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2021 American Geophysical Union Fall Meeting

December 13, 2021 6:15-7:15 PM CST

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

NOAA's National Water Center: Programmatic Update and Opportunities for Collaboration

Mary Erickson, Ed Clark, Fred Ogden, Nels Frazier, Matt Williamson, Keith Jennings, Chris Massey

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Deputy Director at NOAA’s National Weather Service

Mary Erickson

Director of NOAA's National Water Center

Ed Clark

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Panelists

- Fred Ogden
  - NOAA Office of Water Prediction, Chief Scientist
- Matt Williamson
  - NOAA Office of Water Prediction, Analysis and Prediction Division
- Keith Jennings
  - NOAA Office of Water Prediction, Analysis and Prediction Division
- Nels Frazier
  - NOAA Office of Water Prediction, Analysis and Prediction Division
- Chris Massey
  - U.S. Army Corps of Engineers, Engineering Research & Development Center Coastal & Hydraulics Laboratory CEERD-HFC-I

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Next Generation Water Resources Modeling Framework: Philosophy and Design

Fred Ogden, Chief Scientist of NOAA's Office of Water Prediction

NOAA OWP | OFFICE OF WATER PREDICTION

National Water Model

- 2011 - Originally proposed by CUAHSI
  - Proposed as a community model
  - Much interest in academic and research communities
  - Ultimately, lacked agency support
- 2014 - NOAA-NWS recognized potential for predictions outside of traditional forecast points
- 2016 - NWM Version 1.0 operationalized by NOAA-NWS, based on WRF-Hydro (NOAH-MP + routing functions + conceptual groundwater)
- 2021 - NWM Version 2.1 operationalized over CONUS, HI, PR, USVI

OWP's Community Advisory Committee for Water Prediction

2019 Report Recommendations:

1. Articulate requirements for further development of the NWM
2. Emphasize improvements using observational data and potential sources of data.
3. Emphasis on improving data assimilation techniques and processes.
4. **Stand up a community development & engagement process, governance, and center; pursue proven mechanisms for community adoption**

The Hydrologic Science Literature Shows…

- Hydrologic models formulated for specific dominant local processes consistently outperform general models, when appropriately applied. (*uniqueness of place*)

- Models with fewer parameters that describe dominant processes outperform general models that emphasize process through parameter values. (*parsimony*)

- Given the lack of comprehensive stormflow generation theory, there is no “one model to rule them all”

Motivation

- Federal agencies struggle with model selection, identifiability and interoperability

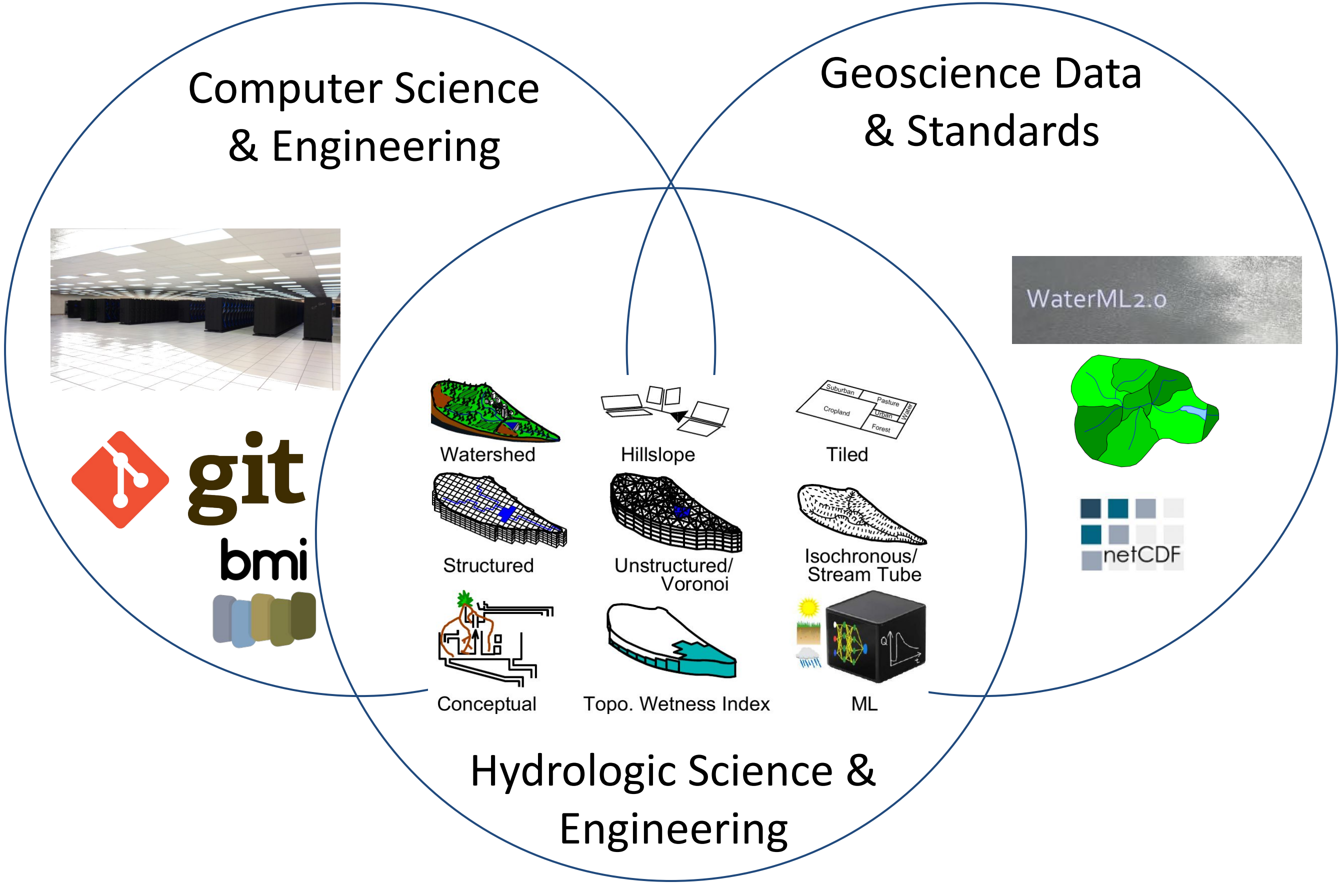
- Legacy codes and heterogeneous computing environments impede advances

- Contemporary open-source software paradigm encourages collaboration, evidence-based selection, identifiability, and promotes interoperability

Proposed Solution

- Develop a computational framework that allows arbitrary methods/models to calculate fluxes of interest and integrate them over arbitrary time scales and control volumes
  - Environment to appeal to domain scientists
  - Contemporary open-source software development methods
  - Provide maximum flexibility
  - Ease model interoperability
  - Allow evidence-based evaluation of different approaches
  - Take advantage of each agency’s considerable experience

Enabling Technologies & Standards



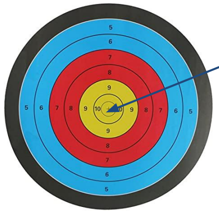
Nextgen Modeling Framework Requirements

- Model agnostic with maximum flexibility
  - As models, data sources, and needs change- so does framework
- Common architecture avoids duplication and promotes interoperability
- Open source development
  - Promote code reuse and development efficiency
  - Authoritative repository for federal water models
  - Ease/encourage participation by partners and community
- Apply standards where applicable
  - Coding, coupling
  - Data and metadata
  - Model verification/validation and test data
- Friendly to domain scientists and engineers

Outcomes from joint NOAA, USACE-ERDC, USGS, USBR requirements workshop 26-28 - October 2020

