# Impacts of Climate Extremes in Brazil

## The Development of a Web Platform for Understanding Long-Term Sustainability of Ecosystems and Human Health in Amazonia (PULSE-Brazil)

by Jose A. Marengo, Luiz E.O.C. Aragão, Peter M. Cox, Richard Betts, Duarte Costa, Neil Kaye, Lauren T. Smith, Lincoln M. Alves, and Vera Reis

**MOTIVATION.** Amazonia has experienced "droughts and floods of the century" during the last 10 years, and this has affected humans and natural systems through direct impacts from the events as well as increased forest fires and an increased risk of diseases. There is more data than ever before to monitor and understand the impact of such climatic extremes. However, the quantity of long-term multitemporal and multisource information increases the complexity of data management and limits the ability of policymakers to act on any improved understanding of Earth system processes. Such capacity, especially in tropical countries, is critical for developing mitigation and adaptation policies to cope with the effects of climate perturbations. This is central for the objectives of the Global Framework for Climate Services (GFCS; http://gfcs.wmo.int/) established during the 2009 World Climate Conference, which was conceived to promote the sharing of science-based knowledge with decision-makers and for prioritizing sectors such as risk reduction, water, human health, and food security.

Currently, it is difficult to synthesize all available information in a comprehensive structure that enables different sectors of the society to understand the consequences of extreme events and support timely decision making. In recognition of this problem of data compilation, management, and visualization, a consortium of cross-disciplinary Brazilian and U.K. scientists, encompassing environmental, human health, and modeling backgrounds, was selected under the umbrella of the International Opportunities Fund, and jointly funded by the São Paulo Science Foundation (FAPESP) in Brazil and the Natural Environment Research Council (NERC) in the United Kingdom to enhance the knowledge in environmental sciences directly applicable to policy decisions.

A key result of this cooperation is the ongoing development of PULSE-Brazil, a Platform for Understanding Long-term Sustainability of Ecosystems and human health, specifically applied to Brazil. PULSE-Brazil (www.pulse-brasil.org/tool/) was conceived as a platform to assimilate available climate, environmental, and human health data and translate this information into user-friendly outputs such as graphs and maps, thereby 1) allowing the establishment of a science-policy knowledge interface about the impacts of climate variability and change on society, 2) increasing public awareness of these issues, and 3) informing the development of adaptation and risk-management strategies.

**AFFILIATIONS:** Marengo—Centro Nacional de Monitoramento e Alertas de Desastres Naturais (CEMADEN), Sao Paulo, Brazil; Aragão—Divisão de Sensoriamento Remoto/Instituto Nacional de Pesquisas Espaciais (DSR/INPE), Sao Paulo, Brazil; Cox and Costa—College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, United Kingdom; Betts and Kaye—Met Office Hadley Centre, Exeter, United Kingdom; Smith—School of Geographical Sciences, University of Bristol, Bristol, United Kingdom; Alves—Centro de Ciencia do Sistema Terrestre/Instituto Nacional de Pesquisas Espaciais (CCST/INPE), Sao Jose dos Campos, Sao Paulo, Brazil; Reis—Instituto de Mudanças Climáticas IMC, Rio Branco, Acre, Brazil

**CORRESPONDING AUTHOR:** Jose A. Marengo, CEMADEN, Rodovia Dutra, km 40, 12630-000, Cachoeira Paulista, Sao Paulo, Brazil

E-mail: jose.marengo@cemaden.gov.br

DOI:10.1175/BAMS-D-14-00177.1

This initiative is especially relevant for coping with the targets of the Brazilian National Plan for Climate Change (BNPCC; www.mma.gov.br/clima/politica-nacional-sobre-mudanca-do-clima/plano-nacional-sobre-mudanca-do-clima), established in 2007 by the government. Elaborated upon by federal and state governments, academics, and civil society, this plan encompasses several aspects of climate change science and dissemination of information, including opportunities for mitigation; impacts, vulnerability, and adaptation; research and development; and education, training, and communication. BNPCC is aligned with the responsibilities assumed by Brazil within the United Nations Framework Convention on Climate Change (UNFCCC; http://unfccc.int/2860.php).

To meet the objectives of the PULSE-Brazil platform, three aspects of the development process require attention: 1) the interaction between scientists and policymakers for designing and producing PULSE-Brazil, 2) the characteristics of the platform itself, and 3) the applicability of the platform for analyzing the impacts of climate extremes on human and natural systems in Amazonia. This paper summarizes the strengths and weakness of the whole process, and provides insight for future initiatives.

