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A Workshop on Using NASA AIRS Data to Monitor Drought for the U.S. Drought Monitor

Alireza Farahmand,

Sharon Ray

Heidar Thrastarson

Stephen Licata

Stephanie Granger

See next page for additional authors

Authors

Alireza Farahmand,; Sharon Ray; Heidar Thrastarson; Stephen Licata; Stephanie Granger; and Brian Fuchs

BAMS Meeting Summary

A Workshop on Using NASA AIRS Data to Monitor Drought for the U.S. Drought Monitor

Alireza Farahmand, Sharon Ray, Heidar Thrastarson, Stephen Licata,
Stephanie Granger, and Brian Fuchs

Using AIRS Products to Monitor Drought for the USDM

What: USDM authors and NASA/JPL AIRS drought team highlighted the capabilities of NASA AIRS products for monitoring drought.
When: 1 April 2022
Where: Online

KEYWORDS: Drought; Extreme events; Climatology; Remote sensing; Satellite observations

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Corresponding author: Alireza Farahmand, alireza.farahmand@jpl.nasa.gov
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AFFILIATIONS: Farahmand, Ray, Thrastarson, Licata, and Granger—Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; **Fuchs**—National Drought Mitigation Center, University of Nebraska Lincoln, Lincoln, Nebraska

Recent studies indicate that drought indicators based on near-surface air relative humidity (RH), air temperature (*T*), and air vapor pressure deficit (VPD), derived from the Atmospheric Infrared Sounder (AIRS) instrument aboard NASA's *Aqua* satellite can detect the onset of drought earlier than other drought indicators, specifically standardized precipitation index (SPI), which is widely used for drought onset detection.

A recent study showed that standardized relative humidity index (SRHI) can detect drought signals earlier than SPI (Farahmand et al. 2015). Relative humidity is a climate variable defined as the ratio of air vapor pressure to saturated vapor pressure. Precipitation and relative humidity are related to each other in the sense that significant precipitation is not expected at low relative humidity. SRHI detected drought onset earlier or at the same time as SPI with a global average of approximately 0.6 (i.e., 60% of all events) and the mean lead time of 1.9 months. Also, SRHI successfully detected the early signs of the 2012 Midwestern drought, the 2011 Texas drought, and the 2010 Russian drought (Farahmand et al. 2015).

In another study, standardized vapor pressure deficit (SVPD) and standardized temperature (ST) indicators from the AIRS mission have been shown to detect drought earlier or at the same time as SPI with an average lead time of 1.5 months and in 60% of events in the CONUS (Behrangi et al. 2016). VPD is an important climate variable, incorporating elements of both temperature and relative humidity. VPD is also a major controlling factor of evapotranspiration demand. With increasing air aridity, VPD increases which in turn indicates greater evaporation stress. Studies show that VPD reported increases during the formation and rapid intensification of drought conditions during the 2011 and 2012 drought events, suggesting that remotely sensed VPD holds considerable potential for drought early warning and assessment (Behrangi et al. 2015; Farahmand et al. 2021).

AIRS and USDM

The U.S. Drought Monitor (USDM) framework is a drought monitoring system that considers several variables including short- and long-term drought indicators, vegetation information, hydrologic indices, and remote sensing information along with the ground validation to create weekly drought maps. The USDM authors combine the objective drought indicators and the subjective inputs of local and regional experts such as state climatologists, National Weather Service staff, extension agents, and hydrologists to synthesize the best available data and manually create weekly drought depictions for the United States. The USDM maps are generally at the spatial resolution of counties. The USDM maps are available since 1999 and show areas of the United States under drought in six classifications: no drought, D0 (abnormally dry), D1 (moderate drought), D2 (severe drought), D3 (extreme drought), and D4 (exceptional drought) (Svoboda et al. 2002).