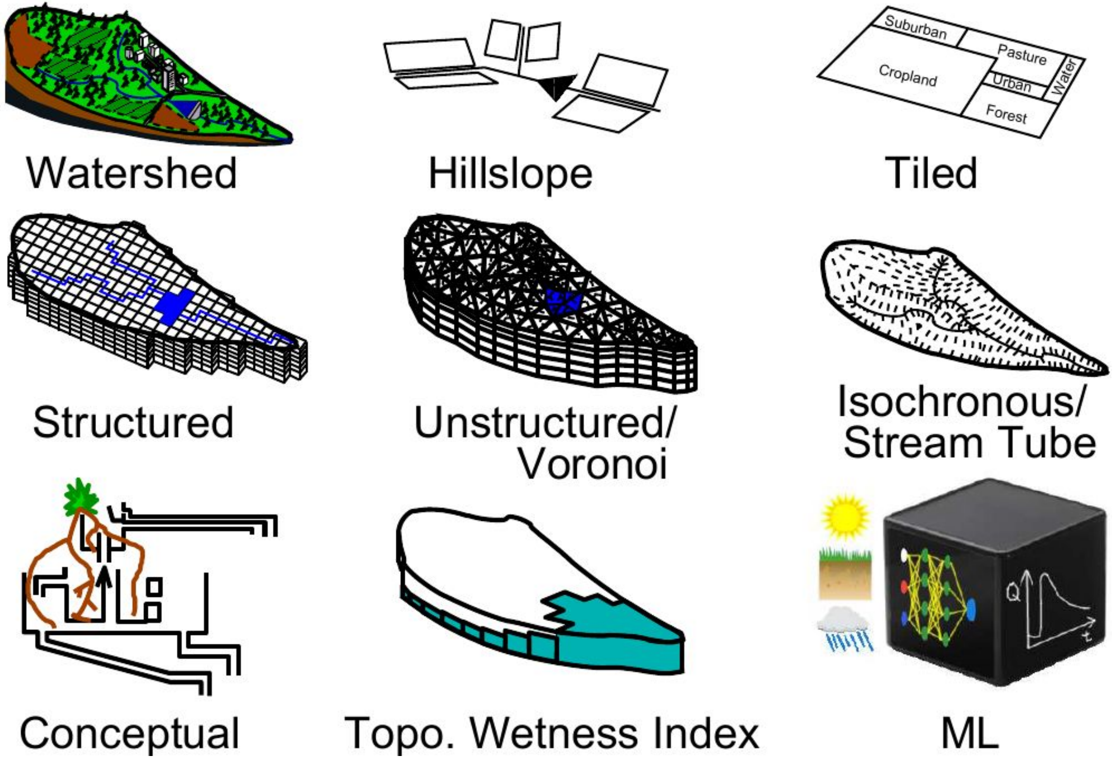
Nextgen Framework Objectives

- Engage federal and academic research communities
- Using open-source, standards-based development
- With well documented multi-language examples
- Using a model agnostic focus on interoperability
- Linked with NOAA and other weather and climate models
- To ease scientific evaluation of coupled models/methods
- Running on hardware from laptops and supercomputers

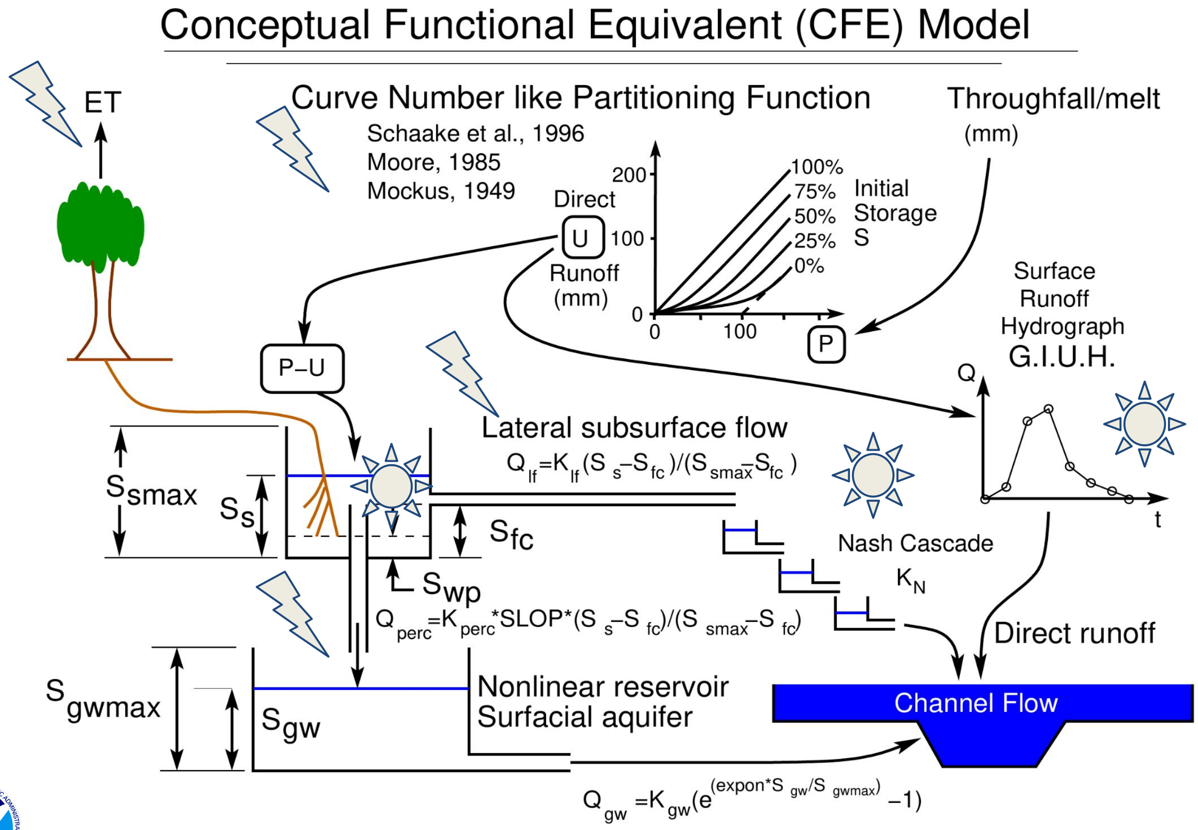


Two weeks for domain science or engineering graduate student or new employee to add new functionality.

Allow Diverse Model Formulations/Discretizations

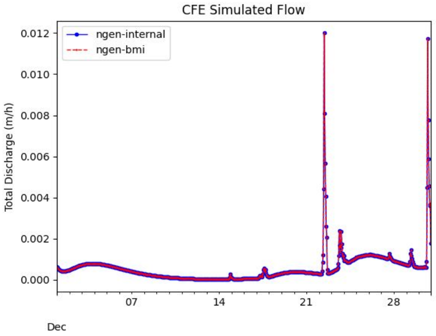


Conceptual Functional Equivalent to NWM



Identical to current NWM

New conceptual replacement function



Community Engagement

- Transparent open-source development
- Unification of data models promotes code interoperability (stop inventing data models)
- Prevent bug re-invention by sharing code
- Support a diverse computational environment (hardware and programming languages)
- Unconstrained use cases (might find use outside hydrology)
- Federal water prediction community evaluates models in common setting
  - Supports scientific evaluation
  - Advances demonstrably superior approaches

Enabling Collaboration

The stage is set:

- Transparent open source code development paradigm
- Standard geospatial data models & libraries
- CSDMS Basic Model Interface - extended to HPC
- Multi-agency need to promote science and interoperability

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

BUREAU OF RECLAMATION

CUAHSI
universities allied for water research

USGS
science for a changing world

NCAR

Next Generation Water Resources Modeling Framework Demonstration

Matt Williamson, Keith Jennings, Nels Frazier - NOAA's Office of Water Prediction, Analysis and Prediction Division

