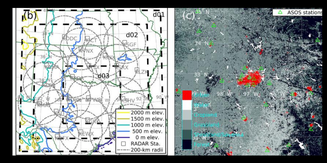
CSSI: Frameworks: Large Scale Atmospheric Research Using an Integrated WRF Modeling, Visualization, and Verification Framework (I-WRF)

Award # 2209711

8/1/2022 – 7/31/2026



PI Rich Knepper, Cornell University; co-PIs Sara C. Pryor, Cornell; Jared A. Lee & Sue Ellen Haupt, NSF NCAR Research Applications Laboratory

i-wrf.org

Project Goals

I WRF

- Cornell University and the NSF National Center for Atmospheric Research are developing a containerized framework for the Weather Research and Forecasting (WRF) model with validation and visualization tools.
- Application containers operate seamlessly across diverse systems, facilitating large-scale, multi-node processing.
- Users can try WRF without the complexities of installation and compilation.
- This lowers the bar for multi-disciplinary researchers interested in using WRF and helps build a pipeline to recruit new scientists.
- Researchers have the flexibility to model on laptops, in the cloud, or on HPC resources.

Science Use Cases

Sara C. Pryor, Cornell University

To validate the I-WRF framework, scaling studies are being conducted on platforms like Jetstream2 and Derecho, focusing on selected use cases that:

1. Demonstrate critical I-WRF container features and capabilities with high-throughput simulations that require advanced diagnostic analyses.
2. Address priorities outlined in the NSF strategic plan, including assessing climate change impacts on the U.S. energy transition.
3. Maximize the dissemination of scientific insights and discoveries, and the new CSSI-enabled I-WRF container framework.

I-WRF Use Cases

- Land Use/Land Cover (LULC) Change in the U.S. Northeast and Feedbacks to Extreme Weather Events and Societal Impacts
S.C. Pryor and Xin Zhou (Cornell)
- Climate Change Impacts on Wind and Solar Resources
Sue Ellen Haupt, Jared A. Lee (NSF NCAR), Sara C. Pryor (Cornell)
- Air Quality in the Northeast Urban Corridor
– Jared A. Lee (NSF NCAR), Sara C. Pryor (Cornell)

S&E Challenges/Advances

The I-WRF project tackles science and engineering (S&E) challenges facing the WRF user community. The table below outlines these challenges, the framework strategy, and the anticipated S&E advancements.

S&E Challenges	I-WRF Framework	S&E Advances
WRF container limited to single node computing	New I-WRF Container will enable multi-node WRF	Container-based modeling that scales
Limited visualization capabilities	New tools will be integrated with the Analysis/Visualization Container such as ParaView	Seamless data analysis experience with enhanced visualization capabilities
Community confidence in research results	Containerized METplus tools will be optimized for I-WRF framework	Faster access to verification tools and refinement of workflows
Difficulty compiling and configuring WRF	Standard multi-node capable containers will be built, tested, and ready to use	Rapid application deployment
Target systems with specialized hardware and/or limited container capabilities	Easy to modify features. Extendable design.	Platform portability to desktop, cloud/edge, and HPC for research flexibility
Consistent execution environment	Reusable and repeatable framework	Reproducible scientific results
Automated container deployment, scaling, and management	Scripted Kubernetes orchestration via Terraform solution will be created for WRF	Reliable container orchestration
Difficulty developing new containers from scratch	I-WRF use case scripts, build files, etc. will be shared with sample data and storage configurations	Creating I-WRF container framework will spur community development of new containers and science apps
~50% students have difficulty configuring their machines to start WRF training exercises	Turnkey container for easier education of students and early career scientists	Increased student recruitment from all relevant domains; bigger pipeline to the close diversity gap
Lack of CI technical support skills, and/or time available	I-WRF will reduce need for CI support; 24x7 virtual workshop training available. NCAR committed to sustaining I-WRF.	Researchers can get started with multi-node WRF without CI staff support, lowering the bar for less resource rich institutions

PY2 Accomplishments

Build the integrated WRF and METplus framework

- Created seamless communication between native WRF output and Model Evaluation Tools (METplus) utilities through containerization.
- Completed version 0.1.0 of I-WRF framework containers.
- Executed Hurricane Matthew test case simulations on Derecho, Jetstream2, AWS, Red Cloud, and a Windows Intel desktop; conducted Hurricane Sandy simulations on Red Cloud and a Mac laptop. Platform portability will increase researcher flexibility.

Improve training at NSF NCAR and other institutions

- Documented Hurricane Matthew test case container simulations on GitHub to facilitate community access and reproducibility.
- I-WRF container simulations will be integrated into NCAR training programs to significantly reduce challenges about 50% of students encounter when configuring their machines for WRF.
- Barriers to entry for institutions with limited resources will be lowered by enabling WRF simulations to be initiated without extensive support from teaching staff.

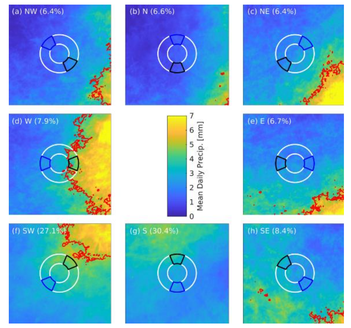
PY2 Accomplishments (cont.)

Support multi-node simulations

- Preparing multi-node support for simulations catering to large-scale runs with diverse inputs such as Xin Zhou's and Sara C. Pryor's Land Use/Land Cover research.

Facilitate ease of use for a wider range of researchers

- Crafting an I-WRF User Guide on the project's NCAR/i-wrf GitHub repository that offers how-to guides and will include generic execution scripts. I-WRF images are hosted on Docker Hub.



Mean daily precipitation during the warm season of 2002-2021, sampled by 850 hPa wind direction from ERA5. White rings show 50 and 100-km radii around centroid of Dallas Fort-Worth. Numbers denote the frequency of observations. Wind-direction-specific sub-sampling areas for comparison of precipitation upwind (blue outline) and downwind (black outline) of DFW. Red contours denote areas where >20% of days have daily precipitation >5 mm. Configurations and input data from this research will be used next for multi-node I-WRF testing on Derecho (Xin Zhou et al.).

Increase project awareness

- PI Knepper and Co-PIs Lee and Pryor delivered six I-WRF presentations at scientific and cyberinfrastructure conferences.
- I-WRF postdoc Xin Zhou was lead author of "Urban Effect on Precipitation and Deep Convective Systems Over Dallas-Fort Worth," published in the *Journal of Geophysical Research,* in May 2024 (https://doi.org/10.1029/2023JD039972).

PY3 Tech Team Plans

- Develop I-WRF framework versions 0.2.0 to 0.4.0 and publicly release version 1.0.0 with easy-to-adapt templates.
- Validate all versions on Derecho or other HPC/cloud platforms.
- Prioritize features that deliver maximum value to researchers, incorporating best practices for configuration and deployment.
- Support significant applications, including LULC (S.C. Pryor & X. Zhou) and climate change impacts on wind and solar energy production (S.E. Haupt, J.A. Lee, & S.C. Pryor).
- Initiate the containerization of WRF-Chem; address challenging bottlenecks and enhance visualization capabilities.

PY3 Broader Impact Plans

- Integrate I-WRF containers into NCAR tutorials and create an I-WRF Virtual Workshop to train users and promote v.1.0.0 usage/pulls.
- Present at six scientific/cyberinfrastructure meetings and publish six papers. Provide four educational demos. Notify Metropolitan State U. of Denver, Central Michigan U., and others of availability.
- Request Cornell student participation via Engineering Teams, an MS-Eng project, and the CSTEP/McNair Scholars program.