EXPLORING TRENDS THROUGH "RAINSPHERE"

Research Data Transformed into Public Knowledge

Phu Nguyen, Soroosh Sorooshian, Andrea Thorstensen, Hoang Tran, Phat Huynh, Thanh Pham, Hamed Ashouri, Kuolin Hsu, Amir AghaKouchak, and Dan Braithwaite

Climate is an area of interest that both influences and is influenced by the global population, and yet the transfer of critical basic knowledge about our climate system from scientists who specialize in the field to the general public is severely deficient. To bridge this gap and make understanding historical climate and climate projections accessible, an intuitive and user-friendly analysis tool called CHRS (Center for Hydrometeorology and Remote Sensing) RainSphere has been developed (hosted at http://rainsphere.eng.uci.edu; a YouTube video tutorial on CHRS RainSphere is available at www.youtube.com/watch?v=eI2-f88iGIY&feature=youtu.be).

CHRS RainSphere was designed as an educational tool that allows users to quickly and easily conduct analyses of historical and future precipitation at spatial scales that range from highly local to global and at daily, monthly, or annual time scales. With automatically generated time series, spatial plots, and basic trend analysis, users can swiftly explore historical precipitation estimates and future projections tailored to their specific interests. Allowing the data to speak for themselves in a way that the public can understand not only helps to spread the comprehension of climate and climate variability but also encourages independent inquisition and discovery of climate studies.

AFFILIATIONS: Nguyen—Center for Hydrometeorology and Remote Sensing (CHRS) and Department of Civil and Environmental Engineering, University of California, Irvine, Irvine, California, and Nong Lam University, Ho Chi Minh City, Vietnam; Sorooshian, Thorstensen, Tran, Huynh, Pham, Ashouri, Hsu, AghaKouchak, and Braithwaite—Center for Hydrometeorology and Remote Sensing (CHRS) and Department of Civil and Environmental Engineering, University of California, Irvine, Irvine, California

CORRESPONDING AUTHOR E-MAIL: Phu Nguyen, ndphu@uci.edu

DOI:10.1175/BAMS-D-16-0036.1

At the heart of CHRS RainSphere is the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks–Climate Data Record (PERSIANN-CDR) (Ashouri et al. 2015). This satellite-based precipitation product provides daily precipitation estimates from 60°S to 60°N latitude at a 0.25° spatial resolution. PERSIANN-CDR is derived from the parent PERSIANN algorithm (Hsu et al. 1997), which utilizes an artificial neural network to assign a surface rain rate based on brightness temperature retrievals of infrared information from geostationary Earth-orbiting satellites and passive microwave information from low-Earth-orbiting satellites. Validation of the PERSIANN product has been performed in several studies (i.e., Sorooshian et al. 2000; Miao et al. 2015, Ashouri et al. 2016). PERSIANN-CDR provides the ability to study extreme hydrometeorological phenomena. The record begins on 1 January 1983 and continues to the present date. This 30+-year retrospective look at global precipitation lends itself to a host of historical precipitation-related questions such as "How does this June's total precipitation compare to the average monthly total precipitation for June?" or "What is the trend in annual precipitation for my country?" These and countless other questions can be answered using PERSIANN-CDR facilitated through CHRS RainSphere.

Complementing the past precipitation estimates from PERSIANN-CDR, CHRS RainSphere features global precipitation projections from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) based on three carbon emission scenarios (RCP2.6, RCP4.5, and RCP8.5 for low, stabilized, and high emissions scenarios, respectively) from the Intergovernmental Panel on Climate Change (IPCC). More details on CMIP5 can be found in Taylor et al. (2012). Ensemble mean IPCC projected precipitation data from 29 CMIP5 models were obtained from the Canadian Climate Data and Scenarios site (http://ccds-dscc.ec.gc.ca). CMIP5 model results were interpolated to a common 1 × 1 degree grid (see more