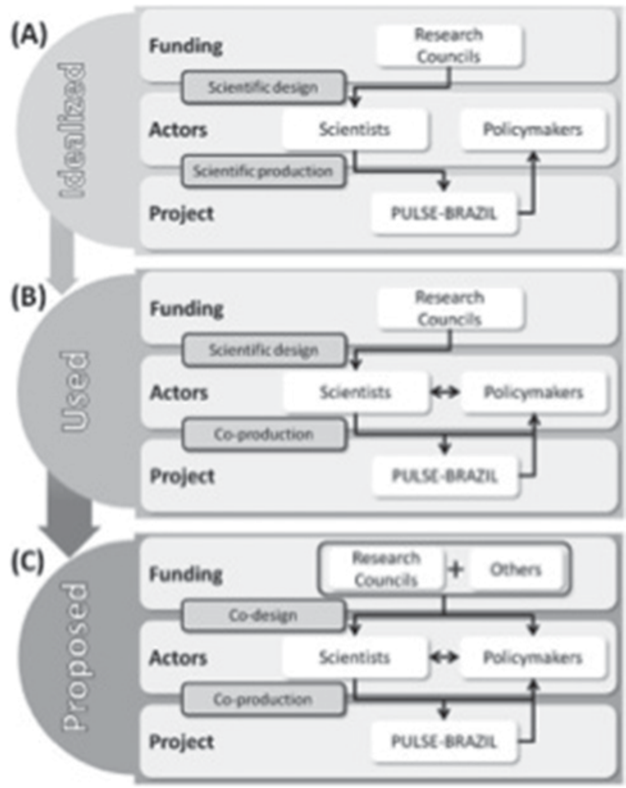


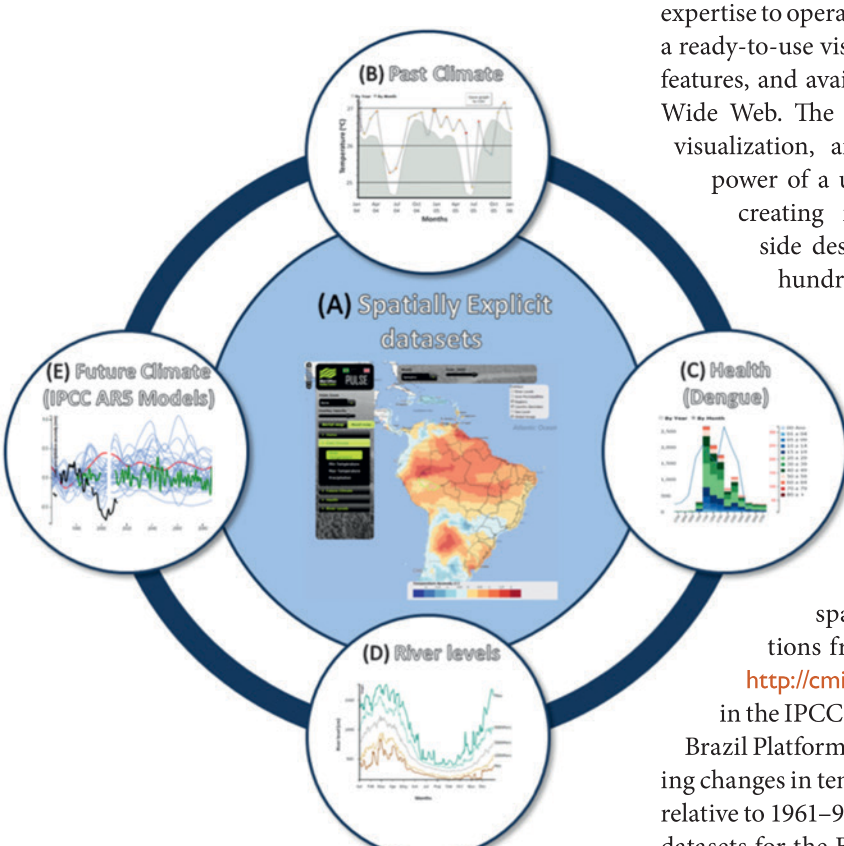

**Fig. 1. Conceptual models identified for designing and producing decision-support tools, based on the PULSE-Brazil experience. (a) Idealized model—proposed by scientists to research council and followed during the initial phase of the project. (b) Used model—jointly conceived by scientists and policy makers. (c) Proposed model—for future initiatives, aiming to enhance the coherence between science knowledge and policy needs and optimize funding input for long-term maintenance of proposed decision-making support tools.**

