



DEPARTMENT OF COMMERCE RESEARCH PERFORMANCE PROGRESS REPORT (RPPR)

For instructions, please visit

http://www.osec.doc.gov/oam/grants_management/policy/documents/RPPR%20Instructions%20and%20Privacy%20Statement.pdf

AWARD INFORMATION	
1. Federal Agency: Department of Commerce / NOAA	2. Federal Award Number: NA22NWS4320003
3. Project Title: Cooperative Institute for Research to Operations in Hydrology	
4. Award Period of Performance Start Date: 04/01/2022	5. Award Period of Performance End Date: 03/31/2027
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	
6. Last Name and Suffix: Burian , null	7. First and Middle Name: Steven ,
8. Title: Professor & Director of Science	
9. Email: sburian@ua.edu	10. Phone Number: 205-348-4037
AUTHORIZING OFFICIAL	
11. Last Name and Suffix: Camp , null	12. First and Middle Name: Jennifer ,
13. Title: Assistant V. P. for Research	
14. Email: jrcamp@ua.edu	15. Phone Number: 205-348-5152
REPORTING INFORMATION	
Signature of Submitting Official: Jennifer Camp	
16. Submission Date and Time Stamp: 01/30/2023	17. Reporting Period End Date: 12/31/2022
18. Reporting Frequency: <input checked="" type="radio"/> Annual <input type="radio"/> Semi-Annual <input type="radio"/> Quarterly	19. Report Type: <input checked="" type="radio"/> Not Final <input type="radio"/> Final
RECIPIENT ORGANIZATION	
20. Recipient Name: UNIVERSITY OF ALABAMA	
21. Recipient Address: 301 ROSE ADMIN BLDG, TUSCALOOSA, AL 35487-0001 USA	
22. Recipient UEI: RCNJEHZ83EV6	23. Recipient EIN: 636001138

ACCOMPLISHMENTS

24. What were the major goals and objectives of this project?

Efforts within CIROH's projects are grouped in four research themes: Improving water resources prediction system capabilities; Advancing community water resource modeling; Innovating hydroinformatics tools and data science applications; and Integrating social, economic, and behavioral science in water resources prediction. Full description of CIROH's Research Themes is outlined below:

Improving Water Resources Prediction System Capabilities. CIROH will improve geospatial intelligence, inputs, probabilistic forcings, data assimilation, operational workflows and tools, and uncertainty quantification extending water resources prediction capabilities and applications.

Advancing Community Water Resources Modeling. CIROH will advance a state-of-the-art, community driven mechanistic hydrological model with hybrid integration of artificial intelligence and data-driven approaches with biophysical-hydrological-social processes coupled to advance the speed, accuracy, and resolution of prediction.

Innovating Hydroinformatics Tools and Data Science Applications. CIROH will promote FAIR data and hydrologic modeling principles with innovations in data and informatics tools and community engagement approaches.

Integrating Social, Economic, and Behavioral Science in Water Resources Prediction. CIROH will serve as an integrator of research-to-operations-to-research (R2O2R) interactions connecting researchers, operators, modelers, data scientists, social scientists, decision makers, and communication and policy experts in a cooperative hydrologic research and prediction community improving the design and delivery of forecasts.

25. What was accomplished under these goals?

Major research goals conducted under the four themes are outlined below. As a new Cooperative Institute, the reporting period is truncated, and research funding was not awarded from NOAA and distributed to researchers until the last quarter of 2022. However, principal Investigators set into motion research preparation activities within their institutions in advance of receiving funding to ensure progress toward CIROH goals. Appendix 1 provides a synthesis of the activities, specific objectives, and the significant results/key outcomes and major findings/developments of CIROH. Appendix 1 also includes initial research efforts and highlights from research projects addressing each of the four research themes.