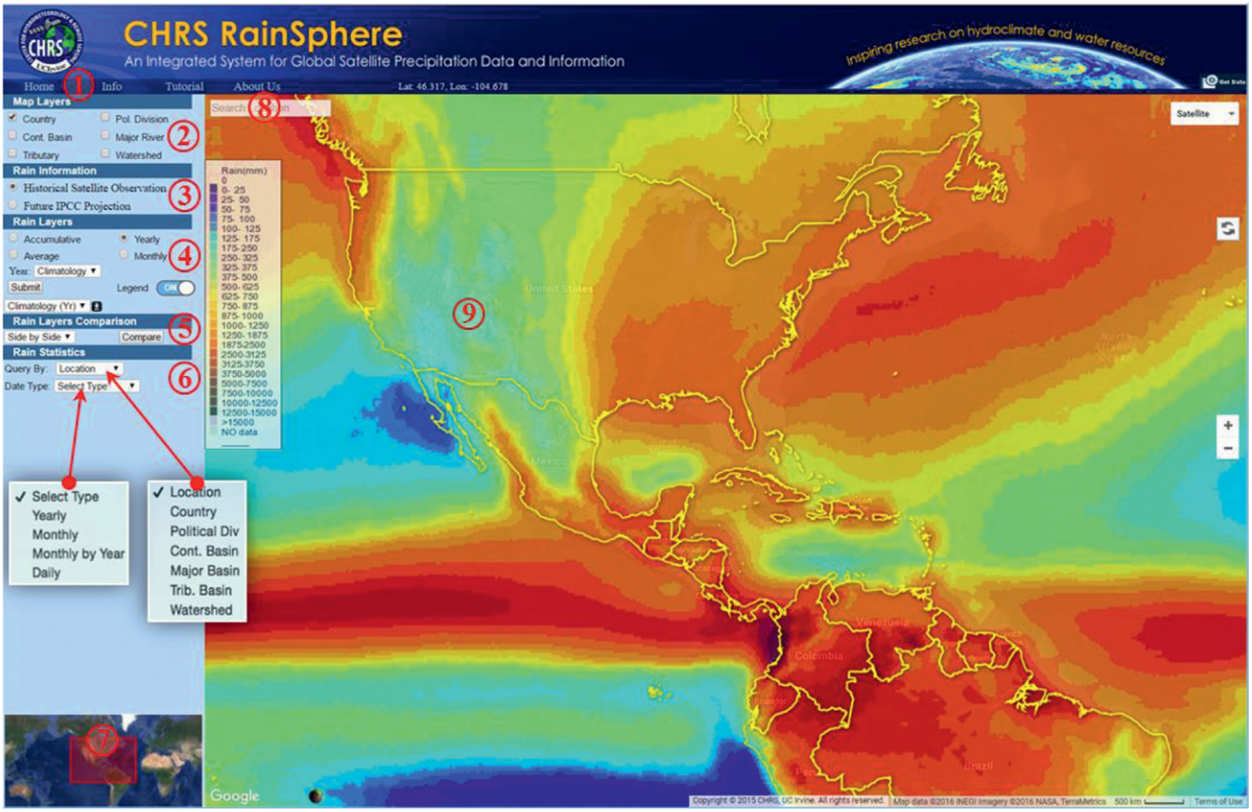

Fig. 1. CHRS RainSphere interface (http://rainsphere.eng.uci.edu): (1) Navigation Bar, (2) Map Layers, (3) Rain Information, (4) Rain Layers, (5) Rain Comparison, (6) Rain Statistics, (7) Reference Map, (8) Search Location, (9) Map Canvas.

details from the technical notes at http://ccds-dscc.ec.gc.ca/?page=technical-notes).

VISUALIZATION. The CHRS RainSphere interface features several options for visualization of precipitation data as well as map layers to provide an additional spatial reference as needed. Options for precipitation data display include total precipitation for a specific year or month, or a customized date range can be specified and the accumulated total or average precipitation for that date range can be displayed. For example, Fig. 1 shows the accumulated total precipitation for 1 January 2014 to 31 December 2014 (consequently, the precipitation display would be identical in this case if the "Yearly" radio button was selected and the year 2014 was selected). Additional map layer options for spatial reference include country boundaries, other political divisions (e.g., states and provinces), continental basins, major rivers, tributaries, and watersheds (Lehner and Grill, 2013). Figure 1 shows the map visualization with the "Country" map layer added for spatial reference.

