Summary of the MERRA-2 Applications Workshop

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Introduction

A meteorological reanalysis incorporates historical weather-related data into a "fixed version" of a numerical model of the atmosphere, i.e., the model version does not change throughout the entire reanalysis time period. In the specific case of the Modern-Era Retrospective analysis for Research and Applications, Version 2, or MERRA-2 reanalysis, the system is based heavily on NASA observations and the Goddard Earth Observing System, Version 5 (GEOS-5) numerical model. Bringing together MERRA-2 developers, data scientists, researchers, communications specialists, and program managers, the MERRA-2 Applications Workshop took place June 19, 2017, at NASA's Goddard Space Flight Center (GSFC). The workshop brought together approximately 80 professionals, both in person and remotely, representing GSFC, other U.S. government agencies, academia, nongovernmental organizations, and the commercial sector. The objectives of the event were to:

- Increase the visibility of MERRA-2 for a wide variety of applications;
- identify cases where MERRA-2 is being used to support decision making;
- identify the stakeholder community's needs in terms of MERRA-2 output, analytic services, and training; and
- enhance the network of MERRA-2 developers, researchers, and end-users—particularly in the Washington, DC area.

The following summary presents the highlights of the day-long workshop. Some of the presentations given will soon be available at *https://science.gsfc.nasa.gov/610/applied-sciences/climate_applications_wg.html*.

Opening Remarks

Both **Steve Platnick** [GSFC—*Deputy Director for Atmospheres, Earth Science Division*] and **Woody Turner** [NASA Headquarters (HQ)—*Program Manager for Ecological Forecasting, Applied Sciences*] gave words of welcome to the meeting participants, one on behalf of GSFC, and the other from NASA HQ. During their remarks, each speaker noted that the event was the first large-scale attempt to coordinate the activities of end-users of the MERRA-2 reanalysis product and to better understand their needs and challenges. **Maggie Hurwitz** [GSFC—*Deputy Applied Sciences Manager*] explained that the workshop fits into GSFC's portfolio of applied sciences activities through its Climate Applications Working Group—GSFC-based scientists and applied sciences leaders seeking to share their experience and to enhance the uptake of GSFC's climate-related and model-based products by end-users.

Overview of MERRA-2 and Related NASA Computing Resources

The morning's first session provided overviews of the MERRA-2 reanalysis product and related NASA computing resources, as well as the process of obtaining and manipulating MERRA-2 output. **Steven Pawson** and **Mike Bosilovich** [both at GSFC] explained that MERRA-2 is created by combining numerous atmospheric datasets with a fixed version of GEOS-5 (1980–present) to produce complete records of hundreds of Earth-system fields (e.g., winds), all of which are consistent both in space and time. Bosilovich noted the advances of MERRA-2 as compared with MERRA-1—e.g., MERRA-2 is better at capturing extreme precipitation and providing aerosol fields—and emphasized that his team is working towards developing a reanalysis of the entire Earth system. He noted that MERRA-2 fields can be downloaded from the Goddard Earth Sciences Data and Information Center (GES DISC) website (*https://disc.gsfc.nasa.gov*). **Dana Ostrenga** [GSFC] highlighted the GES DISC's subsetting and regridding tool, which allows application users to select specific fields, time periods, and regions of interest. **John Schnase** [GSFC] noted that at ~400 Tb for the entire MERRA-2 collection, it is a burden to download and store, and that it is difficult and time-consuming to perform simple operations on MERRA fields (e.g., computing mean values). In response, MERRA Analytic Services, a tool still in beta testing, was developed to combine high-performance computing [via the NASA Center for Climate Simulation (NCCS)] and web services to reduce the data burden. **Ana Prados** [GSFC] noted that NASA's Applied Remote Sensing Training (ARSET) program helps end-users learn how to download and manipulate MERRA-2 fields, with particular utility in monitoring climate variability, analyzing extreme weather events, and providing hydrometeorological inputs to decision-support tools.