ACCOMPLISHMENTS (cont'd)

26. What opportunities for training and professional development has the project provided?

At the CIROH Science Meeting in October, a roundtable discussion was facilitated to identify professional training and higher education programs for workforce development. Two areas to target for 2023 training programs included large-scale hydrologic modeling and machine learning. The session also brought ideas for student engagement activities connected to career opportunities. This included ideas related to experiential learning (e.g., internship and job shadowing program), certificates, and early student outreach.

CIROH took the first step to determine research community training needs. A key research goal for CIROH is to develop a strong community of practice advancing water prediction modeling and in particular the developmental version of the Next Generation Water Resources Modeling Framework. To start, CIROH developed a draft survey that will be administered to the research community in early 2023 to identify training needs for software development and computational hydrologic research. The survey questions have been developed to cover topics of Software Development, Visualization/Data Analysis, The Water Model, and Computational Infrastructure. Survey questions are being evaluated now by the University of Alabama Institutional Review Board. Training programs for the research community are scheduled to launch in May 2023 at the CIROH Users Conference.

CIROH is developing a program for students at one institution to have a pathway to get an advanced degree at other CIROH universities. Opportunities for exchange, research collaboration, and networking will be provided to enable easy transition and a more robust preparation program for NOAA workforce.

27. How were the results disseminated to communities of interest?

Upon receipt of the NOAA award, CIROH subsequently issued subawards to applicable consortium members and partners to begin research activities. As a result, CIROH researchers were able to produce preliminary results and products that were shared at major conferences (e.g., American Geophysical Union (AGU) Annual Meeting), in journal articles, open science development resources (e.g., GitHub), and presentations at informal meetings and events. See Appendix 3 for a listing of these products.

During the reporting period, CIROH developed plans for research product dissemination in 2023 to include a monthly national webinar, website research products page, additional dedicated GitHub repositories, a newsletter, and a User's Conference. Researchers will also be attending many conferences and meetings with special focus on the American Meteorological Society Annual Conference and specialty conferences sponsored by the American Society of Civil Engineers, American Water Resources Society, and CUAHSI. Further, special issues of community journals are being planned as CIROH research gets off the ground.

ACCOMPLISHMENTS (cont'd)

28. What do you plan to do during the next reporting period to accomplish the goals and objectives?

CIROH efforts to advance its research goals in 2023 will be directed into the further development of research-enabling technologies, conducting the funded research projects, and organizing outreach and dissemination for impact.

Research-enabling technology development for 2023 will center on establishing a research cloud computing environment, activating research integration DevOps personnel and processes, and advancing technology for data access, prediction system testing, and model evaluation.

CIROH has funded a total of 13 projects at the end of 2022 that directly address the goals and objectives. Preliminary accomplishments were highlighted in other reporting elements and in Appendix 1. CIROH administered a process to select and support 2023 funding additional research projects. The 2023 projects will launch over the summer of 2023, providing two sets of projects producing research results in the next reporting period. CIROH will work with the principal investigators and research teams of those projects to accelerate and amplify the dissemination of research products. Further, the products will be integrated into developmental versions of models and tools and translated when appropriate into operational testing with NOAA OWP and other stakeholders.

A key activity for CIROH in 2023 will be the coordination of the dozens of research projects and alignment of those projects with potential operational development pipelines. CIROH established the connections at the October 2022 Science Meeting and has further identified specific points of contact for each funded and to be funded project so 2023 has regular facilitated interaction across the research to operations pipeline. Also planned are web portals for research products, apps, and access to research computing infrastructure.

CIROH will also engage internal and external advisory bodies to improve its progress toward goals and objectives. A key element of this activity will be the regular interaction with the Council of Fellows and Senior Advisory Board. Both bodies will be engaged to generate research priorities, identify and support translation along research to operations pipelines, and facilitate broader dissemination and use of research of research products. The Executive Advisory Board will continue to help connect research to operations and operations to research. The advisory bodies will be engaged in the review of research activities as part of the Annual CIROH Science Meeting. This interaction will help to elevate the quality and impact of the research, which will further progress CIROHs goals and objectives.