In addition to the options for precipitation and map layers, the user can adjust the basemap to either a satellite image (shown in Fig. 1) or a map layer, and can toggle labels on or off. Furthermore, when zooming in to a higher spatial resolution than the full global view (not shown), a location reference box in the lower left corner of the interface is drawn to show exactly where on the globe the current view is located.

BROWSING THE DATA. CHRS RainSphere provides a wide range of options for querying data. In addition to the map layer options previously mentioned, spatial query options include spot locations (highly localized regions, see Fig. 1). The location query option is a searchable tool that places a pin on the location entered in the "Search Location" bar. Alternatively, the user can manually click a point to query the data rather than use the search bar. Selection of any of the other spatial query options automatically generates a labeled map layer for that option, and the user need only click on the spatial unit of interest to query the precipitation data.

Along with the spatial querying options, users have at their disposal several temporal options under the "Date Type" drop-down menu, including yearly, monthly, monthly by year, and daily time periods (Fig. 1). When combined with the spatial query options, these temporal options provide a flexible framework for precipitation data exploration.

DATA INTERPRETATION. At the final stage of the data browsing process, an automated report is generated for the spatial location and time period selected. These reports include information on the query method used, the region of interest, and the time period selected. A bar plot with the precipitation for each time step (day, month, or year) within the time range selected appears with its corresponding mean and linear regression. These basic statistics allow for expedient interpretation of general trends and average behavior for the selected area during the selected time. A Mann-Kendall test is also performed, and results are automatically generated and reported as part of the statistics suite. The Mann-Kendall test is used to statistically investigate whether to reject the null hypothesis of no trend in the data, with a p value equal to or greater than 0.05 in this calculation indicating acceptance of the null hypothesis. Below that value the alternative hypothesis is accepted with a smaller value of p indicating higher confidence that a trend exists. This test has been demonstrated as a useful tool for evaluating global climate trends (see Damberg and AghaKouchak 2014). More information about the Mann-Kendall test can be found in Mann (1945) and Kendall (1976). For illustration, Fig. 2 displays the statistical summary for yearly precipitation in the state of California from 1983 to 2015.

It is well known that 2013 was a severe drought year in California, and in fact, a quick scan of the figure shows that it was the driest year in California for the past three decades (highlighted in the green dotted circle in Fig. 2). Users can also visually see how many years the state has been below the average precipitation level and that there is a slight downward trend in annual precipitation for the past 33 years. The figure also provides information on the statistical significance of the trend. All of this information is available in a highly interpretable form with but a few