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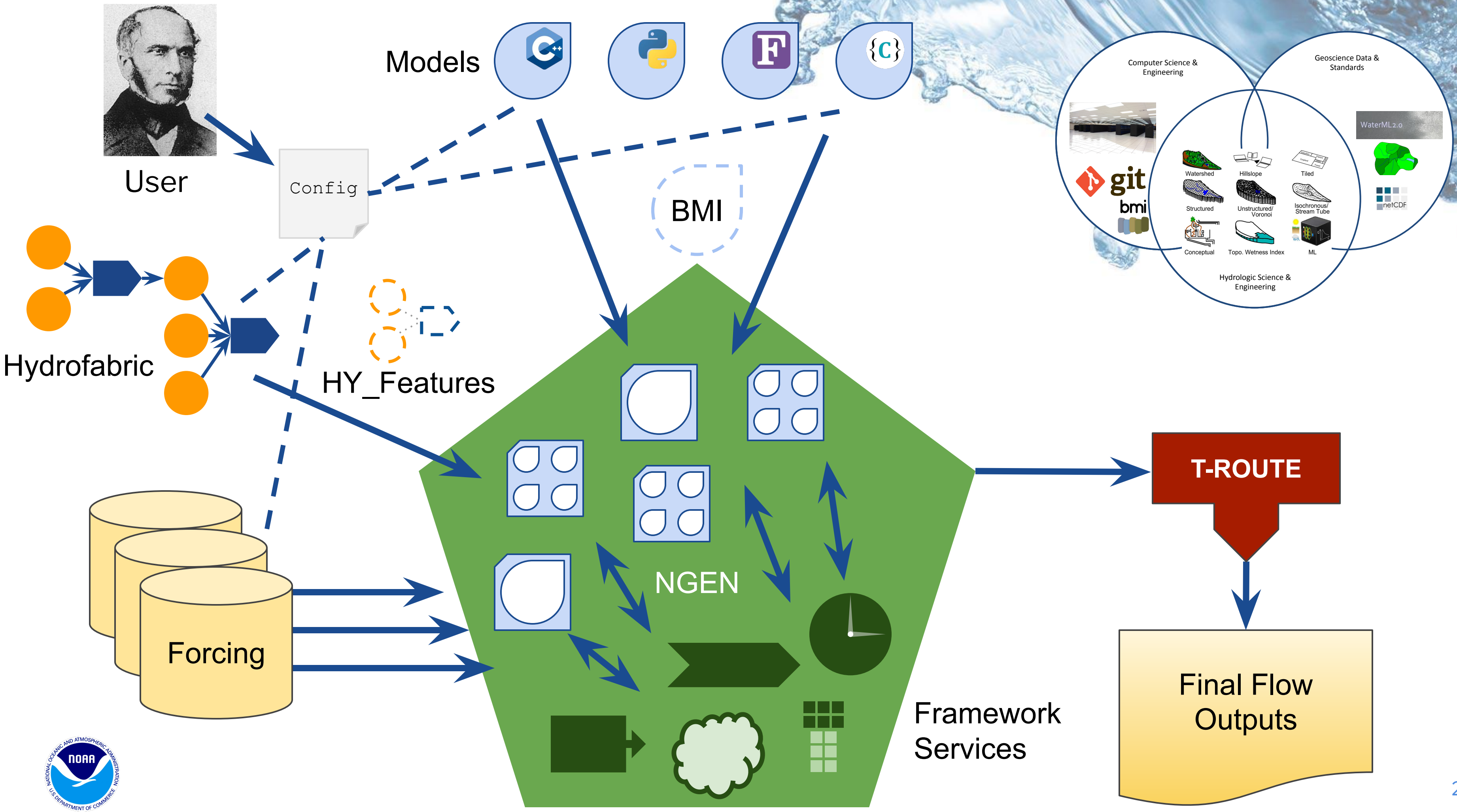
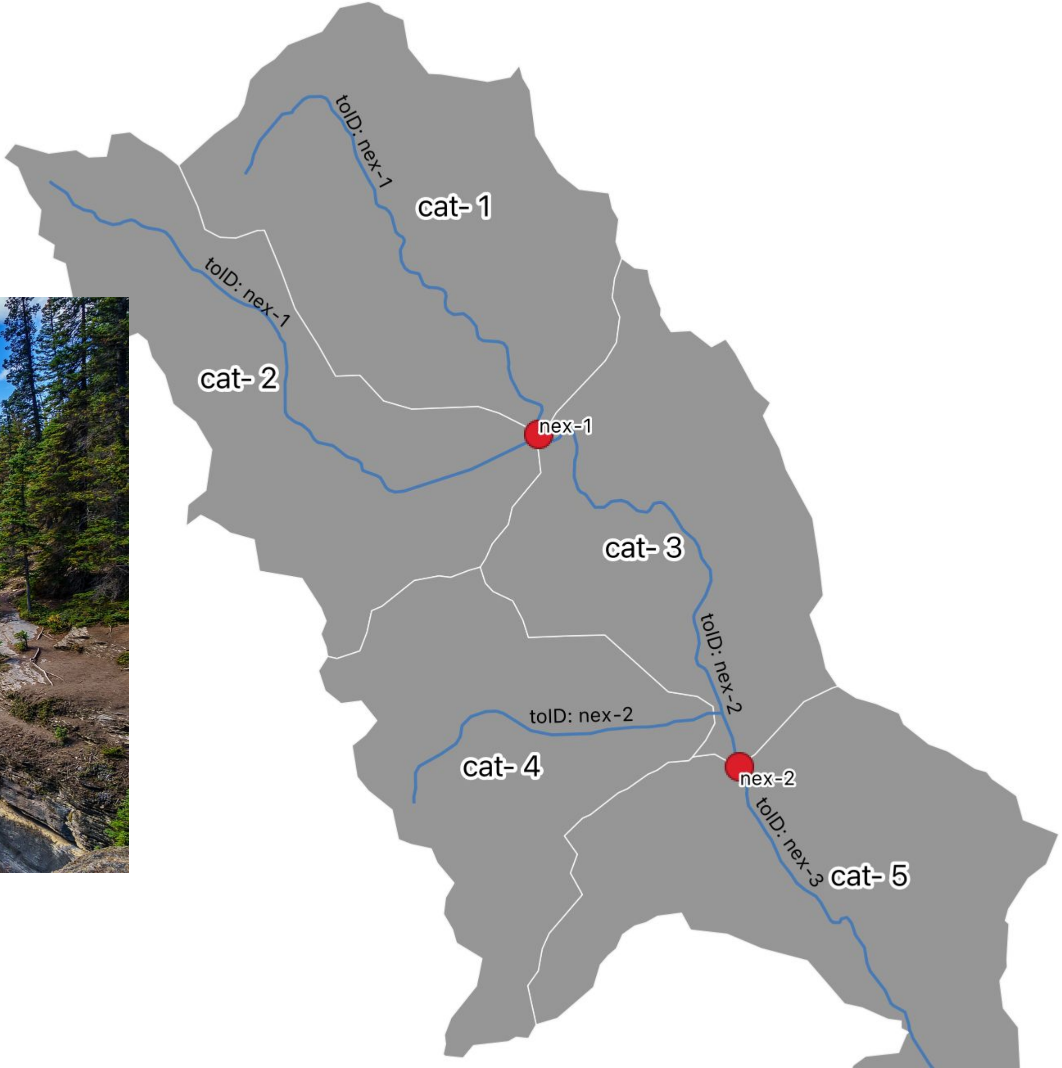
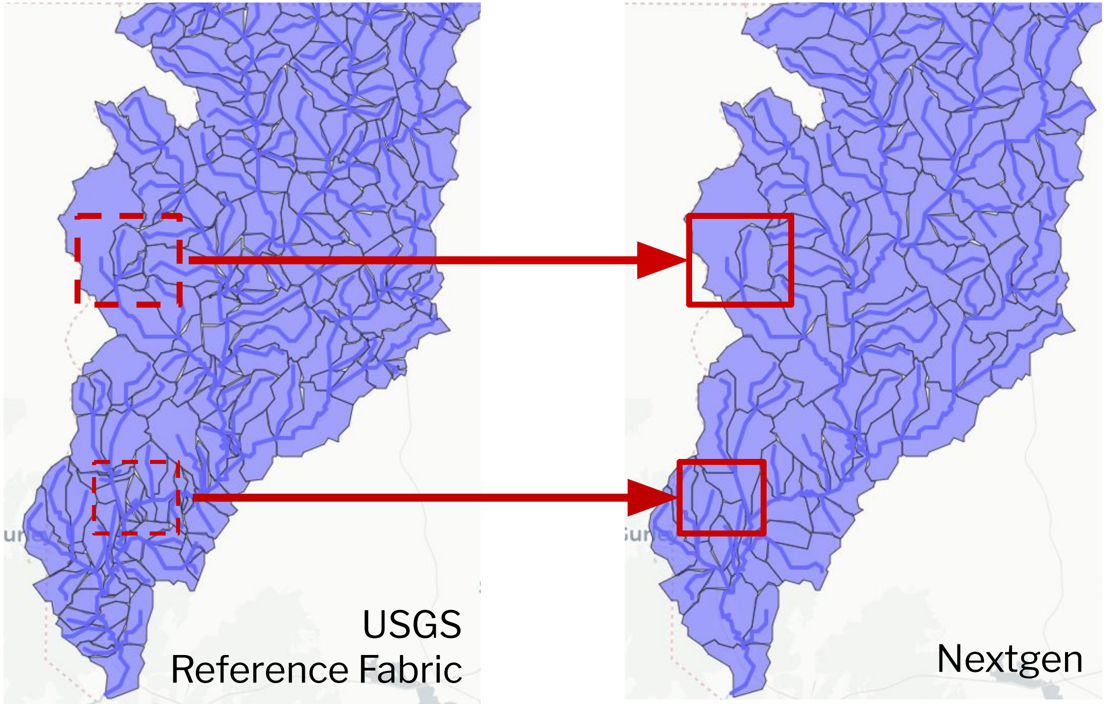