CIROH will broaden participation across the hydrologic sciences community in research and education initiatives related to research themes. The Users Conference will be open to all in the research community. Training workshops will connect many new investigators and students to CIROH research, which will engage numerous researchers not affiliated with CIROH and not funded by CIROH projects. We envision a force multiplier effect that CIROH will help to advance with follow up engagement and regular

PRODUCTS

29. Publications, conference papers, and presentations

See Appendix 3 - CI Publications, Presentations

PRODUCTS (cont'd)

30. Technologies or techniques

See Appendix 4 - Products

31. Inventions, patent applications, and/or licenses

See Appendix 4 - Products

Attach a separate document if more space is needed for #6-10, or #24-50.

PRODUCTS (cont'd)

32. Other products

See Appendix 4 - Products

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

33. What individuals have worked on this project?

See Appendix 2 – Project List

See Appendix 5.1 - CI Cumulative Partners

See Appendix 5.2 – Employee Support Table

Attach a separate document if more space is needed for #6-10, or #24-50.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS (cont'd)

34. Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Nothing to Report

35. What other organizations have been involved as partners?

CIROH has strategically engaged partners in government, academia, and the private sector. Reporting this year, we will provide a list of partners in these categories see Appendix 7.

Attach a separate document if more space is needed for #6-10, or #24-50.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS (cont'd)

36. Have other collaborators or contacts been involved?

Like the previous item, the collaborators and contacts are organized into academia, government, and private sector. Reporting this year, we will provide a list of collaborators in these categories see Appendix 7.

IMPACT

37. What was the impact on the development of the principal discipline(s) of the project?

CIROH is a broad consortium of 14 members, 14 core partners, and numerous other collaborators across academia, government, and the private sector. Across this breadth of experts, CIROH's principal disciplines are hydrologic science, computer science, data science, water resources engineering, geography and geographic information technologies, and social and behavioral science. Other disciplines involved in CIROH include meteorology and atmospheric science, electrical and computer engineering, geomorphology and geological sciences, mathematics, biology, and communication. CIROH anticipates making impacts in several of the principal disciplines but will be focused on the interface of disciplines. CIROH will emphasize advances at the intersection of hydrologic science, computer science, data science, and decision science.

Given this is the first reporting period for CIROH, minimal impact has been made on the development of the principal disciplines and the interdisciplinary confluence. Appendix 8 provides a few examples where CIROH has engaged several disciplinary leaders who are already making an initial impact.

IMPACT (cont'd)

38. What was the impact on other disciplines?

As noted in the previous response, CIROH is a broad consortium of 14 members, 14 core partners, and numerous other collaborators across academia, government, and the private sector. Across this breadth of experts, CIROH's principal disciplines are hydrologic science, computer science, data science, water resources engineering, geography, social and behavioral science. Other disciplines involved in CIROH include meteorology and atmospheric science, electrical and computer engineering, geological sciences, mathematics, biology, and communication. At this point, CIROH has not made advances and is not in a position to make advances in the other disciplines soon. CIROH's interest in communication and its direct linkage with atmospheric science are areas we anticipate impacting in the future.

39. What was the impact on the development of human resources?

The most significant impact on human resources development of CIROH is the rapid escalation of research staff. Appendix 5 shows well over 100 researchers of various types have been hired by CIROH principal investigators across the consortium. The impact of this distributed development of human resources is to strengthen the community around critical areas of research. The timing of the hiring of researchers at the University of Alabama and across the country was mostly in the fall, starting in August and continuing until the end of the year. CIROH's impact on this segment of human resources will be substantial in 2023 as training programs and research activities emerge. See Appendix 9 for further details of CIROH's human resource development.

See Appendix 5.1 - CI Comprehensive Partners List
See Appendix 5.2 - CI Employee Support table
See Appendix 9 - CIROH HR Development Impact

IMPACT (cont'd)

40. What was the impact on teaching and educational experiences?

All CIROH research project leads have been proactive about initiating their efforts to achieve their project-level research goals and objectives. Much of this involved the engagement of students. Although students are getting engaged in research activities, the CIROH impact on new courses, teaching, and other educational experiences was limited in the first reporting period.