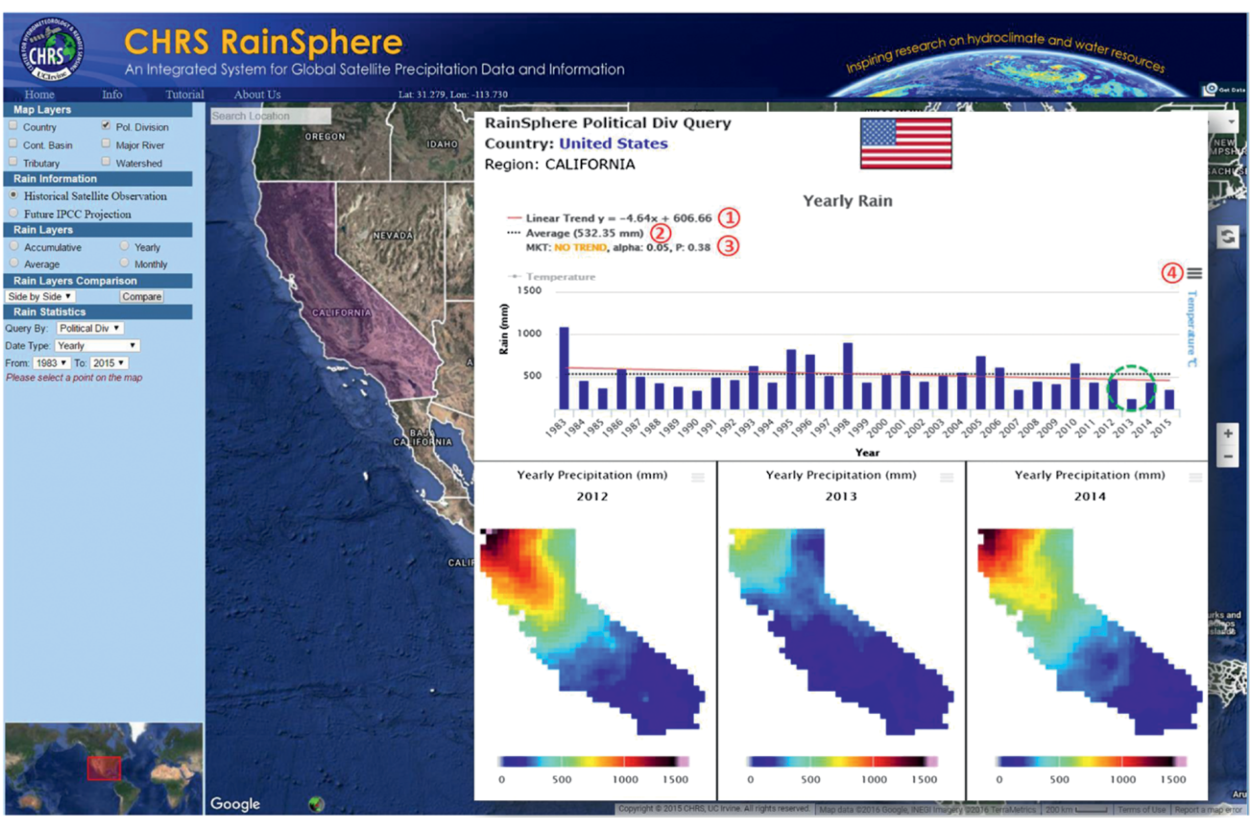

Fig. 2. Rain Query Report: (1) Rain Linear Trend, (2) Rain Average, (3) Mann-Kendall Test, (4) Download Image/Data.