Given the aforementioned value of AIRS drought products in detecting drought onset, the AIRS drought team initiated a conversation with the National Drought Mitigation Center (NDMC) in early 2016 to explore the possibility of integrating AIRS drought products into the USDM process. The AIRS drought team later visited the NDMC at the

University of Nebraska Lincoln (UNL) in the spring of 2016 and showcased the value of AIRS near surface RH, *T*, and VPD drought products in detecting drought onset. NDMC agreed to evaluate and potentially utilize AIRS drought products in generating weekly drought maps. To that end, each of the AIRS RH, *T*, and VPD drought products were binned into four time scales of 7-, 14-, 28-, and 56-day averages resulting in a total of 12 drought products that could be utilized to help with drought assessment. All 12 drought products were formatted specifically for use by USDM authors including a specific type of projection, data format, and color bar. All data have been staged at the publicly accessible NASA JPL server and pulled by NDMC every Monday since April 2017. In 2020, the AIRS project added an "integrity" check before delivering all products to ensure maps follow the requirements set by USDM. It is important to note the AIRS drought products are derived from direct satellite observations, which add another remotely sensed tool to the suite of satellite products being utilized in the weekly USDM assessment.

Workshop development

Although AIRS drought products have been successfully delivered to NDMC since 2017, the AIRS project had little insight into the value of these products and the extent to which they were utilized by the USDM authors. The AIRS project sought to determine whether a future investment in its drought products would be of value to the drought community. In addition, the team wanted to know if the drought products are currently being used in the USDM process and, if so, could specific requests or suggestions by the authors inform future product development? To that end, the AIRS project hoped to find out the following from USDM authors:

1) Are you using AIRS products?
2) Do you understand how to use the products?
3) Do you find value in the products or have suggestions to improve the products?

To justify further investment in the AIRS drought products and to gather information from the USDM authors, the AIRS project proposed to hold a training session to reintroduce the products to the authors and provide a set of best practices and case studies to help maximize the utility of the AIRS products. The training goals are summarized in the following:

1) Provide training to the USDM authors on best practices using AIRS data.
2) Survey the USDM authors with questions that will allow the AIRS project to determine the next steps.

For step 1, the AIRS drought team initiated a conversation with Brian Fuchs of the NDMC who is one of the USDM authors. Brian Fuchs expressed interest and encouraged the JPL team to hold the workshop and to administer surveys to gather information from the USDM authors. A short survey would immediately follow the workshop and assess the effectiveness of the training. A long survey would be distributed several months after the workshop and assess the value and usability of AIRS drought products after giving the authors time to use the products. Finally, the NDMC offered to provide a review of the surveys using the services of social scientists on staff.

After polling the USDM authors, 1 April 2022 was selected as the training date. Training materials were prepared by the AIRS drought team and uploaded to the AIRS website. The AIRS project performed two test runs, one internally and one with Brian Fuchs. An invitation for the workshop was composed by the AIRS project and emailed to the authors by Brian Fuchs to ensure all authors were notified. The email included the training agenda, a brief history

Table 1. Short survey prepared by the AIRS drought team and administrated during the workshop.

Question	Mentimeter format
What is your main area of interest regarding drought? *Examples: Monitoring, forecasting, impacts on vegetation, agriculture*	Open ended
Have you used the AIRS drought products previously in the development of the USDM?	Pick one Frequently Sometimes I used them but they didn't work for me Never used them
After this training, how likely are you to use the AIRS drought products?	Pick one Very likely Likely Not likely
Which AIRS drought products are most useful to you? *Examples: 7-day RH, 14-day VPD*	Pick one each from 2 lists: Products and cadences
Under what circumstances would you most likely use the AIRS drought product(s)? *Examples: Early warning & long-term drought; flash drought*	Open ended
Would an AIRS drought product (RH, *T*, VPD) at a different time scale be useful to you? If so, please specify *Example: 3-month VPD, 6-month RH*	Open ended
A posttraining survey is planned at a later date. How much time would you like to use the AIRS products before the survey is released?	Pick one 3 months 6 months 1 year

of the AIRS drought products for the USDM, and the objective of the workshop. The meeting was planned for 90 min, but was scheduled for 2 h in case more time was needed for Q&A. Additionally, both the short and long surveys were reviewed and improved by the AIRS project, Abigail Nastan (Systems Engineer at JPL), Brian Fuchs (NDMC), and NDMC social scientists prior to the training. Table 1 shows the short survey questions that were administrated using the Mentimeter web-based application.

