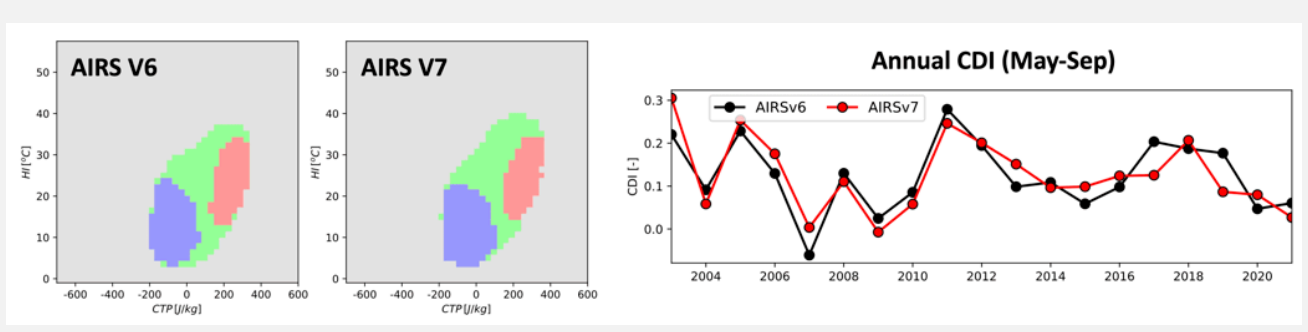


Fig. 9 - Difference in CDI Climatology May-Sep (-0.002) for a location in Eastern Kansas (38.5, -96.5).

Lastly, we consider a grid cell over Southern Illinois (Fig. 10), which shows a strong wet bias in the CDI between V6 and V7. At this location there is no classification of dry coupling in the CTP-HI space which leads to the very large bias towards wet coupling in V7. Particularly after 2012, there is little correlation between V6 and V7 at this location.

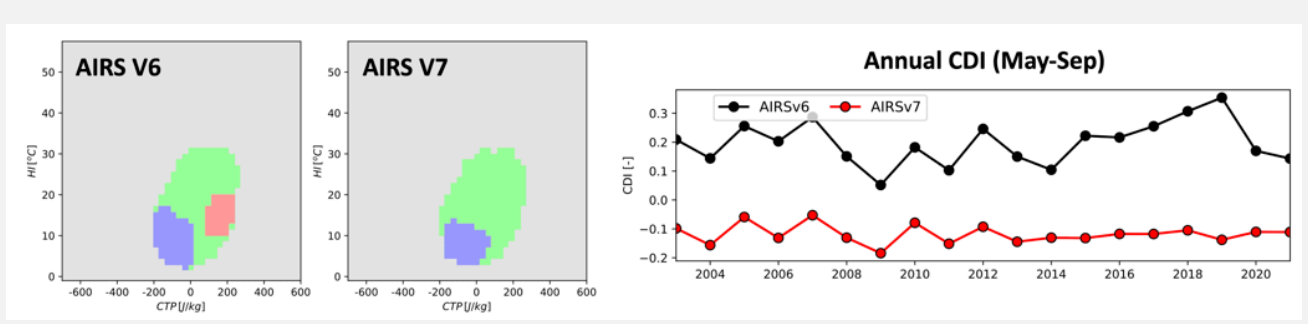


Fig. 10 - Difference in CDI Climatology May-Sep (0.316) for a location in Southern Illinois (38.5, -89.5).

This change in the CDI from V6 and V7 has implications for the persistence of the coupling regimes in V7 compared to V6 that has global impact and will change the predictability of drought evolution through stochastic models (Fig. 11). In particular, the US and Eurasia show an increase in the atmospherically controlled persistence at the expense of dry persistence (Western US) and wet persistence (Eastern US).