**DESIGN AND PRODUCTION OF PULSE-BRAZIL.** Scientific research is virtually constrained by funding opportunities, which often are focused on disciplinary priorities. This in turn limits potential transdisciplinary collaboration. PULSE-Brazil started with a cross-disciplinary academic design and production model, aimed at supporting decision-making (Fig. 1a). A series of PULSE meetings between U.K. and Brazilian scientists was undertaken in 2012 to design the platform. The state of Acre, located in western Amazonia, was identified as a key pilot partner for PULSE-Brazil, in part because of its governmental interest in environment sustainability, and also because the state has suffered a number of damaging climatic extremes, such as droughts and floods, since 2005, increasing the need to prepare for and adapt to climate change. In 2013, at a meeting held at the Met Office (UK), an introduction to the implications of extreme climate events in Acre was presented by a team of PULSE scientists from the Oswaldo Cruz Foundation (FIOCRUZ) under the Brazilian Ministry of Health and the National Institute for Space Research (INPE) under the Brazilian Ministry of Science, Technology and Innovation. In response, current policy experiences were described by a group of Acre officials that were present and active at the meeting. Two main sets of information were identified at this meeting as critical for policy decisions in Acre state: 1) the combined effects of climate and land-use changes on droughts, with consequences for the incidence of fires, floods, and human health, and 2) the direct impacts of recent hydrological extremes in Amazonia on human health. Moreover, this meeting interestingly revealed that tropical governments not only have a need for accessing long-term Intergovernmental Panel on Climate Change (IPCC; www.ipcc.ch/)-type projections, but also a growing demand for shorter-term information on climate extremes to assist their decision-making processes.

This valuable contribution by government officials required a change of the PULSE-Brazil model to a participatory concept, adopting a scheme where the design of the tool concept followed scientific standards, but its implementation allowed the interaction between stakeholders and scientists, in a coproduction fashion (Fig. 1b). Facing this new challenge, scientists and policymakers agreed to a pilot testing period for the PULSE-Brazil platform at the end of 2013, based on the communicated needs of Acre state officials.

**THE PULSE-BRAZIL PLATFORM.** The PULSE-Brazil platform was designed as a web application tool developed using the latest open-source technologies to create a flexible visualization and analysis tool (Fig. 2). This platform has a number of key components to power it: a) HTML5 has good browser cross-compatibility and the ability to make responsive websites for different types of devices, including mobile devices; b) GeoServer is an open-source server for sharing geospatial data. Designed for interoperability, GeoServer publishes data from any major spatial data source using open standards. For PULSE, it allows for the display and interrogation of more than 5,000 highly detailed municipalities and their associated data; c) Open Layers, which creates interactive maps, including polygon formats for displaying state and municipality boundaries as well as gridded data for representing climate models and observation data; and d) d3.js, which is an open-source JavaScript library for manipulating documents based on data, allows developers to create unlimited visualizations and graphs. PULSE-Brazil provides visualization of spatial and temporal information offering interactive querying and data downloads.

**Fig. 2. Main visualization features of the PULSE-Brazil platform, including (a) the dataset menu, gridded past and projected climate, and human health data. Also shown are example graphic representations of (b) historical climate, (c) human health, (d) river levels for Acre state, and (e) CMIP5 climate projections.**




Importantly, these technologies are all freely available. Although no support is available from large geographic information systems (GIS) companies such as ESRI and Oracle, copious support is accessible online. Unlike many other platforms or GIS that allow climate data visualization and analysis but require expertise to operate, PULSE-Brazil was designed to be a ready-to-use visualization tool with intuitive query features, and available for access through the World Wide Web. The data are prerendered, accelerating visualization, and a client-side design uses the power of a user's computer for processing and creating interactive graphing. The client-side design makes the system scalable for hundreds of concurrent users.