User
Config
Models
BMI
Hydrofabric
HY_Features
Forcing
NGEN
Framework Services
T-ROUTE
Final Flow Outputs
Computer Science & Engineering
Geoscience Data & Standards
Hydrologic Science & Engineering
git
bmi
WaterML2.0
netCDF
Watershed
Hillslope
Tiled
Structured
Unstructured/ Voronoi
Isochronous/ Stream Tube
Conceptual
Topo. Wetness Index
ML

Nextgen Hydrofabric



Nextgen Hydrofabric

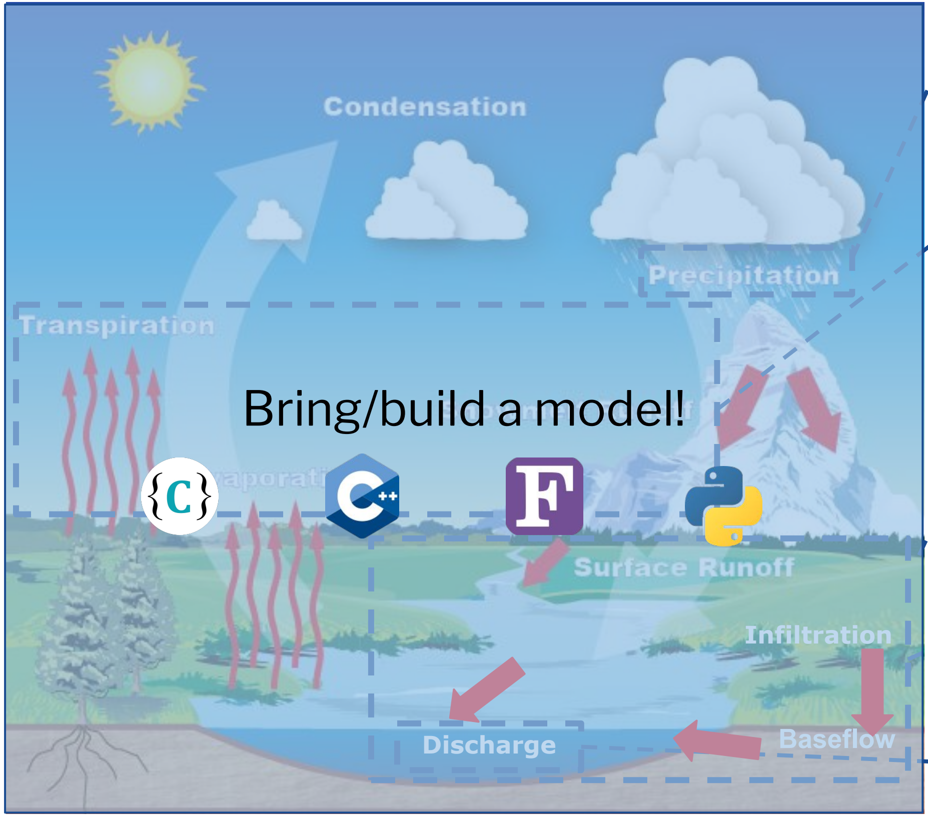
- Start with reference hydrofabric
- Refactor and aggregate to optimize basin size
- Open-source tools available via OWP GitHub



n = 281
cat. < 3 km^2 = 177

n = 104
cat. < 3 km^2 = 0

Nextgen Formulations



Forcing
- Data read in and passed to formulations

Noah-OWP-Modular
- Surface energy and water fluxes

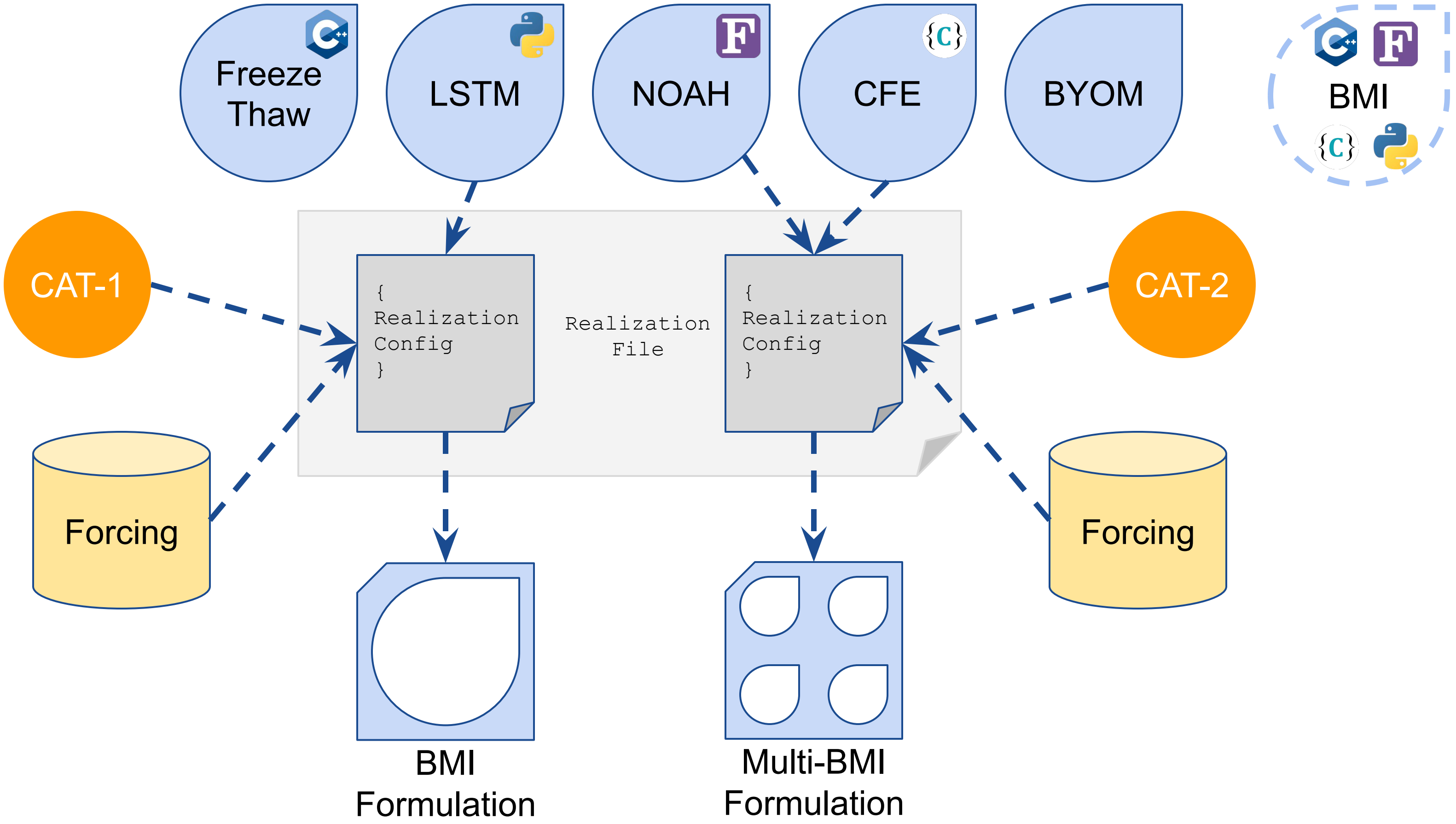
TOPMODEL
- Foundational rainfall-runoff model