Higher Education: CIROH projects have hired many students. Project-specific training of the students included physics-informed machine learning (differentiable modeling), field methods, geospatial analysis and mapping, and laboratory procedures. These educational experiences were all informal. Course development was initiated by CIROH to create courses in machine learning, large-scale hydrologic modeling, and hydroinformatics. These courses are scheduled for delivery at CIROH institutions in 2023. Materials will be compiled and shared through community platforms such as CUAHSI Virtual University and HydroLearn.

K-12 and Public Outreach: CIROH researchers had initial contacts with external speaking and engagement opportunities. At the University of Alabama, a program for life-long learning was created and delivered to one cohort. The program is being refined and packaged for regular annual delivery to introduce the local community to operational water prediction and the role of research. Numerous CIROH researchers participated in public events (e.g., Rocket City Weather Fest, Intergenerational Thinkshop for Hydromet Early Warning Early Action) provided early venues for researchers to share their perspective and about CIROH. CIROH also participated in global engagement activities including COP 27 meeting.

41. What was the impact on physical, institutional, and information resources that form infrastructure?

CIROH was awarded in April 2022. Research proposals were submitted in May 2022. NOAA awarded projects starting in August 2022 and extending into the fall. Research project setup started in August of 2022 and extended through the end of 2022. This timeline naturally limited the impact of CIROH on physical, institutional, and information resources to be preliminary. Here we report a few impacts in the three areas.

Development of physical infrastructure across CIROH focused on setup of computational infrastructure, laboratory facilities, and field sites. At the University of Alabama, CIROH's research cloud computer resource was conceptualized, and the building of the infrastructure was initiated.

Research project startups across the consortium involved several lab infrastructure impacts. Several labs (Surface Dynamics Modeling Lab at the University of Alabama, Wemple Research Lab at the University of Vermont, The Integrated Spatial Modeling & Remote Sensing Technologies Lab (iSMART) at Stevens Institute of Technology, Gaming and Simulation Lab at the University of Vermont) coordinated their efforts across institutions aimed at creating the enabling technology for establishing a cooperative network of shared hydrologic observations data derived from in situ sensors. The network of shared data has the potential to serve as data (information) infrastructure to advance capabilities for modeling and forecasting.

Building on the computational resources, CIROH advanced research enabling technologies as spotlighted in other parts of the report. An important milestone was the creation of open-source software to enable access to National Water Model (NWM) retrospective results stored in the cloud. Other impactful accomplishments supporting research were the development of a transferable instance of the NextGen Water Resources Modeling Framework for researcher use and the opening of a JupyterHub portal for experimenting with NWM data. These infrastructure initiatives will allow current and future sponsored projects to utilize the shared data to further expand the scope of research on hydrology.

Institutionally, CIROH Members and Partners established entities to support the advancement of the CI. For example, CIROH Member University of Iowa's Board of Regents approved a new Center for Hydrology Development (CHD) at the IIHR – Hydrosience & Engineering. This new center will help connect IIHR to CIROH, bringing the strength of a national leader in hydrologic research and education.

For information resources, CIROH established a web site and GitHub repositories for organizing and sharing research and education products.

Attach a separate document if more space is needed for #6-10, or #24-50.

IMPACT (cont'd)

42. What was the impact on technology transfer?

CIROH is by nature focused on research to operations, connecting the hydrologic sciences research community to NOAA (and other public and private sector entities) operational water predictions. We have established a process for facilitating the operations to research, and research to operations pipeline, which will enable the translation of research advancements into operational water prediction. CIROH researchers will also be engaged with their work in traditional technology transfer for commercial applications. The work of CIROH researchers will be open source but may involve commercial operations of those open-source developments going forward.

CIROH researchers have started and defined some technologies they will advance following open science protocols. Notably, CIROH has provided open-source tools through GitHub repositories and web portals for the community for rapid data access, streamflow prediction evaluation, snow modeling, flood inundation mapping, and hydrologic information systems. Some of these resources are spotlighted in Appendix 1.