Based on the latest scientific information and clear demands from policymakers, the PULSE-Brazil tool was initially populated with: a) climate observations up to 2012 from the Climatic Research Unit (CRU; www.cru.uea.ac.uk/data), University of East Anglia, at a 1°×1° spatial resolution; b) climate projections from the CMIP5 archive, located at http://cmip-pcmdi.llnl.gov/cmip5/ (and as used in the IPCC 5th Assessment), where the PULSE-Brazil Platform displays decadal-mean maps showing changes in temperature, precipitation, and runoff relative to 1961–90 values; c) river-level observational datasets for the Brazilian state of Acre covering the

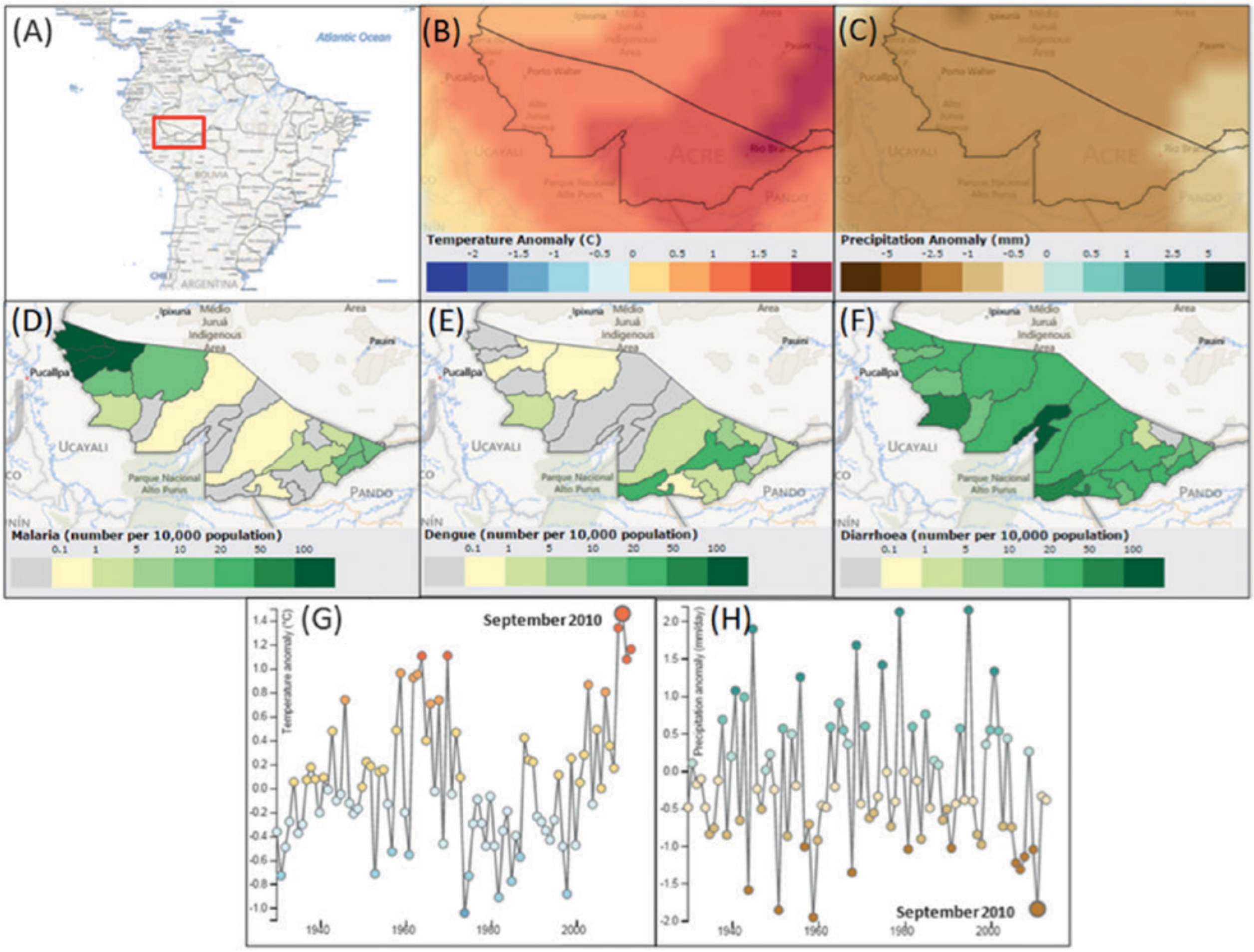



**Fig. 3. Climate and health patterns for September 2010 in Acre state southwest Amazon, defined by the red box (a). Panels (b) and (c) show spatially explicit temperature (°C) and rainfall (precipitation, mm) anomalies, respectively. Panels (d), (e), and (f) present the recorded cases (in numbers of cases per 10,000 inhabitants) for malaria, dengue fever, and diarrhea, respectively. Polygons represent the municipalities of Acre state. Panels (g) and (h) show time series of historical temperature and rainfall anomalies during September, respectively. Note the extreme anomalies in 2010.**

past 40 years; and d) human health data from the Brazilian Unified Health System (SUS; www2.datasus.gov.br/DATASUS/index.php) for regional hospitalization data for key climate- and environmentally sensitive diseases: malaria, dengue fever, diarrhea, leptospirosis, and respiratory diseases.