MERRA-2 Earth Science Applications

The morning's second session showcased seven applications of MERRA-2 for weather, climate, water, and agriculture. **Ken Kunkel** [North Carolina Institute for Climate Studies] and **Jim Biard** [North Carolina State University] explained how they combine MERRA-2 fields and pattern-recognition software to identify

weather fronts. **Allie Collow** [GSFC] described her research using MERRA-2 to identify the contributions of frontal and low-pressure weather systems to extreme precipitation events in the northeast U.S. **Robert Field** [NASA Goddard Institute for Space Studies (GISS)] described the Global Fire Weather Database (GFWED), which is based on the Fire Weather Index (FWI) System (*http://cwfis.cfs.nrcan.gc.ca/background/summary/fwi*) and integrates the weather factors influencing the likelihood of a vegetation fire starting and spreading—*https://data.giss.nasa.gov/impacts/gfwed*. His analysis focused on the link between weather conditions (summarized by the FWI) and the burned area—see **Figure**. **Mark Carroll** [GSFC] showed how the Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER) wildfire decision support tool (*http://giscenter.isu.edu/Research/Techpg/nasa_RECOVER/index.htm*) can produce burned-area maps within five minutes. The NASA-funded State of the Global Water and Energy Cycle Project (SGWECP) uses MERRA-2 to constrain the global water budget; **Tim Donato** [George Mason University (GMU)], representing GMU's SGWECP, noted that the representation of the global water budget varies across satellite datasets and reanalyses, and that more research is needed in this area.

Kristi Arsenault [GSFC] noted that MERRA-2 fields underpin NASA's Land Information System (LIS)—*https://lis.gsfc.nasa.gov*—which ultimately provides forecasts of growing conditions to the Famine Early Warning System Network (FEWS NET)—*https://www.fews.net*. **Alex Ruane** [GISS] discussed the Agricultural Model Intercomparison and Improvement Project (AgMIP)—*http://www.agmip.org*—in which agricultural model simulations are intercompared using a standardized climate-forcing dataset (AgMERRA) that is based on MERRA fields. AgMERRA provides gap-filled time series of weather-related fields (e.g., temperature), particularly useful in developing countries where there may be no local measurements.

Andrea Molod [GSFC] and **Maggie Hurwitz** moderated a panel discussion with several of the NASA speakers—see photo below. Speakers discussed the potential decrease in the latency of MERRA fields and the concomitant increase in the utility of MERRA-2 for near-real-time applications and analysis. MERRA-2 users praised the continuity of the MERRA-2 products over 38 years of output, which provide historical context and estimates of interannual variability—information sorely needed for agricultural applications.