CFE
- Conceptual Functional Equivalent (CFE)
- Runoff routines mimic current NWM

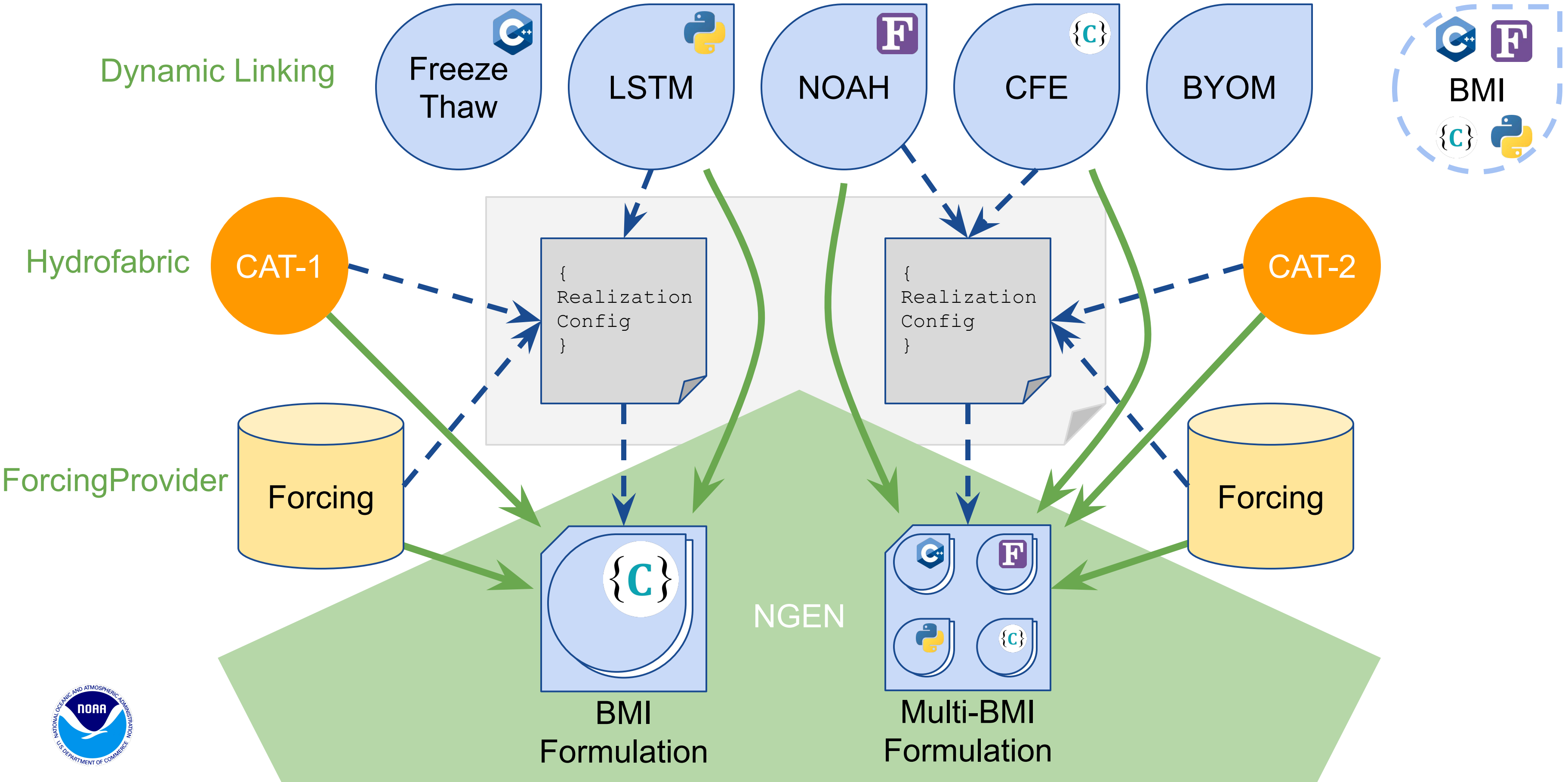
LSTM
- Long Short Term Memory
- Machine learning model

BMI

Connecting BMI-enabled models in Nextgen



Connecting BMI-enabled models in Nextgen



Demo — Get Nextgen via GitHub

```
git clone https://github.com/NOAA-OWP/ngen.git
```

- Few dependencies
  - But make sure they're installed and accessible
- Now you can:
  - Build the models you're running
  - Build Nextgen
  - Set up your files
  - Run Nextgen

```
$ ./cmake_build/ngen catchment_data.geojson cat-1 \
nexus_data.geojson nex-2 \
Realization_01350140_noahowp_NewNOAHOWP.json
    Hello there 0.1.0
    Building Nexus collection
    Building Catchment collection...
```

Demo

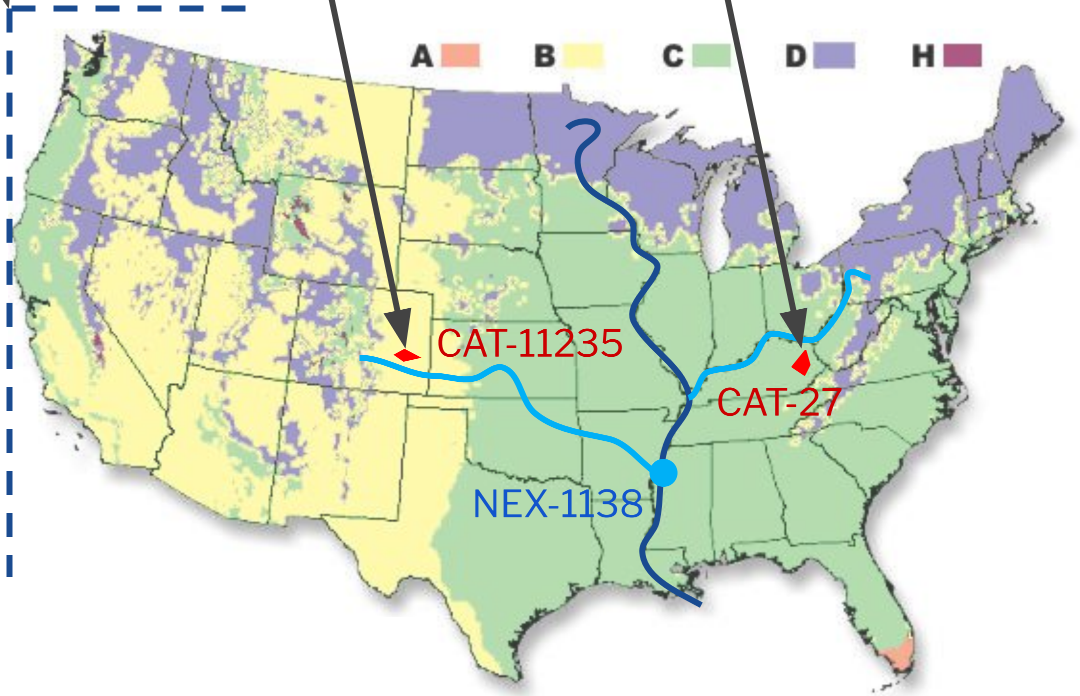
Files you need to run

- Realization Configuration
  - ngen configuration
- Hydrofabric
  - catchment_data.geojson
  - nexus_data.geojson
- Forcing Data
  - CSV, future: netCDF, other
- For parallel, Partitions
  - partitions.json

Global Realization
- Model A
- Init Config A1

Override Realization
- Model B
- Init Config B1

Override Realization
- Model A
- Init Config A2



Demo

Realization Configuration

Simulation Time Configuration

Routing Configuration

```
"time": {
    "start_time": "2007-01-01 00:00:00",
    "end_time": "2019-12-30 00:00:00",
    "output_interval": 3600
},
 "routing": {
     "t_route_connection_path": "../ngen/extern/t-route/src/ngen_routing/src",
     "t_route_config_file_with_path": "./routing/ngen_routing_res.yaml"
 }
```

Demo

Global Realization Configuration

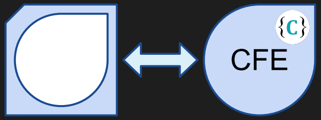
Using model built from https://github.com/NOAA-OWP/cfe/

```
{
Realization
Config
}
```

Location of BMI library

Model Config File

Catchment runoff variable name

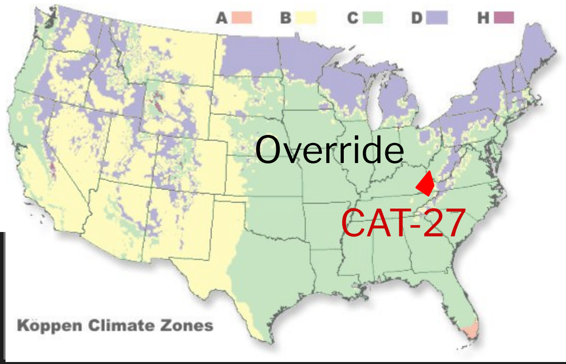



```
"formulations": [
    {
        "name": "bmi_c",
        "params": {
            "model_type_name": "bmi_c_cfe",
            "library_file": "../ngen/extern/cfe/cmake_build/libcfebmi.so",
            "init_config": "../CFE/{{id}}_bmi_config_cfe_pass.txt",
            "allow_exceed_end_time": true,
            "main_output_variable": "Q_OUT",
            "registration_function": "register_bmi_cfe",
            "variables_names_map": {
                "water_potential_evaporation_flux": "potential_evapotranspiration",
                "atmosphere_water__liquid_equivalent_precipitation_rate": "precip_rate",
                "atmosphere_air_water~vapor__relative_saturation": "SPFH_2maboveground",
                "land_surface_air__temperature": "TMP_2maboveground",
                "land_surface_wind__x_component_of_velocity": "UGRD_10maboveground",
                "land_surface_wind__y_component_of_velocity": "VGRD_10maboveground",
                "land_surface_radiation~incoming~longwave__energy_flux": "DLWRF_surface",
                "land_surface_radiation~incoming~shortwave__energy_flux": "DSWRF_surface",
                "land_surface_air__pressure": "PRES_surface"
            },
            "uses_forcing_file": false
        }
    }
],
```