Workshop agenda

The agenda of the training included three sections: context, best practices for interpreting the imagery, and going forward, all described below.

Context

The benefits of satellite data, AIRS data for drought monitoring, and the history of AIRS, NDMC, and USDM were discussed in this section. This content is covered in the first section of this paper.

Best practices for interpreting the imagery

This portion of the workshop covered the methodology used in the creation of products, color in the AIRS imagery, and three drought-development case studies.

High-level summary about the methodology. All drought products are derived from daily AIRS version 6 level 2 HDF data files. Level 2 data are organized according to a satellite swath path at 50 km resolution but are not gridded. Surface RH and *T* exist as data fields in the delivered data products. Surface dewpoint temperature (Td) is calculated from RH and *T*. This enables the calculation of the third parameter VPD using *T* and Td (Behrangi et al. 2016). The AIRS

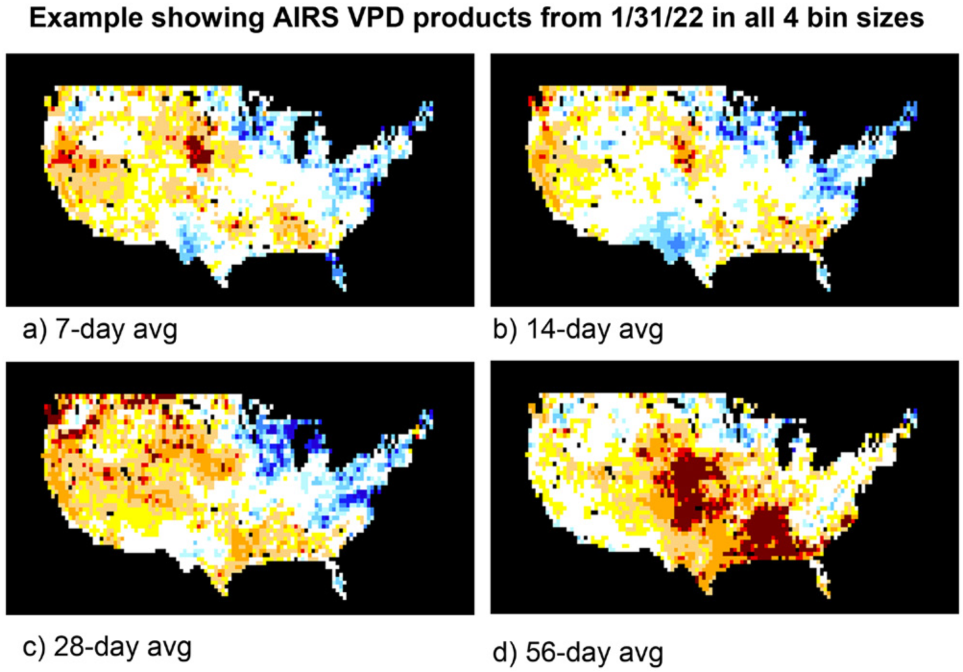

Fig. 1. **An example set of AIRS drought products for the period ending on 31 Jan 2022.**

data extracted for these plots are only from the ascending node which corresponds to daylight conditions. Each daily dataset is then averaged into a latitude–longitude box measuring 0.5°. To derive drought conditions, we calculate the percentile rank of the most recent 7-, 14-, 28-, and 56-day periods for these parameters, within the context of those same calendar date ranges from the AIRS science data record going back to 1 September 2002. To that end, the Gringorten method is applied (Farahmand et al. 2015; Behrangi et al. 2016).