43. What was the impact on society beyond science and technology?

CIROHs projects are working with communities to promote resilience. This includes policy, communication, understanding behaviors and perceptions, and working to foster diversity, equity, and inclusion efforts. This effort is being coordinated by CIROH's public outreach efforts and CIROH's research under Theme 4. CIROH aims to connect researchers, operational professionals, and stakeholders to co-produce solutions for community resilience. This will be a major area of impact reported on in the future.

IMPACT (cont'd)

44. What percentage of the award's budget was spent in foreign country(ies)?

1 , Less than 1% of the award budget was spent in foreign countries during the reporting period.

CHANGES/PROBLEMS

45. Changes in approach and reasons for change

Nothing to Report

CHANGES/PROBLEMS (cont'd)

46. Actual or anticipated problems or delays and actions or plans to resolve them

(1) Amendment 7 - CIROH has experienced a challenge in setting up the subaward to the Oak Ridge National Laboratory (ORNL) consortium partner. ORNL is a Federally Funded Research and Development Center (FFRDC) operated by UT-Battelle, LLC pursuant to a management and operations contract with the United States Department of Energy (DOE). The University of Alabama (UA) issued ORNL subaward documents initially, at which time ORNL advised that it cannot accept flow-down provisions from the Cooperative Agreement between NOAA and UA, and therefore cannot enter into a subaward agreement with UA. ORNL advised UA that its management and operations contract with the DOE prohibits the acceptance of any flow-down provisions. As such, UA cannot issue a subaward or other agreement to ORNL which would comply with 2 C.F.R. §200 or the Cooperative Agreement between UA and NOAA. CIROH, in conjunction with the UA Office for Research & Economic Development, consulted extensively with NOAA and ORNL in an effort to find a solution to issue funding to ORNL. After thoughtful, extensive discussion, it has been determined that the only path forward, in light of ORNL's position, is an Interagency Agreement between NOAA and ORNL to allow NOAA to directly fund ORNL's work. Representatives from the NOAA National Water Center (NWC) and ORNL are currently finalizing the terms and conditions for those agreements.

(2) Amendment 8 – CIROH had to extend the special award condition for amendment 8 regarding the hiring deadline of key personnel "Assistant Research Professional - Remote Sensing Analyst" and continues its search to fill the position. First, we had to work closely with NOAA to define the position description, how the search was conducted, and how the position would be connected to the National Water Center within creating and posting job announcements. This is being completed during a prosperous job market in which we had to search for an extremely specialized person for this unique opportunity. Therefore, UA needed to keep the position open for an extended period to receive an adequate number of qualified applicants. At the end of the 2022 calendar year, CIROH has viable applicants and is currently conducting the evaluation process. CIROH is confident this position will be filled in the early part of 2023.

(3) Amendments 4 – 13 CIROH project amendments were awarded after the designated research project start date of 8/1/2022. Due to the timing of the start of research projects, the set-up of the individual projects and subawards did not happen until the start of the fall academic semester at most consortium institutions. The consequence of this has been student and post-docs and other researchers being hired to start at the end of 2022 or beginning of the spring 2023 semester. Therefore, CIROH is making plans with the PIs to accelerate the projects and get them on pace by July 2023, the end of the first year of the research projects. However, there may be carry-over requests/no-cost extension requests for year-1 funding. CIROH plans to submit its next grouping of proposals with June 1st start dates, which will allow for adequate time for PIs to plan to hire in accordance with the fall semester.

47. Changes that had a significant impact on expenditures

Nothing to Report

CHANGES/PROBLEMS (cont'd)

48. Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Nothing to Report

49. Change of primary performance site location from that originally proposed

Nothing to Report

PROJECT OUTCOMES

50. What were the outcomes of the award?

CIROH Member and Partner institutions sought to startup their activities and research projects proactively. Several research projects succeeded in achieving early milestones and producing research outputs. These are highlighted here, organized by research theme.