Demo

Realization Configuration

Global



Overriding Catchments

Use Python Module

Use Machine Learning Model

Use Specific Forcing

```
"catchments": {
    "cat-27": {
        "formulations": [
            {
                "name": "bmi_python",
                "params": {
                    "model_type_name": "lstm",
                    "python_type": "bmi_lstm.bmi_LSTM",
                    "init_config": "../LSTM/cat-27.yml",
                    "main_output_variable": "land_surface_water__runoff_depth",
                    "variables_names_map": {
                        "atmosphere_water__time_integral_of_precipitation_mass_flux": "RAINRATE"
                    },
                    "uses_forcing_file": false
                }
            }
        ],
        "forcing": {
            "path": "../forcing/huc_01/csv/cat-27.csv",
            "provider": "CsvPerFeature"
        }
    },
```

Demo Run

Output

Time series spatial animations of:

- Flow throughout HUC01
- ET throughout HUC01
- Snow accumulation throughout HUC01
- Water input to surface throughout HUC01

Output

Noah-OWP (Fortran) + CFE (C)

HUC01 (14,632 catchments)

3-year run (1 year warmup)

1h 56m

Single node

48 cores (Xeon 8160M)

96 processes

Output

LSTM (Python)

HUC01 (14,632 catchments)

3-year run (1 year warmup)

2h 40m

Single node

48 cores (Xeon 8160M)

96 processes

Output

Noah-OWP (Fortran) + CFE (C)

LSTM (Python)

HUC01 (14,632 catchments)

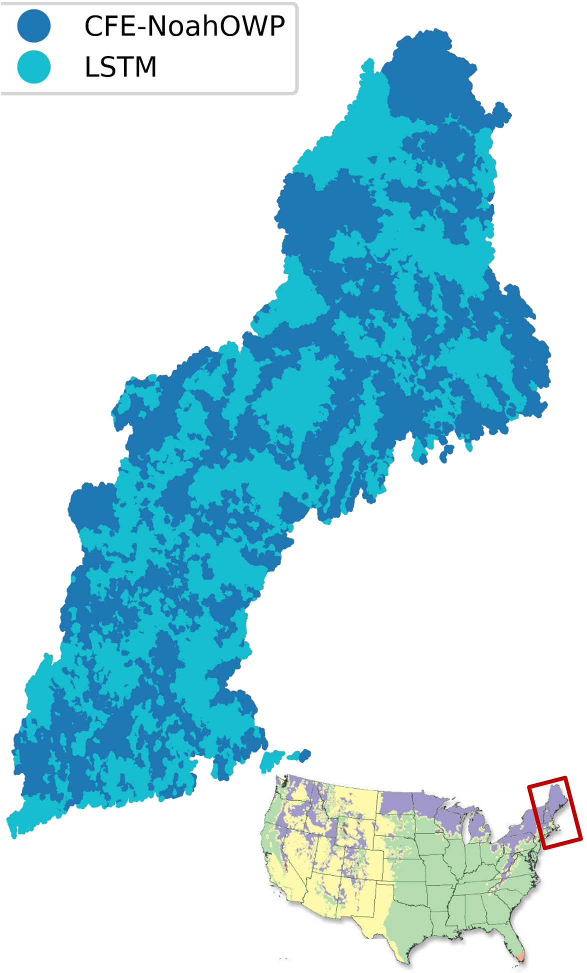
3-year run (1 year warmup)

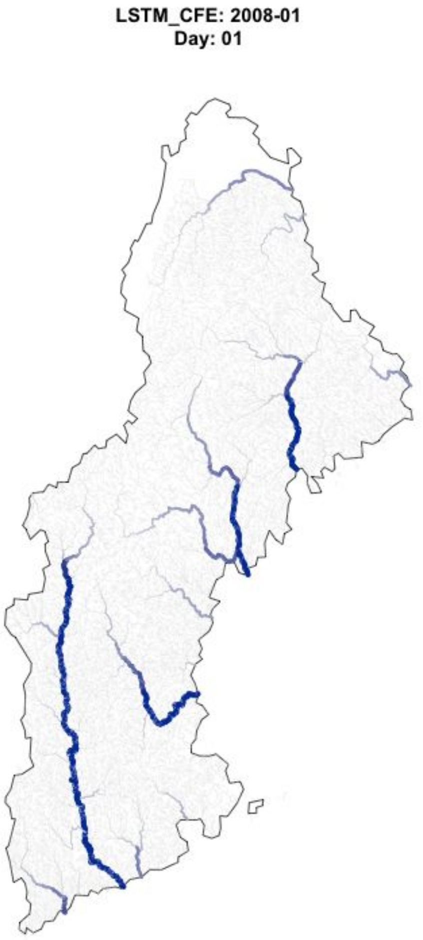
3h 0m

Single node

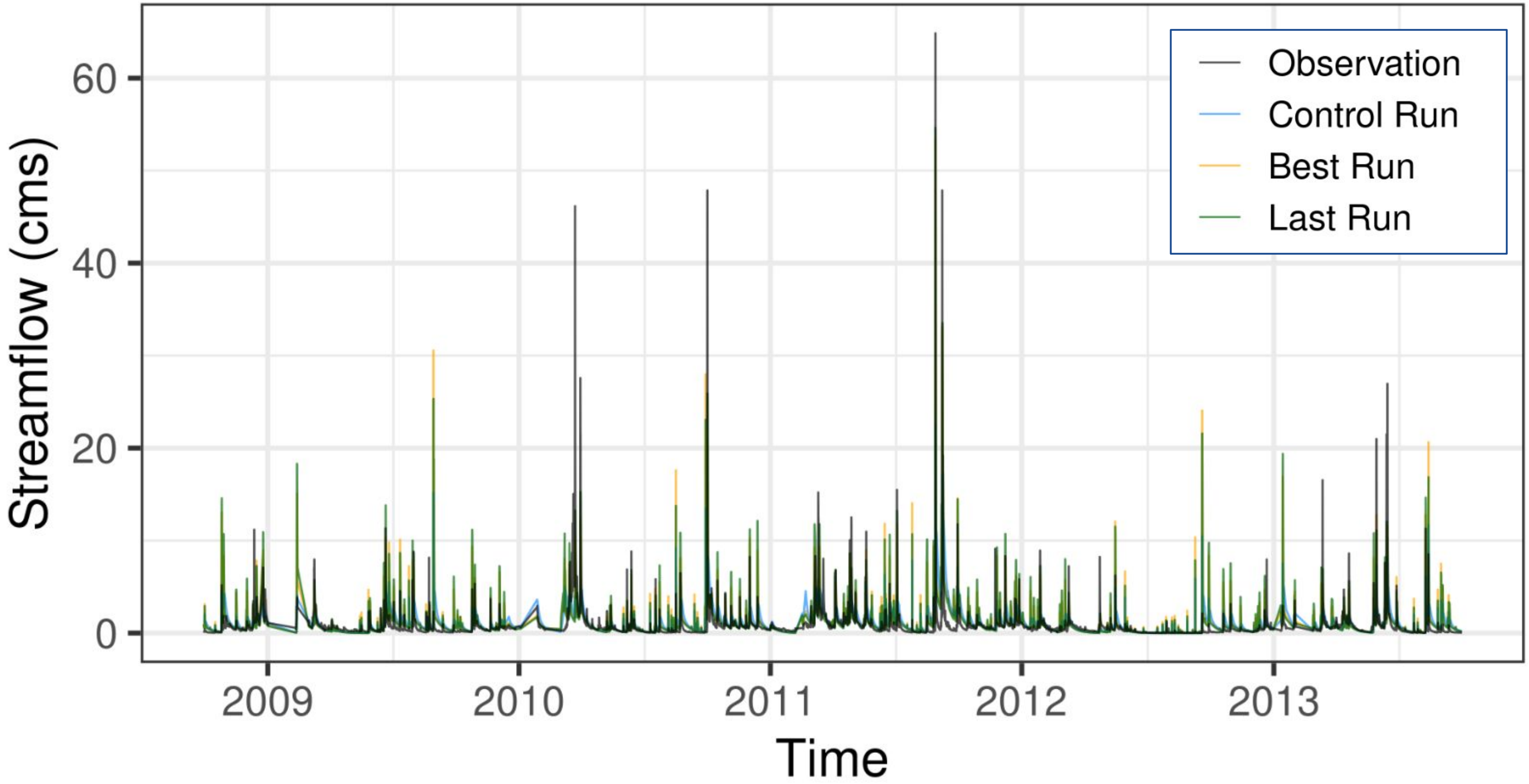
48 cores (Xeon 8160M)