Finally, for each drought parameter and each of the four date range categories, a GeoTIFF file is generated, which shows an RGB triplet value (0–255) that translates the percentile rank into a specific color. The final integrated USDM drought map highlights AIRS data from the following drought categories: D0: yellow; D1: tan; D2: orange; D3: red; D4: brown. Figure 1 shows an example of AIRS VPD drought products for the period ending on 31 January 2022 in 7-day (Fig. 1a), 14-day (Fig. 1b), 28-day (Fig. 1c), and 56-day (Fig. 1d) averages.

Best practices for flash and conventional drought monitoring. We compared the AIRS drought indicators to Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2), SPI and standardized soil moisture index (SSI) for drought onset detection in three case studies. MERRA-2 provides reanalysis precipitation and soil moisture data at the resolution of 0.625° longitude × 0.5° latitude since 1980 (Gelaro et al. 2017). We used the moderate drought threshold of the 20th percentile and various smoothing scales depending on the type of drought. For simplicity, we only showcased AIRS VPD drought indicator (SVPD) results during the training.

Figure 2a shows the development of the 2012 Midwestern flash drought based on 2-month indicators of SVPD2, SPI2, and SSI2. The blue line indicates SVPD2, the red line indicates SPI2, and the yellow line indicates SSI2. As indicated, VPD showed the onset of drought several months earlier than precipitation and soil moisture. Precipitation showed the drought signals in May 2012. Soil moisture did not show drought conditions until June 2012. For this event, AIRS VPD data picked up a drought signal that might otherwise have been overlooked by precipitation and soil moisture.

In Fig. 2b, the development of the 2019 Southeastern flash drought is shown. This event developed rapidly during fall 2019. Due to rapid development, we assessed the drought