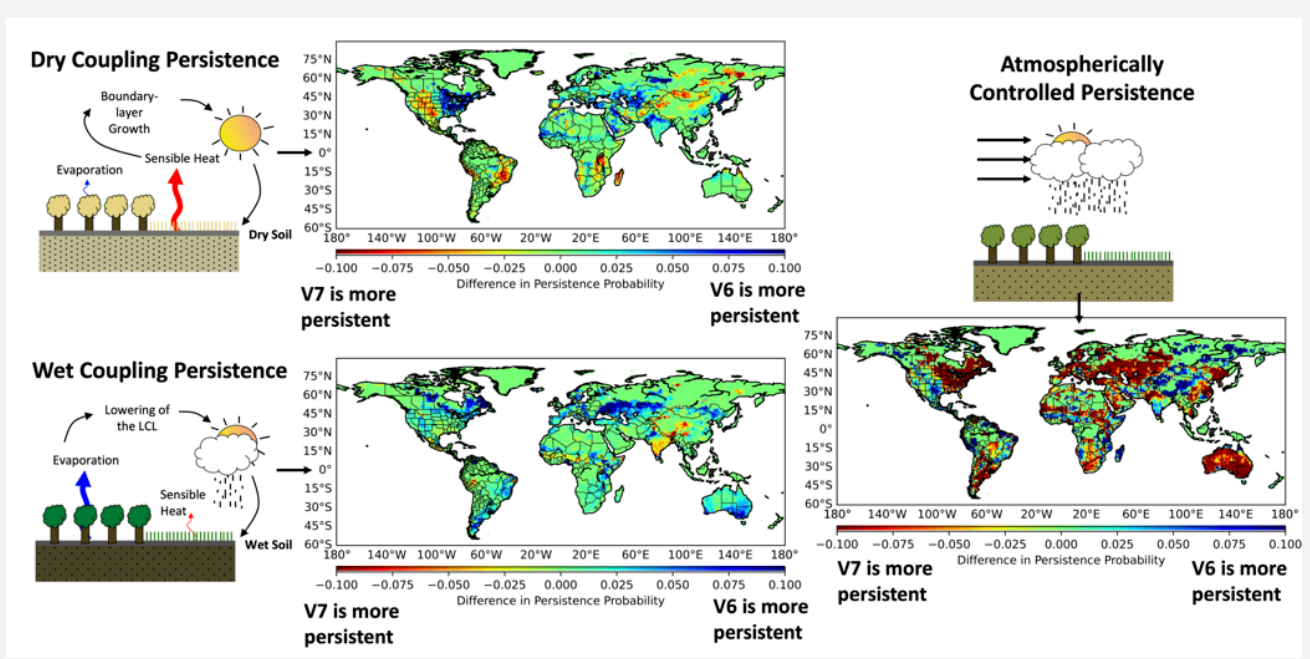


Fig. 11 - Global change in persistence of the three coupling regimes between AIRS V6 and V7.

5.0 - WHY THE CHANGE IN COUPLING?

The change from V6 to V7 resulted in the elimination of the dry coupling regime for a large area of the Eastern US. One possible reason for this is the sample size difference between V6 and V7 (**Fig. 12**).