96 processes

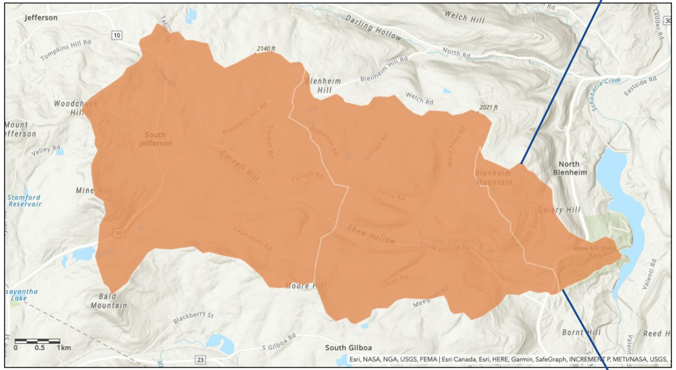


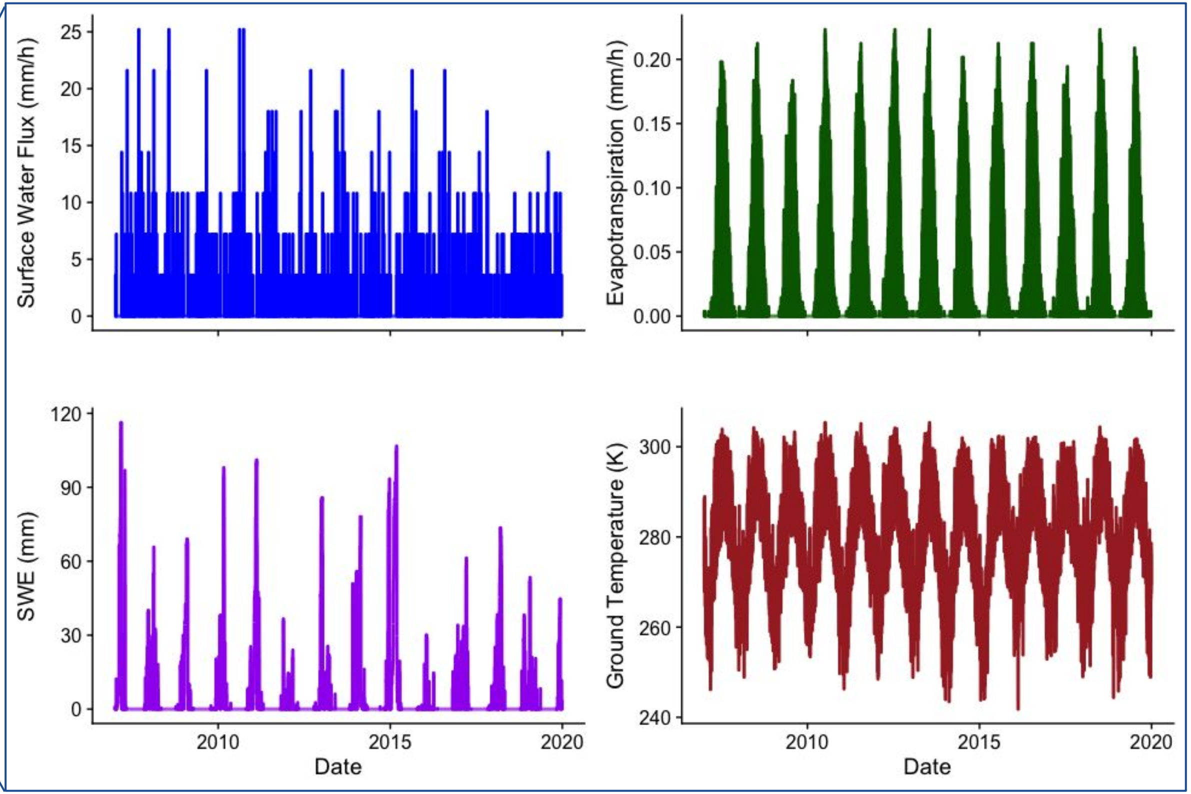


Calibration First Efforts



Additional Output Variables





Parallel Scaling

Noah-OWP (Fortran) + CFE (C)

HUC01 (14,632 catchments)

