Multi-scale hydrologic prediction using the community WRF-Hydro modeling system

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WRF-Hydro System Description

A community-based, supported coupling architecture designed to provide:

1. An extensible multi-scale & multi-physics land-atmosphere modeling capability for conservative, coupled and uncoupled assimilation & prediction of major water cycle components such as precipitation, soil moisture, snowpack, groundwater, streamflow, inundation

2. ‘Accurate’ and ‘reliable’ streamflow prediction across scales (from 0-order headwater catchments to continental river basins & minutes to seasons)

3. Research modeling testbed for evaluating and improving physical process and coupling representations
WRF-HYDRO SYSTEM DESCRIPTION

Column Land Surface Models:
Noah/NoahMP/SAC-HTET*

Output Variables:
Evapotranspiration
Soil moisture/Soil Ice
Snowpack/snowmelt
Runoff
Radiation Exchange
Energy Fluxes
Plant Water Stress

Terrain Routing Models:
Overland, subsurface flow

Output Variables:
Stream Inflow, Surface Water Depth, Groundwater Depth, Soil Moisture

1-way coupling or 2-way coupling

Channel & Reservoir Routing Models:
Hydrologic and Hydraulic

Output Variables:
Streamflow
River Stage
Flow Velocity
Reservoir Storage & Discharge
Hydrologic Prediction with the Community WRF-Hydro System
WRF-Hydro Process Permutations and System Features

- ~180 possible ‘physics’ component configurations for streamflow prediction:
  - 3 up-to-date column physics land models (Noah, NoahMP, CLM)
  - 3 overland flow schemes (diffusive wave, kinematic wave, direct basin aggregation)
  - 4 lateral/baseflow groundwater schemes (Boussinesq shallow-saturated flow, 2d aquifer model, direct aggregation storage-release: pass-through or exponential model)
  - 5 channel flow schemes: diffusive wave, kinematic wave, RAPID-Muskingum for NHDPlus, custom network Muskingum/Muskingum Cunge

- Simple level-pool reservoir with management
- Data assimilation: ensemble (DART) and nudging

Ensemble Flood Forecasting in the Southeast U.S. with WRF-Hydro
2014 WRF User’s Workshop, K. Mahoney (NOAA-ESRL)
WRF-Hydro v2.2 Physics Components

Physics-based runoff processes:

- **Overland Flow** - Diffusive wave, Kinematic wave, Catchment aggregation

- **Groundwater Flow** – Boussinesq flow, Catchment aggregation

- **Channel Flow** – Diffusive wave, Kinematic wave, Reach-based Muskingum and Muskingum-Cunge
WRF-Hydro v2.2 Physics Components

Subsurface routing:
- 2d groundwater model
- Coupled to bottom of LSM soil column through Darcy-flux parameterization
- Independent hydraulic characteristics vs. soil column
- Full coupling to gridded channel model through assumed channel depth and channel head
- Detailed representation of wetlands

Surface ponded water from coupled groundwater in WRF-Hydro

B. Fersch, KIT, Germany
Rwrfhydro: R package for WRF-Hydro Model Evaluation

https://github.com/mccreigh/rwrfhydro

- Set of R tools to support WRF-Hydro pre- and post-processing
- Open source, community tool
- Full documentation and training vignettes
- Major Features:
  - Domain visualization
  - Remote sensing & geospatial data prep
  - Output post-processing
  - Observation data acquisition and processing
  - Model output evaluation and visualization
Current WRF-Hydro Applications around the world:

1. **Operational Streamflow Forecasting:**
   - U.S. National Weather Service, National Water Center
   - Israeli Hydrological Service
   - State of Colorado-Upper Rio Grande River Basin (CWCB, NSSL)
   - NCAR-STEP Hydrometeorological Prediction Group
   - U. of Calabria reservoir inflow forecasting

2. **Streamflow prediction research** (U. Ankara, Arizona State U., Karlsruhe Inst. Tech.)