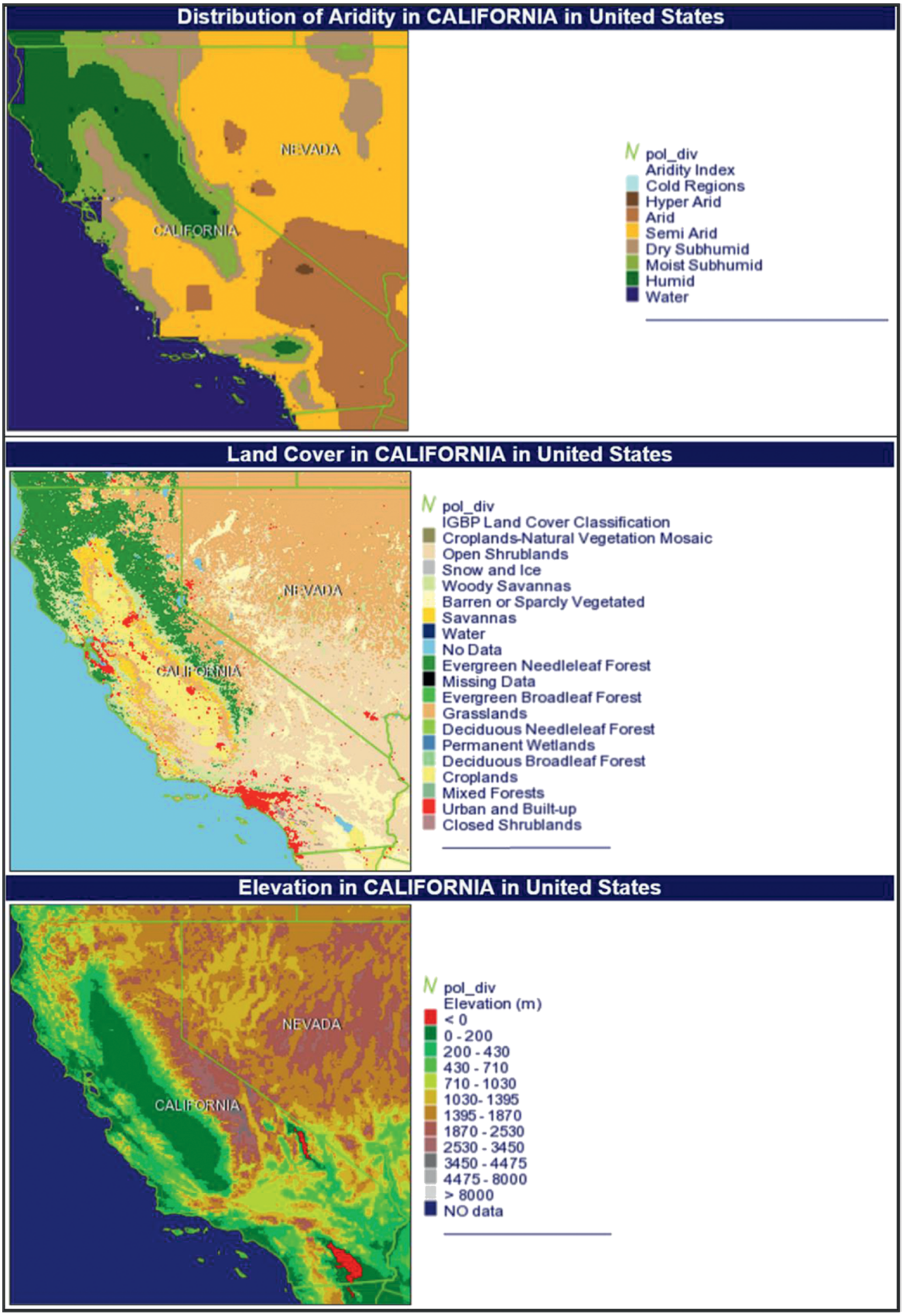

Fig. 3. Area information summary: Distribution of aridity, land cover, and elevation. Land cover classification is from the International Global Biosphere Programme (IGBP).

mouse clicks within the CHRS RainSphere tool. While it is interesting to see how a region's total or average precipitation varies in time, the spatial distribution tendencies may also be of interest. CHRS RainSphere provides the user with the option to explore spatial patterns of precipitation within a specified area. From these visualizations, valuable information may be extracted, including which subregions get the most or least precipitation or if there is an apparent shift in the location of either wet or dry extremes. In addition to outreach and educational applications, CHRS RainSphere can also support researchers in their data extraction and processing. Extracting local or country-scale data from remote sensing observations and climate model simulations is time consuming. With the built-in GIS-based features, RainSphere enables users to extract local watershed-scale and country-scale data very efficiently. Users also have the opportunity to download both the time series analysis data and the spatial analysis data from these reports for their own use, or save the entire generated report as a PDF.

Rounding out the automatically generated reports is a summary of the land use/land characteristics of the selected region of interest. These reports include distribution of aridity, land cover, and elevation. An example of this summary is shown for the state of California in Fig. 3. See Channan et al. (2014) for a thorough description of the data used in these summaries.

LOOKING INTO THE FUTURE. While interpretation of the climate system in terms of past precipitation is critically important, the next logical piece is to examine possibilities of future climate precipitation scenarios. CHRS RainSphere provides users with this capability via the option to select future IPCC projections rather than historical satellite-based observations. With this option, the same features as the historical option for rain map layer visualization are still available, along with all of the querying methods. The exception is that the finest temporal resolution for model projections is restricted to monthly.