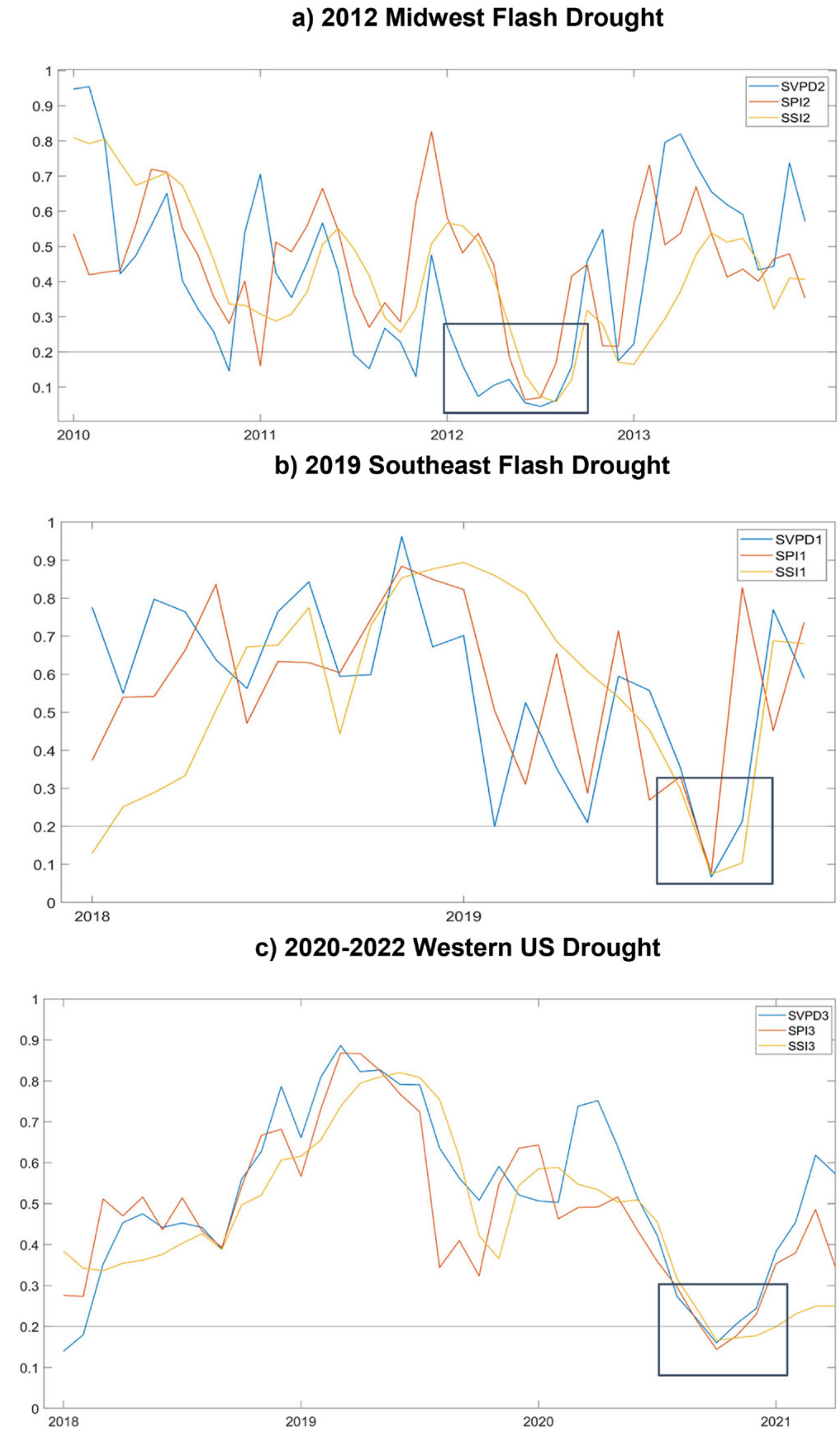

Fig. 2. **Assessment of drought onset for three case studies of (a) 2012 Midwestern flash drought, (b) 2019 Southeastern flash drought, and (c) 2020–22 western U.S. drought.**

development using 1-month drought indicators of VPD (SVPD1), precipitation (SPI1), and soil moisture (SSI1). As shown, the drought onset was simultaneously captured by all three indicators of SVPD, SPI, and SSI. In this case study of a very abrupt flash drought, the SVPD1, SPI1, and SSI1 signals all began at the same time.

Figure 2c shows the development of the 2020–22 western U.S. drought. To investigate this event, we looked at the 3-month drought indicators (SVPD3, SPI3, and SSI3), as this event was not considered a flash drought. As shown, the drought onset was simultaneously captured by all indicators. Although this event was not a flash drought, AIRS-based drought indicators along with drought indicators of precipitation and soil moisture were able to detect the drought onset. The results of these case studies have provided insight into the capability of AIRS data in identifying the precursor conditions of droughts, particularly in the case of flash droughts.

Going forward

The validation and continuity of AIRS drought products were discussed in the last portion of the workshop.

Validation. The AIRS drought products are derived from data products that are validated as part of the general AIRS data-validation strategy. All key variables are validated with independent datasets such as ground-based stations, other satellites, and reanalysis datasets. The AIRS level 2 near-surface air temperature and relative humidity data that are used to produce the AIRS drought products released to the USDM are validated as part of this process.

The latest version of AIRS data available to the public is version 7. In this version, a global, daily VPD product is included as a level 2 product. No comparison to the long-term data record (i.e., drought status) is included and the data are not processed to be reported as percentiles. However, all the data needed to create a long-term record for temperature, humidity, and VPD are available from September 2002 to the present.

The latest test report published with the release of version 7 includes an analysis of temperature, relative humidity, and VPD, specifically in the context of drought. It is based on the two latest versions of AIRS data (versions 6 and 7) and focuses on the case of the 2011 major drought in Texas. In summary, both versions 6 and 7 were found to capture anomaly locations and time series in the 2011 Texas drought.