Research Theme 1: Improving Water Resources Prediction System Capabilities

Traditional approaches to characterize uncertainty in computational models of coupled natural and human systems range from global sensitivity analysis of model parameters to Monte Carlo simulation experiments, decomposition analyses and propagation of errors analysis. CIROH researchers were able to rapidly develop information theoretic approaches, such as Shannon, Entropy, MaxEnt, Kullback Leibler Divergence (KLD), and Fisher, Index etc., to provide powerful complementary approaches to characterize uncertainty, and evaluate uncertainty in testbeds. CIROH researchers explored these propositions by applying unsupervised machine learning algorithms (Bayesian Network Models and Random Forest Models) to the simulation outputs derived from 180 scenarios of an integrated model that predicts water quality in Missisquoi Bay of Lake Champlain under alternate hydro-climatic, land use and nutrient management regimes for 2000-2050 timeframe. The best fit machine learned models are then analyzed to characterize the uncertainty by measuring node force derived from KLD, normalized symmetric mutual information and relative uncertainty of water quality predictor variables extracted from the integrated model.

The output from the National Water Model gives predictions for the flow in the nation's rivers and streams in a format dictated by the sequence of model execution. Each output file gives flow for all waterways for one moment in time per file. In order to derive hydrograph time series of model results for individual points requires several computationally costly post-processing steps. We explored several methods of improving access to the NWM results, reducing the time and computational cost to obtain a at-a-point time series information by an order of magnitude or more. We achieved this result using innovative cloud approaches to data and computing and by consolidating the model outputs on a per-forecast basis using several different file formats.

Research Theme 2: Advancing Community Water Resources Modeling

CIROH researchers produced several advances that will lead to impactful research outcomes as the work is disseminated. Areas of focus included river routing (developing a differentiable river routing model that can learn process parameterization for the channels based on downstream geometry), capability to process geospatial datasets into the format for physics-informed machine learning hydrologic models, and development of benchmark hydrologic variable test watersheds using alternative model formulations.

Research Theme 3: Innovating Hydroinformatics Tools and Data Science Applications

CIROH has created an early capability to estimate the width and depth of river channels and estimate the roughness of river channels across the contiguous U.S. Once implemented, these will provide improved forecasting capabilities across many applications. Complementing this geospatial processing outcome, CIROH research also produced a new capability to calculate floodwater depth from satellite imagery and an online portal that shows flood initiation conditions in over 1000 forecasting locations across the U.S. with a real time link to forecast from the nation's operational

DEMOGRAPHIC INFORMATION FOR SIGNIFICANT CONTRIBUTORS (VOLUNTARY)

<p>Gender:</p> <p><input type="radio"/> Male</p> <p><input type="radio"/> Female</p> <p><input type="radio"/> Do not wish to provide</p>	<p>Ethnicity:</p> <p><input type="radio"/> Hispanic or Latina/o Not</p> <p><input type="radio"/> Hispanic or Latina/o Do not wish to provide</p>
<p>Race:</p> <p><input type="radio"/> American Indian or Alaska Native Asian</p> <p><input type="radio"/> Black or African American</p> <p><input type="radio"/> Native Hawaiian or other Pacific Islander</p> <p><input type="radio"/> White</p> <p><input type="radio"/> Do not wish to provide</p>	<p>Disability Status:</p> <p><input type="radio"/> Yes</p> <p style="padding-left: 20px;"><input type="checkbox"/> Deaf or serious difficulty hearing</p> <p style="padding-left: 20px;"><input type="checkbox"/> Blind or serious difficulty seeing even when wearing glasses</p> <p style="padding-left: 20px;"><input type="checkbox"/> Serious difficulty walking or climbing stairs</p> <p style="padding-left: 20px;"><input type="checkbox"/> Other serious disability related to a physical, mental, or emotional condition</p> <p><input type="radio"/> No</p> <p><input type="radio"/> Do not wish to provide</p>

Attach a separate document if more space is needed for #6-10, or #24-50.