As demonstrated in Fig. 4, data queries with future projections feature three time series options, one for each of the three IPCC carbon emission scenarios. Like the averages and linear trends, each time series can be toggled on or off by clicking on it to show only the information desired.

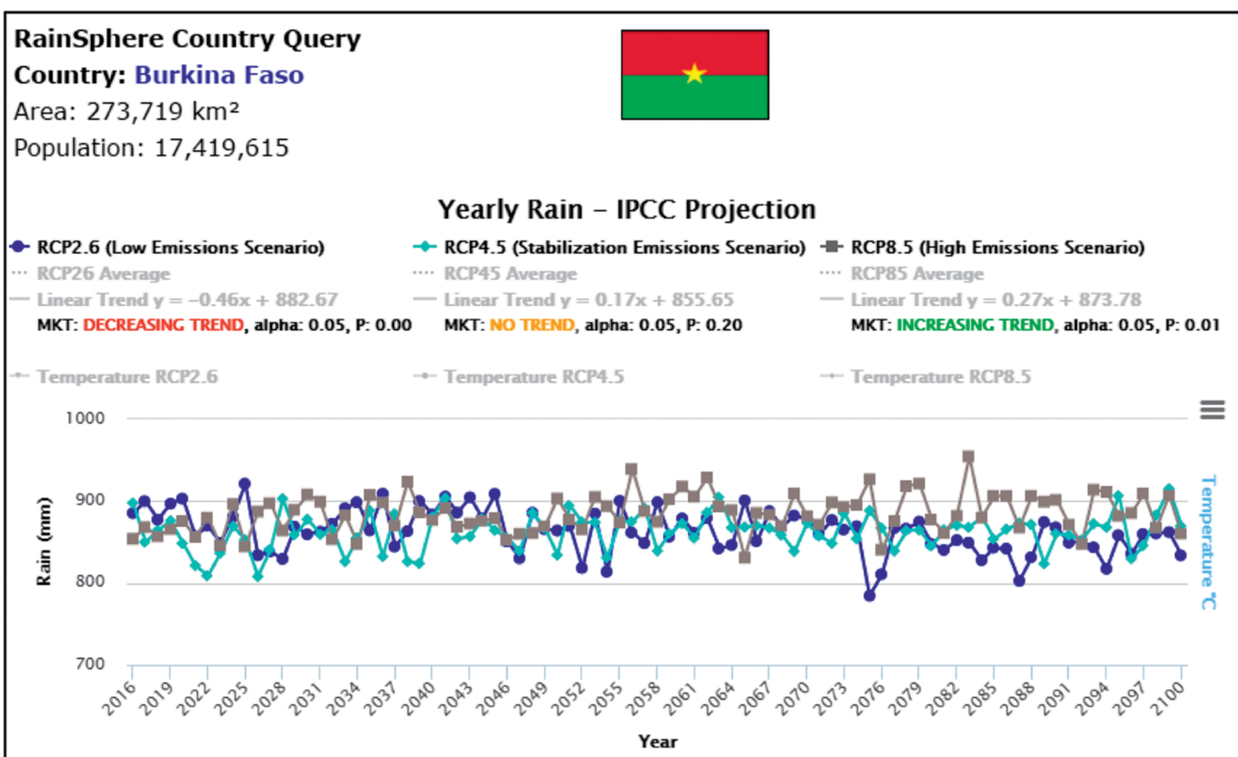

Fig. 4. Sample IPCC projection for Burkina Faso.

This particular example highlights the complexity of characterizing the future climate—when all else is considered equal, varying the concentration of carbon may result in an increase, decrease, or no change in the amount of annual precipitation for the country shown. Furthermore, with very little effort, users will quickly find that this pattern is not the case for all countries. It is anticipated that access to such an expedited evaluation tool will help in minimizing unfounded generalizations about the climate system in addition to allowing users to focus on a region of interest if desired.