**VISUALIZING CLIMATE IMPACTS USING PULSE-BRAZIL.** The Amazonian state of Acre suffered two droughts (2005 and 2010) leading to water shortages, forest fires, and a proliferation of diseases. Using the visualization capacity of the PULSE-Brazil tool, we tested whether the impacts of the 2010 drought in Acre state could be clearly identified.

Exploring the gridded climate data, the occurrence of positive temperature anomalies up to 2 degrees in the southeast flank of the state during September 2010 is clear (Fig. 3b). The high temperatures occurred in parallel to negative rainfall anomalies across the state (Fig. 3c). Shifting through the data menu, the PULSE-Brazil user is able to conclude that this coincided with the occurrence of malaria reaching more than 100 cases per 10,000 inhabitants in the northwest portion of Acre (Fig. 3d). In Brazil, studies show that more than 90% of malaria cases are in Amazonia. Dengue fever, conversely, is more concentrated in the municipality of Rio Branco with 20 to 50 cases per 10,000 inhabitants (Fig. 3e). It is well established that temperature affects the dengue viruses and vector populations. Rainfall is the main variable that influences habitat availability for the dengue mosquito, *Aedes aegypti*. Diarrhea seems to be widely spread across the state, even during the dry season (Fig. 3f).

Finally, flipping through the menu and clicking over Acre state, users can create a graphical summary of historical temperature and rainfall anomalies for the month of September (Figs. 3g and 3h, respectively). This can be done for any historical or projected dataset included in the PULSE-Brazil platform.

**STRENGTHS AND WEAKNESSES.** The information disseminated through the PULSE-Brazil web portal provides valuable monthly-to-decadal-scale climate, ecosystem, and human health information for scientists and society. A strong feature of this platform is its capacity to display a wide range of spatially explicit regional datasets from multiple sources in a single environment. This characteristic of the tool, we believe, makes it especially useful in the context of the GFCS, the BNPCC, and its contributions to the UNFCCC.

PULSE-Brazil is not yet a complete data-rich tool for all Brazilian regions. However, the platform can provide a set of municipality-, state-, and national-level information without having to contact each individual data provider. This is particularly important for health data, as any data produced by Brazilian government institutions must become publicly available following the 2011 Information Access Law (Law 12.527/2011). The dialogue between scientists and policymakers is essential for the coproduction of platforms such as PULSE-Brazil. Examples of specific user-driven contributions are the introduction of river-level information for Acre state (Fig. 2d) and the fire risk dataset that will be incorporated in the near future.

The PULSE-Brazil database structure is concentrated in a single institute, the UK Met Office. Therefore, a key challenge for the longevity of this initiative is to decentralize the platform by identifying host institutes with necessary resources for maintaining and upgrading the system. A potential strategy for future developments is to shift the whole model of this type of initiative toward a codesign and coproduction process (Fig. 1c), with well-established commitments from end users.

**PERSPECTIVES.** The result of PULSE-Brazil is a web application that effectively visualizes many different modeling and observed datasets, in gridded and graphic formats, promoting a broader understanding of the impacts of climate on human health and ecosystems, supporting policymaking decisions to lessen these impacts. A close interaction between scientists and policymakers in the Brazilian state of Acre has resulted in the coproduction of a platform with customized features, without affecting the broad, national-level scope of the tool.

The PULSE-Brazil team is now expanding the health data beyond Acre state to cover all 5,570 municipalities in Brazil; including active fire data from MODIS (collection 5 Global Monthly Fire Location Product, MCD14ML; https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms); and updating the system with regional climate model outputs. Additionally, PULSE-Brazil is being applied in the littoral city of Santos, in the State of Sao Paulo, where we are investigating coastal vulnerability to sea level rise, extremes, and also the impacts of climate variability and change on human health in this city, particularly the spread and projected impacts of dengue fever. Ultimately, PULSE-Brazil scientists will continue to seek strong institutional partnerships with a view to expanding this initiative to other tropical nations.