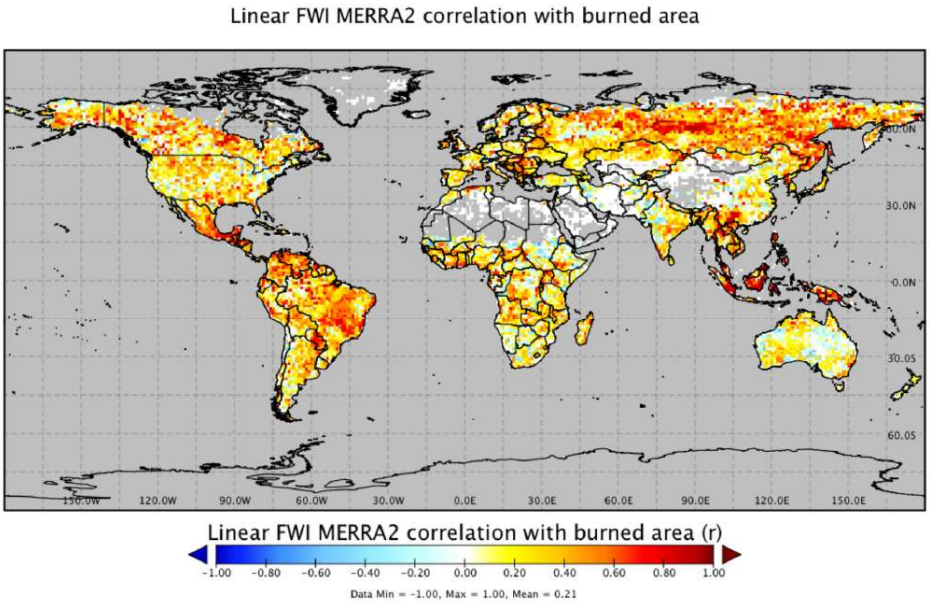

Figure. The map shows the correlation between burned area and Fire Weather Index (FWI)—which is computed using MERRA-2 data (1981-present)—at the peak of the local fire season. Calculations of FWI based on the National Oceanic and Atmospheric Administration's (NOAA's) Climate Prediction Center (CPC) precipitation measurement yield similar results. **Image credit**: Robert Field

Andrea Molod [*standing*] and **Maggie Hurwitz** [*behind lectern*] chaired a panel discussion, during which the panelists articulated why MERRA-2 is a great resource for end users, and how they expect the MERRA series of products to evolve in the coming years. Panelists included [*left to right*]: Mike Bosilovich, Dana Ostrenga, Mark Carroll, Steven Pawson, and Kristi Arsenault [all GSFC]. **Photo credit:** Robin Kovach

MERRA-2 Applications Beyond Earth Science

The early afternoon session showcased six applications of the MERRA-2 reanalysis beyond the Earth science community, in the areas of renewable energy, civil engineering, and public health. **Mark Stoelinga** [Vaisala] noted the importance of MERRA-2's 50-m (~164-ft) altitude wind fields to the wind energy sector; Stoelinga said that analyses using both the current and previous version of MERRA have increased the understanding of near-surface wind fields and thus informed significant investment decisions in the renewable energy sector. Likewise, **Manajit Sengupta** [National Renewable Energy Laboratory] noted the importance of MERRA-2 in driving the National Solar Radiation Database (*http://rredc.nrel.gov/solar/old_data/nsrdb*), a tool used in solar energy prospecting and solar generator design. Both Sengupta and Stoelinga noted that end-users in their respective fields have adopted MERRA-2 because of its relatively low data latency and observation-quality datasets, as compared with other reanalyses—e.g., the ECMWF family of reanalysis products (*https://www.ecmwf.int/en/research/climate-reanalysis*). **Paul Stackhouse** [NASA's Langley Research Center] stated that MERRA-2 has been used to define the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' (ASHRAE) building climate zones. MERRA-2 fields have underpinned research carried out by **Chuck Schwartz** [University of Maryland, College Park] on the sensitivity of pavement materials to weather parameters. **Jen Stowell** [Emory University] showcased her research group's studies using remote sensing to study the health effects of air pollution; she explained that the MERRA-2 reanalysis could augment this research by providing additional fields (e.g., aerosols) at high spatial resolution over a long study period. **Antar Jutla** [West Virginia University] outlined the use of MERRA-2 and other reanalyses in understanding water-borne infectious disease. In particular, hydrometeorological fields from MERRA-2, again in combination with pattern recognition software, are being used to understand the seasonality and evolution of cholera outbreaks, to plan vaccination programs, and ultimately to mitigate cholera risks.

Parallel Sessions

The midafternoon activities featured three parallel discussion sections, summarized below.

Using MERRA-2 for Case Study and Recent Event Analysis

The first section, led by **Allie Collow** [GSFC] and **Robert Field** [GISS], discussed the use of MERRA-2 for case studies and recent event analyses. MERRA-2 users noted that it would be helpful to know which observations fed into the reanalysis at a particular time, as well as the associated uncertainties, explaining that for extreme event studies at small scales, it would be helpful if the MERRA-2 output were released with both UTC and local time labels.