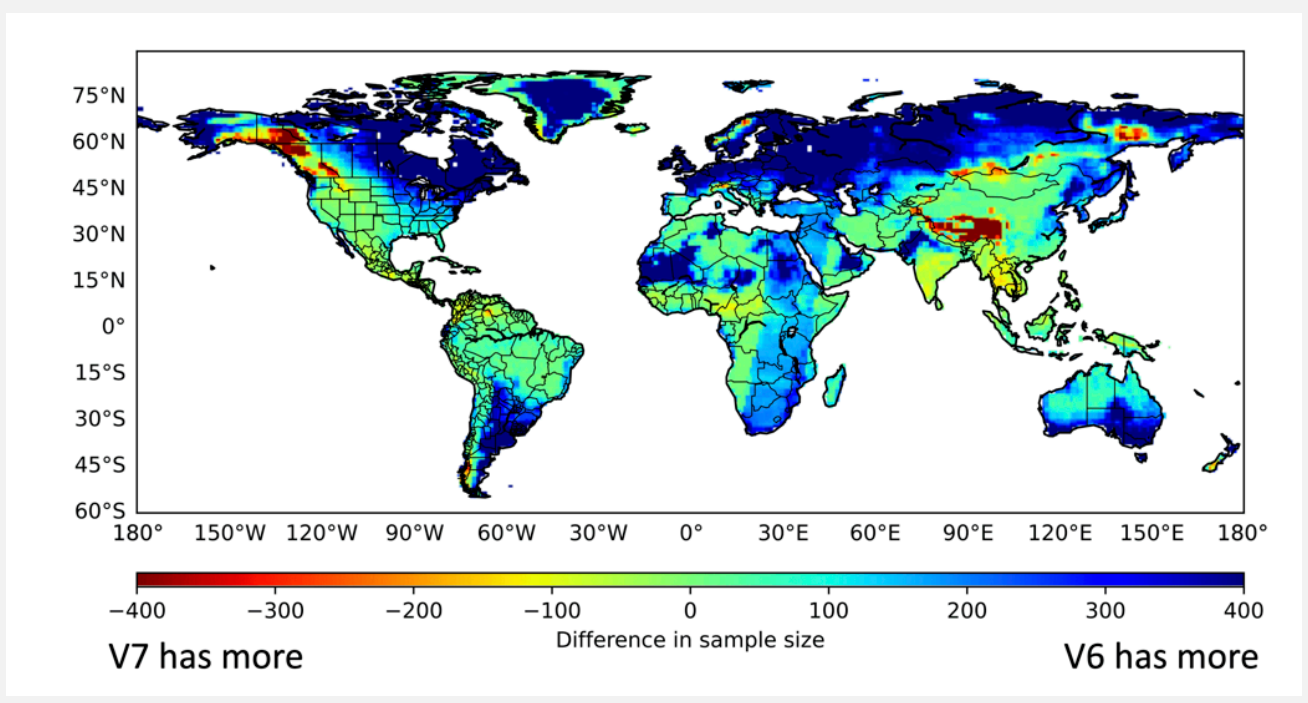


Fig. 12 - The difference in sample size between AIRS V6 and V7 for May-Sep 2003-2021. For most of the globe (including the Eastern US), AIRS V7 has fewer observations of both the CTP and HI.

AIRS V7 has a smaller sample than V6 for a large area of the globe including the Eastern US. However, the sample size difference does not explain the difference in the V6 and V7 in the Western US. This difference in sample size and the absence of the dry coupling regime in V7 can be accounted for in the coupling classification by increasing the number of surrounding grid cells used in the classification and thus increasing the sample size. Increasing the surrounding grid radius from 1 (Fig. 7) to 3 (**Fig. 13**) in the coupling classification reduces the wet bias in the CDI.