**ACKNOWLEDGMENTS.** This work was funded by the joint FAPESP 2011/51843-2 and NERC NE/J016276/1 International Opportunities Fund. PULSE-Brazil development is also funded by the FAPESP grant (2012/51876-0) under the Belmont Forum Cooperation Agreement. Marengo and Aragão thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for their Research Productivity Fellowship.

## FOR FURTHER READING

Aragão, L. E. O. C., Y. Malhi, R. M. Roman-Cuesta, S. Saatchi, L. O. Anderson, and Y. E. Shimabukuro, 2007: Spatial patterns and fire response of recent Amazonian droughts. *Geophys. Res. Lett.*, **34,** L07701, doi:10.1029/2006GL028946.

——, B. Poulter, J. B. Barlow, L. O. Anderson, Y. Malhi, S. Saatchi, O. L. Phillips, and E. Gloor, 2014: Environmental change and the carbon balance of Amazonian forests. *Biol. Rev. Camb. Philos. Soc.*, **89,** 913–931, doi:10.1111/brv.12088.

Hales, S., N. De Wet, J. Maindonald, and A. Woodward, 2002: Potential effect of population and climate changes on global distribution of dengue fever: An empirical model. *Lancet,* **360,** 830–834, doi:10.1016/S0140-6736(02)09964-6.

Hazzard, E., 2011: Openlayers 2.10 beginner's guide. Packt Publishing Ltd.

Horta, M. A., P. A. Fonseca, D. Costa, C. Barcellos, and S. Hacon, 2014: Temporal relationship between climatic factors and the occurrence of dengue fever in an Amazonian urban center, Brazil. *Int. J. Epidemiol. Infect.,* **2,** 80–87, doi:10.12966/ijei.11.04.2014.

Marengo, J. A., and J. C. Espinoza, 2015: Extreme seasonal droughts and floods in Amazonia: Causes, trends and impacts. *Int. J. Climatol.,* in press.

——, and Coauthors, 2008: The drought of Amazonia in 2005. *J. Climate,* **21,** 495–516, doi:10.1175/2007JCLI1600.1.

——, L. S. Borma, D. A. Rodriguez, P. Pinho, W. R. Soares, and L. M. Alves, 2013a: Recent extremes of drought and flooding in Amazonia: Vulnerabilities and human adaptation. *Amer. J. Clim. Change,* **2,** 87–96, doi:10.4236/ajcc.2013.22009.

——, L. M. Alves, W. R. Soares, D. A. Rodriguez, H. Camargo, M. Paredes, and A. Diaz Pablo, 2013b: Two contrasting seasonal extremes in tropical South America in 2012: Flood in Amazonia and drought in Northeast Brazil. *J. Climate,* **26,** 9137–9154, doi:10.1175/JCLI-D-12-00642.1.

Mauser, W., G. Klepper, M. Rice, B. S. Schmalzbauer, H. Hackmann, R. Leemans, and H. Moore, 2013: Transdisciplinary global change research: The co-creation of knowledge for sustainability. *Curr. Opin. Environ. Sustain.,* **5,** 420–431, doi:10.1016/j.cosust.2013.07.001.

Meadow, A. M., D. B. Ferguson, Z. Guido, A. Horangic, G. Owen, and T. Wall, 2015: Moving toward the deliberate co-production of climate science knowledge. *Wea. Climate Soc.,* **7,** 179–191, doi:10.1175/WCAS-D-14-00050.1.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley, 2005: Impact of regional climate change on human health. *Nature,* **438,** 310–317, doi:10.1038/nature04188.

Pessanha, J. E. M., 2012: Risk assessment and risk maps using a simple dengue fever model. *Dengue Bull.,* **36,** 73–86.

Smith, L. T., L. E. O. C. Aragão, C. E. Sabel, and T. Nakaya, 2014: Drought impacts on children's respiratory health in the Brazilian Amazon. *Sci. Rep.,* **4.**

Tomasella, J., L. S. Borma, J. A. Marengo, D. A. Rodriguez, L. A. Cuartas, C. A. Nobre, and M. C. R. Prado, 2011: The droughts of 1996–1997 and 2004–2005 in Amazonia: Hydrological response in the river main-stem. *Hydrol. Processes,* **25,** 1228–1242, doi:10.1002/hyp.7889.

Weaver, C. P., and Coauthors, 2014: From global change science to action with social sciences. *Nat. Climate Change,* **4,** 656–659, doi:10.1038/nclimate2319.

Youngblood, B., 2013: GeoServer Beginner's Guide. Packt Publishing Ltd.