Using MERRA-2 for Planning and Design for Climate Variations

Mike Bosilovoch and **Allison Leidner** [NASA HQ] chaired a discussion about planning and designing for climate variations. Participants explained that data consistency is highly valued by reanalysis end-users, so MERRA producers should attempt to minimize discontinuities related to data processing or changes in the observing system. The group's consensus was that end-users would like to make use of MERRA-2 time series to compute trends and analyze climate extremes. Likewise, the group agreed that end-users highly value the length of the data record that MERRA-2 provides (1980-present), which is being used to characterize drought, climate variability, decadal oscillations, and *climate analogues*—places that experience similar conditions, but may be separated in space or time. Participants recommended that future versions of MERRA continue to offer long time series, and include data over land (i.e., by incorporating soil moisture and surface temperature observations into the reanalysis), as well as dynamic vegetation models.

MERRA Analytics and Related Software Tools for Accessing MERRA Fields

John Schnase and **Enidia Santiago-Arce** [GSFC] led a session during which participants discussed MERRA Analytic Services and related software tools to access MERRA fields. Schnase noted that MERRA Analytic Services is working toward processing and comparing with other reanalyses (e.g., the ECMWF family of reanalysis products), and will be able to handle ensembles of reanalyses in the future. Santiago-Arce discussed mechanisms for the government to engage with and distribute software (e.g., decision-support tools) to the private sector.

Discussion Session Wrap-Up

Danielle Wood [GSFC—*Former Applied Sciences Manager*] led the closing large-group discussion, which tied together the key points raised during the parallel sessions and throughout the workshop. Participants noted that extensive documentation, the large collection of data fields, and the availability of related tools (e.g., Giovanni)[1] enhance the value of MERRA-2 for a wide range of applications.

[1] Giovanni stands for Goddard Earth Sciences Data and Information Services Center (GES-DISC) Interactive Online Visualization ANd aNalysis Infrastructure. To learn more, read "The Second Gregory G. Leptoukh Online Giovanni Workshop" in the May–June 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 3**, pp. 14-18—*https://go.nasa.gov/2h40UKg*]. Giovanni can be accessed at *https://giovanni.gsfc.nasa.gov/giovanni*.

Closing Remarks

The workshop was successful by all accounts. Participants responded to brief surveys both before and after the workshop, with responses that show that all participants felt that the workshop enhanced their knowledge about the MERRA-2 reanalysis and its wide range of applications. Before the workshop, 30% of respondents said they had a high level of expertise with MERRA; this number increased to 50% after the workshop. Many participants reported that they made new contacts, thereby enhancing the end-user community and increasing end-users' awareness of NASA resources.

Survey responses also indicated interest in a second MERRA-2 applications workshop. Such a workshop could address how to access new data analytics tools and interfaces to further facilitate access to and use of data, techniques for downscaling MERRA-2 output for fine-scale applications, guidance for trend analysis, and working with temporal artifacts in the MERRA-2 collection. A second workshop might focus on a particular thematic area, such as natural disaster analysis or renewable energy applications. Participants were keen to collaborate with NASA's Global Modeling and Assimilation Office (GMAO) to better incorporate the needs of applications users into the next generation of MERRA products. Meanwhile, existing and planned ARSET Program training courses will help participants access and process the MERRA-2 fields needed for their particular research and related applications. ■

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Conclusion

The 2017 ESIP Summer Meeting brought together a diverse, cross-sector and -domain community to address common problems. The most important takeaway from ESIP meeting attendees is always the value and importance of networking across the Earth science data and informatics community. ESIP allows individuals to put their work in a broader context and find new connections that enrich their professional lives. The meeting is just the beginning of such fruitful collaborations. We are grateful for the continued support from the ESIP community and their rich contributions to this meeting. ■