Continuity. The AIRS instrument is expected to cease operations in the near future, but similar sounder data will continue to be available from other satellites. The Cross-track Infrared Sounder (CrIS) instrument will continue delivering similar capability, also paired with the Advanced Technology Microwave Sounder (ATMS). The CrIS and ATMS instruments on board the Joint Polar Satellite System (JPSS) have yielded global atmospheric temperature, pressure, and moisture profiles from space since 2011. AIRS products delivered to the USDM are not currently produced from CrIS/ATMS data but can be derived using the same principles. In the future, it is likely the AIRS drought products can be replicated using data from the CrIS instrument. Plans are being considered at this time but are not in place.

Discussion and survey

The training received exceptional attendance and feedback from eight USDM authors (there are a total of nine USDM authors). The entire workshop plus Q&A and survey was completed in 90 min. The training was recorded for distribution to the extended drought community. All training slides and recordings are now available on the AIRS website at airs.jpl.nasa.gov/applications/drought.

A short survey immediately followed the meeting. The following is the summarized outcome of the survey. The outcomes are ordered according to the survey questions (see Table 1):

1) Drought monitoring is the main area of interest of USDM authors. Other interests include historical perspective, forecasting, drought and agriculture, short term and seasonal, and new tools and ideas.

2) Prior to the training, most authors never or sometimes used the AIRS drought products. However, after the training, most authors are likely or very likely to use the AIRS drought products. This was an encouraging outcome for the AIRS project.
3) The most useful products in order would be VPD 28-day, VPD 14-day, and VPD 7-day. This indicates the USDM authors were most interested in the VPD drought products.
4) USDM authors would most likely use the AIRS drought products for flash drought monitoring, drought onset detection, and drought early warning.
5) Authors are interested in several products for time scales that are currently not provided including 3-day, 6-week, 3-month, and 6-month products. The 3-day product was requested for potential heatwave monitoring. The AIRS drought team will look into generating these requested time scales. However, due to the natural orbit of the AIRS mission, 3-day drought products will include major spatial gaps. Drought products at other requested time scales would not include any spatial gaps.
6) USDM authors would like to test and utilize AIRS drought products for at least 6 months before participating in the long survey.

In addition to the preplanned survey questions, we discovered an interest in generating AIRS drought products in spatial scales other than the continental United States. The authors indicated an interest in drought maps for U.S. territories including Puerto Rico and U.S. Virgin Islands. The AIRS project will investigate this request although the relatively coarse resolution (based on the AIRS footprint of around 50 km) might not meet the stakeholder expectations. However, the authors also indicated an interest in global drought products, which could be a promising tool for monitoring large-scale drought.

During the survey, several authors commented on the usefulness of the training. The comments included 1) "JPL could have the market cornered on the VPD and RH products. We need to find a way to get this out in front of more people in the climate/drought communities"; 2) "These are unique tool/products that USDM authors don't have from another source"; 3) "JPL has set the bar high for effective training."

Concluding remarks

A key takeaway of the AIRS drought product training for the organizers and potential users, including U.S. Drought Monitor authors, is that training is critical to increasing the usability of data products, and may have a significant impact on the future strategic and technical development of the AIRS drought products. Organizers also realized that it takes a team to create the training materials. Specifically, having a USDM partner as part of the training team was highly beneficial in determining what matters to the stakeholder, receiving feedback about training materials, and facilitating communication with all USDM authors.

Currently, the AIRS drought team is investigating improvements suggested by the USDM authors that include providing drought products at additional time scales, for U.S. territories, and at the global scale. A subsequent survey will be sent out to authors around 10 months after the workshop to obtain extended feedback for identifying potential future suggested improvements. Finally, as the AIRS mission reaches its end of life, the AIRS drought team is investigating options for data continuity by combining AIRS data and other satellites, such as CrIS/ATMS.

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