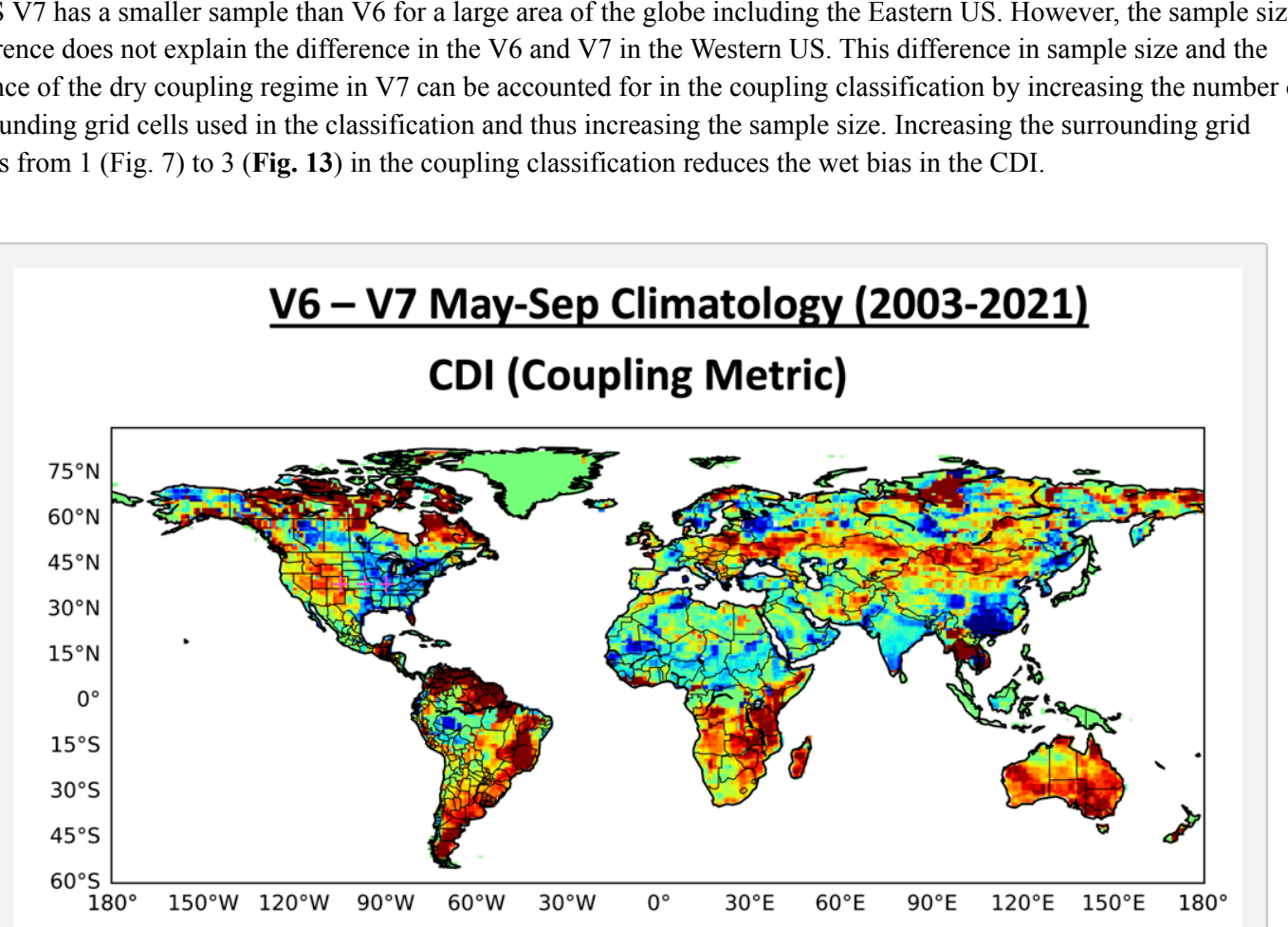


Fig. 13 - Seasonal (May-Sep) Climatological difference between CDI (coupling metric) between AIRS v6 and AIRS v7 with a larger sample size in the classification.

While a decrease in the wet coupling bias is achieved in the Eastern US by increasing the sample size, the dry bias across the globe is increased. This indicates that the change from V6 to V7 does still impact the CTP and HI and therefore the coupling even when accounting for sample size. This leads to the question, do these changes result in a more representative product? To assess this we compare the correlation of the CTP and HI from AIRS V6 and V7 with a merged reanalysis product that uses MERRA, CFSR and ERA5 (**Fig. 14**).