It should be noted that the 0.25° resolution of PERSIANN-CDR data may affect the reliability of the product when looking at domains such as watersheds or political divisions on CHRS RainSphere that are smaller than 0.25°.

CLOSING REMARKS. CHRS RainSphere is a user-friendly tool intended for self-guided education of the general public. By organizing a dataset of large historical precipitation and future precipitation projections into a system that includes intuitive search capabilities as well as the ability to automatically generate reports with basic statistics and summaries, users can quickly and easily gain meaningful information without the inconvenience of data processing and plotting. Researchers can also use the system for extracting historical data and projected simulations for further analysis. Although the system is sophisticated enough for use by experts, removing this barrier allows nonexperts to explore the global climate in terms of precipitation and will hopefully facilitate a more inclusive conversation about climate and climate change in the near future.

ACKNOWLEDGMENTS. This research was partially supported by the Cooperative Institute for Climate and Satellites (CICS) program (NOAA prime award #NA14NES4320003, subaward #2014-2913-03) for OHD-NWS student fellowship, the Army Research Office (award#W911NF-11-1-0422), and the National Science Foundation (NSF award #1331915). A collection of open-source software was utilized to create the visualization and querying capabilities of CHRS RainSphere. These include MapServer by the University of Minnesota, Highcharts by Highsoft AS, and Google Maps API by Google Inc.

FOR FURTHER READING

Ashouri, H., K. L. Hsu, S. Sorooshian, D. K. Braithwaite, K. R. Knapp, L. D. Cecil, B. R. Nelson, and O. P. Prat, 2015: PERSIANN-CDR: Daily precipitation climate data record from multisatellite observations for hydrological and climate studies. *Bull. Amer. Meteor. Soc.,* **96,** 69–83, doi:10.1175/BAMS-D-13-00068.1.

——, P. Nguyen, A. Thorstensen, K. L. Hsu, S. Sorooshian, and D. Braithwaite, 2016: Assessing the efficacy of high-resolution satellite-based PERSIANN-CDR precipitation product in simulating streamflow. *J. Hydrometeor.,* **17,** 2061–2076, doi:10.1175/JHM-D-15-0192.1.

Channan, S., K. Collins, and W. R. Emanuel, 2014: Global mosaics of the standard MODIS land cover type data. University of Maryland and the Pacific Northwest National Laboratory, College Park, Maryland.

Damberg L., and A. AghaKouchak, 2014: Global trends and patterns of drought from space. *Theor. Appl. Climatol.,* **117,** 441–448, doi:10.1007/s00704-013-1019-5.

Hsu, K., X. Gao, S. Sorooshian, and H. V. Gupta, 1997: Precipitation estimation from remotely sensed information using artificial neural networks. *J. Appl. Meteor. Climatol.,* **36,** 1176–1190, doi:10.1175/1520-0450(1997)0362.0.CO;2.

Kendall, M., 1976: *Rank Correlation Methods.* 4th ed. Griffin, 202 pp.

Lehner, B., and G. Grill, 2013: Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrol. Processes, 27,* 2171–2186, doi:10.1002/hyp.9740.

Mann, H., 1945: Nonparametric tests against trend. *Econometrica,* **13,** 245–259, doi:10.2307/1907187.

Miao, C., and Coauthors, 2015: Evaluation of the PERSIANN-CDR daily rainfall estimates in capturing the behavior of extreme precipitation events over China. *J. Hydrometeor.,* **16,** 1387–1396, doi:10.1175/JHM-D-14-0174.1.

Sorooshian, S., K. L. Hsu, X. Gao, H. V. Gupta, B. Imam, and D. Braithwaite, 2000: Evaluation of PERSIANN system satellite-based estimates of tropical rainfall. *Bull. Amer. Meteor. Soc.,* **81,** 2035–2046, doi:10.1175/1520-0477(2000)081<2035:EOPSSE>2.3.CO;2.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl, 2012: An overview of CMIP5 and the experiment design. *Bull. Amer. Meteor. Soc.,* **93,** 485–498, doi:10.1175/BAMS-D-11-00094.1.