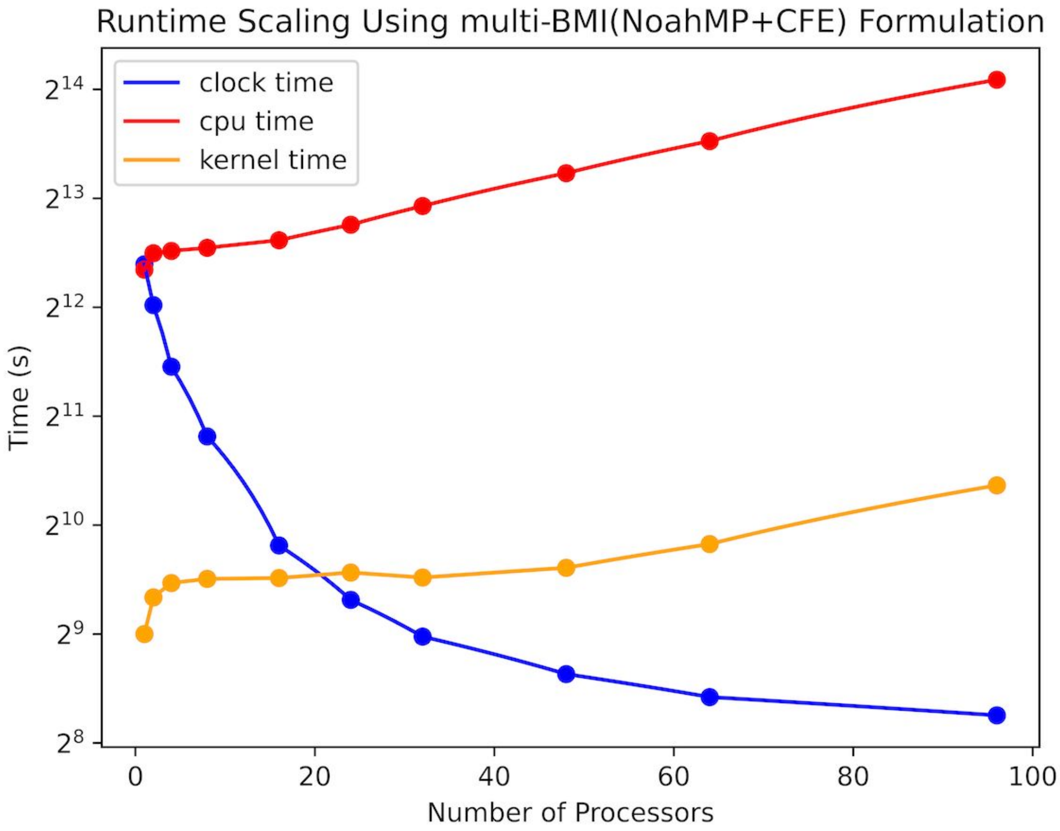
2 month runs

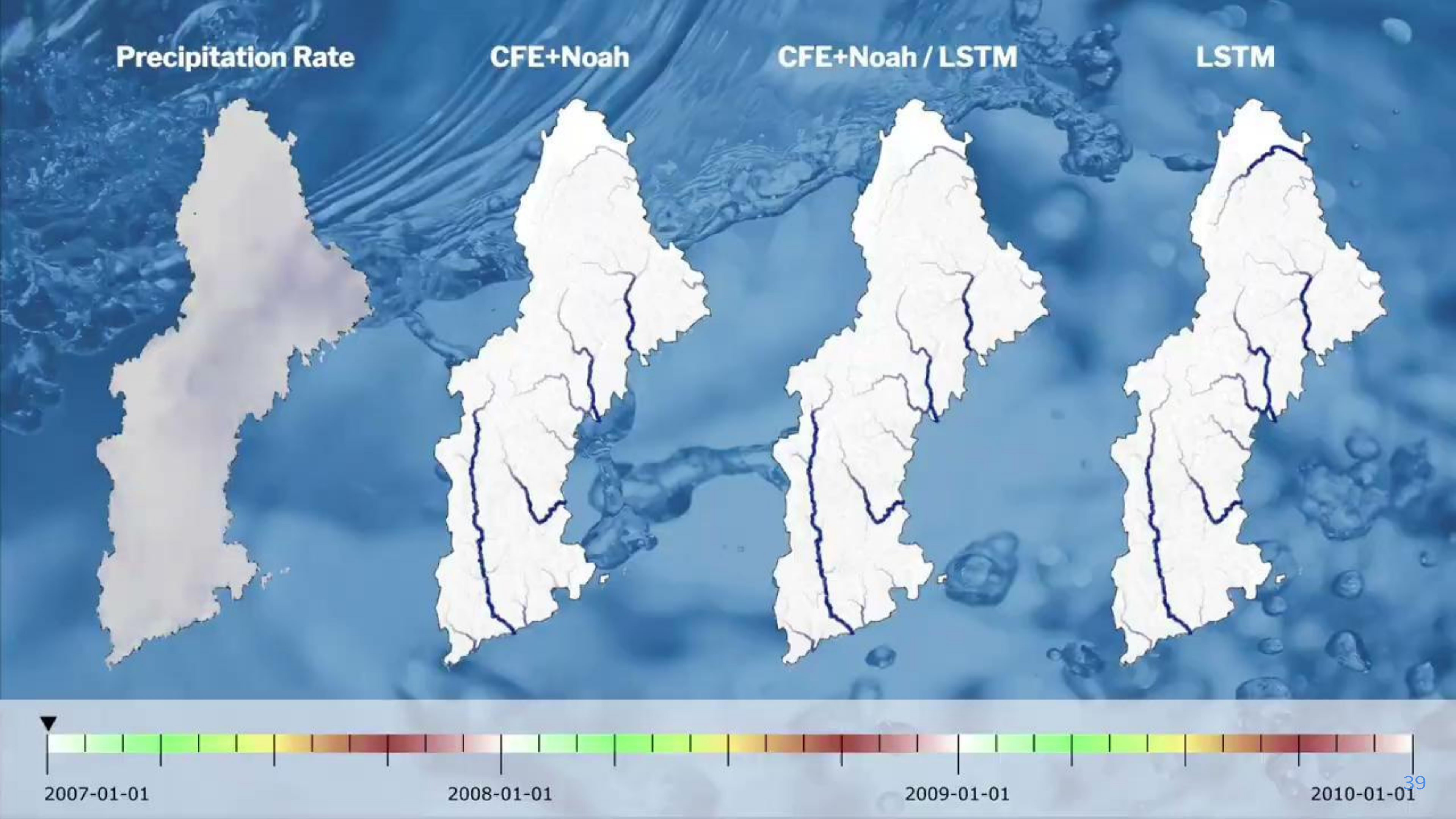
Effective scaling

Single node

48 cores (Xeon 8160M)

1 to 96 processes




Precipitation Rate
CFE+Noah
CFE+Noah / LSTM
LSTM
2007-01-01
2008-01-01
2009-01-01
2010-01-01

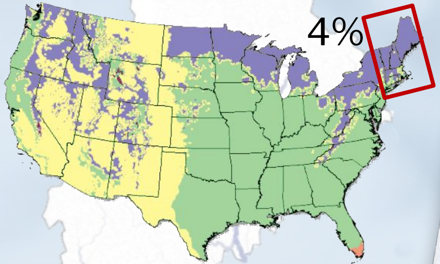
Next Generation National Water Model

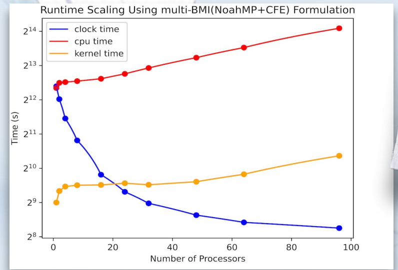
Modular and Open Source

Truly Heterogenous

+

Scalable





4% CONUS
@ 3yr ~3h
1 node x 48 cores

CONUS ~1yr per day
... or ...
1y/h with 25 nodes

+ Multilanguage
+ML & New Technology
+Maintainable

2007-01-01 2008-01-01 2009-01-01 2010-01-01

Be a Nextgen contributor!

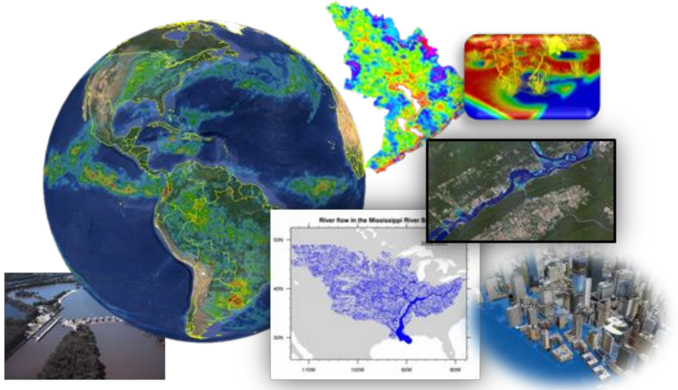
All code available in Open Source projects on GitHub

- https://github.com/NOAA-OWP …
    - /ngen
    - /hydrofabric
    - /noah-owp-modular
    - /cfe
    - /topmodel
    - /lstm
    - /evapotranspiration
    - /SoilFreezeThaw (beta)

Next Generation Water Resources Modeling Framework Testimonial

Chris Massey, U.S. Army Corps of Engineers, Engineering Research & Development Center Coastal & Hydraulics Laboratory
CEERD-HFC-I

USACE Comprehensive Hydro-Terrestrial Risk Management



Provides advanced quantitative, actionable flood risk Information to support operations, contingency response, planning, design, and O&M

NOAA’s Next Generation Water Resources Modeling Framework aligns well with USACE needs and goals. It allows both federal agencies to work together to achieve separate missions within the hydro-terrestrial risk management arena.

National Challenge

- US inland and coastal damage has **increased from $5B to $50B/year over the past 40 years and fatalities have increased tenfold**
- **Flood risk assessment is reactive and lacks** critical hydro-terrestrial system context
- Rising sea levels, aging infrastructure, population growth, ~~and~~ economic growth, and heightened national security challenges increase the demand for flood risk resilience

Strategic Target / Major Capabilities

1. Common operating framework to evaluate comprehensive flood hazard on a continental scale
2. Next generation remote and space-based observations assimilated in real time
3. Innovative integration of high-fidelity simulation and artificial intelligence
4. Advanced and modular numerical methods and physics packages for interaction of atmospheric, inland, and coastal processes
5. Advanced tools for uncertainty quantification
6. Hazard assessment tools for risk-based project design and operation based on trade space analytics

Outcome

- Reduction in flood risk and casualties due to disasters
- Reduced time & cost, improved skill in modeling/design of projects
- Efficient tools to drive sediment, environmental, and structural evaluations (engineering/O&M)
- Improved Federal coordination & cooperation

Q&A

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Connect with OWP

https://github.com/NOAA-OWP/OWP-Presentations

- OWP GitHub: https://github.com/NOAA-OWP
- NextGen GitHub: https://github.com/NOAA-OWP/ngen
- OWP Strategic Plan: https://www.nohrsc.noaa.gov/owp_files/docs/OWP_Strategic_Plan_FY2021-FY2026_FINAL.pdf
- Twitter: https://twitter.com/nwsnwc
- YouTube: https://www.youtube.com/channel/UCIIC2c3weRXNATL1fs7SECA
- Facebook: https://www.facebook.com/NWSNationalWaterCenter

AGU FALL MEETING

FRONTIERS IN HYDROLOGY MEETING | “THE FUTURE OF WATER” NOW ACCEPTING ABSTRACT SUBMISSIONS

Sponsored by AGU Hydrology Section and CUAHSI, #FIHM22 aims to develop actionable solutions to some of the largest water problems facing our world today.

Help shape the #FIHM22 inaugural meeting by submitting an abstract by 26 January 2022.

Please join session 142579 as the Office of Water Prediction will host a session titled “Advancing the State-of-the-Science of Water Resources Modeling - Community Development at the Intersection of Domain, Data, and Computer Sciences”.

AGU ADVANCING EARTH AND SPACE SCIENCE

Frontiers in Hydrology

19-24 June 2022
San Juan, Puerto Rico

https://www.agu.org/fihm

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Thank You!

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https://water.noaa.gov