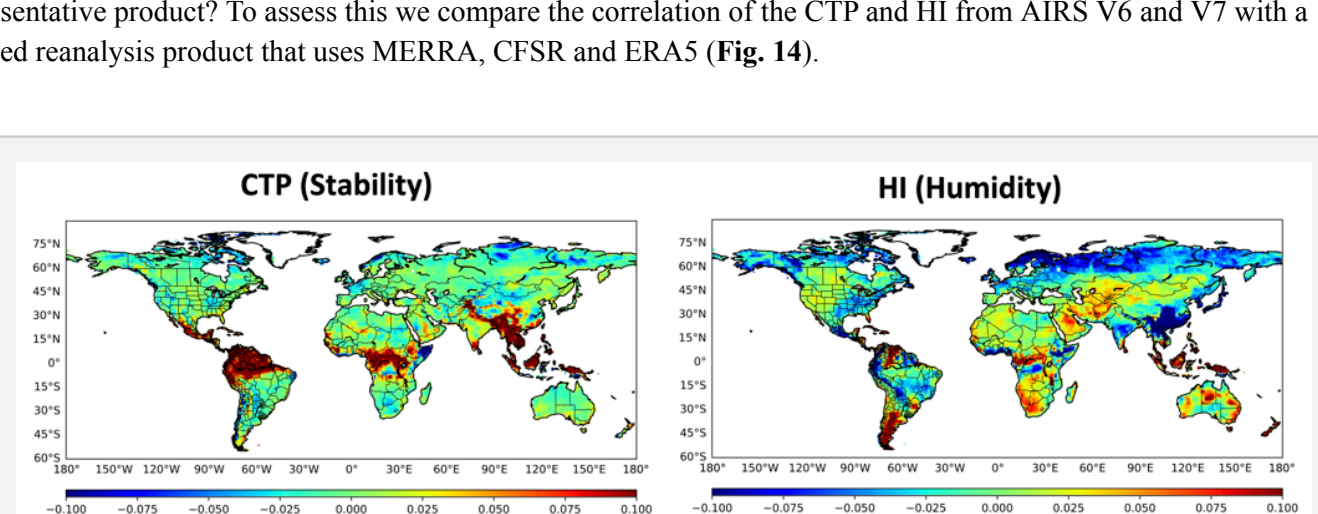


Fig. 14 - The difference in Spearman Correlation between AIRS V6 and AIRS V7 with a merged reanalysis reference data set.

For the stability metric, V6 shows a higher correlation with the reference data set over the tropics than V7. The humidity metric shows a much more nuanced result that varies across the globe. It is noteworthy that the eastern US has a larger correlation in V7.

6.0 - CONCLUSIONS

Below is a summary of the main results from this work:

- Changes from AIRS V6 to V7 resulted in minor changes in the stability metric, but more substantial changes in the humidity metric.
- These changes from AIRS V6 to V7 are more pronounced during summer.
- This influenced the coupling metric towards more dry coupling in the western US and the eastern US towards more wet coupling.
- These changes are seen both in the CTP-HI space and the resulting timeseries.
- These changes result in higher persistence probabilities in dry coupling for the western US at the expense of both wet and atmospherically regimes, while the eastern US has a lower persistence in dry coupling and an increase in atmospherically controlled.
- The bias towards wet coupling in the Eastern US is partially explained by the decrease in sample size in the AIRS V7 and can be improved by increasing the sample size in the coupling classification. However, even with this there is still a wet bias in the eastern US and dry bias in the western US in AIRS V7 compared to AIRS V6.
- Comparing AIRS V6 and V7 to a reference reanalysis data set indicates that V7 has a larger correlation than V6 over the eastern US for the humidity index, however other areas of the globe show mixed results.

Funding: Soil Moisture Active- Passive Science Team NNH19ZDA001N-SMAP

TRANSCRIPT

ABSTRACT

A long research history has shown the influence of soil moisture on the evolution of the boundary layer and the initiation of convection, and ultimately, precipitation, and how these processes provide a feedback mechanism between the land and the atmosphere that provides a means of predictability. A lot of this work was based on understanding the role of the land state in the earth system through interactions and feedbacks using both observations and prediction models, with most of this work relying on models as there is a lack of observations of land-atmosphere variables that span a global domain. The development of satellite-based land-atmosphere coupling metrics has great potential for providing a global reference data set of land atmosphere interactions that can be used for evaluating and improving earth system models. One example of this is the Coupling Drought Index (CDI) metric which uses the low-level atmospheric humidity (HI), atmospheric instability (i.e., convective triggering potential, CTP) and soil moisture to provide a land-atmosphere metric entirely based on remote sensing. One challenge with using satellite data is that satellite data inherently has a lot of uncertainty as well as a large spatial and vertical resolution for the atmospheric variables. The Atmospheric Infrared Sounder (AIRS) is a remote sensing-based observation that provides the needed atmospheric variables to calculate the CTP and HI on a global domain. The AIRS data set was recently updated from version 6 to version 7, which included improvements in the retrievals and calculations of the atmospheric profile variables. In this work we compare differences in the CTP and HI and the resulting coupling classification using the Coupling Drought Index (CDI) metric with SMAP soil moisture over the US. The results show that changes from AIRS V6 to V7 resulted in minor changes in the stability metric, but more substantial changes in the humidity metric. These changes from AIRS V6 to V7 are more pronounced during summer. These changes have implications for the coupling metric and indicate that the western US tends towards more dry coupling, where the eastern US tends towards more wet coupling. These changes are seen both in the CTP-HI space and the resulting timeseries. These changes result in higher persistence probabilities in dry coupling for the western US at the expense of both wet and atmospherically regimes, while the eastern US has a lower persistence in dry coupling and an increase in atmospherically controlled.