3. **Diagnosing climate change impacts on water resources**
   - Himalayan Mountain Front (Bjerknes Inst.)
   - Colorado Headwaters (U. Colorado)
   - Bureau of Reclamation Dam Safety Group (USBR, NOAA/CIRES)


5. **Diagnosing the impacts of disturbed landscapes on coupled hydrometeorological predictions**
   - Western U.S. Fires (USGS)
   - West African Monsoon (Karlsruhe Inst. Tech)
   - S. America Paraná river (U. Arizona)
   - Texas Dust Emissions (Texas A&M U.)
   - Landslide Hazard Modeling (USGS)
EXAMPLE APPLICATIONS

Boulder, Colorado - 2013 Flood Modeling
Upper Rio Grande Basin – Water Supply Forecasting
Baja, Mexico - Hurricane Odile Impacts
CONUS – Streamflow Prediction
Modeling the Sept. 2013 Floods:

WRF-Hydro simulated streamflow using NOAA radar-gauge observed rainfall

Streamflow in cms
Hydrologic Prediction with the Community WRF-Hydro System

Getting to Street Level Impacts

St. Vrain River
Longmont
Leftbank Creek

Hygiene
North St.
Vrain River
Twin Peaks Golf Course
Golden Ponds Park and Nature Area
Lagman Reservoir
Plateau Rd
Lasea Rd
Prospect Rd
Rozelle Rd
Moffosh Lake
Lakeshore Dr
21st Ave 21st Ave
17th Ave
75th Ave
Mountain View Ave
111 Ave
Marini St
Twin Peaks Golf Course
Clover Basin Dr
Creekside Dr
Plateau Rd
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Rio Grande Basin: Water Supply Forecasting

Figure 1. Colorado-New Mexico Water compact basins of the Upper Rio Grande River basin

NSSL NOXP
Experimental Radar

Conejos Basin
ASO-SWE

WRF-Hydro
Model Domain

In-situ
Stations

Hydrologic Prediction with the Community WRF-Hydro System
Rio Grande Basin: Model Simulated Snow Water Equivalent

Hydrologic Prediction with the Community WRF-Hydro System
Rio Grande Basin: Model Simulated Accumulated Streamflow

Conejos River Near Mogote

Rio Grande at Del Norte

Rio Grande South Fork

Alamosa River Above Terrace Reservoir

Hydrologic Prediction with the Community WRF-Hydro System
Hydrologic impacts of hurricane landfall

HWRF/WRF-Hydro
Hydrologic impacts of hurricane landfall

HWRF/WRF-Hydro
National Water Modeling Initial Operating Capability (IOC):

- Operational forecast streamflow guidance for currently underserved locations
  - ~ 4,000 → 2.7 million river reaches

- Spatially continuous estimates of hydrologic states for the nation through enhanced physical accounting of major water cycle components
  - snowpack, soil moisture, ET, channel flow, flood inundation
IOC Model Benchmark Evaluation: Streamflow

Correlation:

71% of basins had correlation > 0.6

Bias:

27% of basins had bias < 20%
IOC Model Benchmark Evaluation: Big Rivers

Streamflow: 14103000 (DESchUTES River at MOODY, NEAR Biggs, OR)

Streamflow: 05568500 (ILLINOIS River at KINGSTON Mines, IL)

Management Impacts

Streamflow: 09163500 (COLORADO River NEAR Colorado-UTAH State)

Streamflow: 01638500 (POTOMAC River at Point of Rocks, MD)

Hydrologic Prediction with the Community WRF-Hydro System
Data Assimilation with WRF-Hydro

1. HydroDART: ensemble DA

2. Nudging: operational streamflow forecasting
“HydroDART” =

WRF-Hydro (offline)

- Multi-model
  - NoahMP & Noah
- Uncertainty specification
- Observation retrieval

https://www.ral.ucar.edu/projects/wrf_hydro

http://www.image.ucar.edu/DARES/DART/

- Filters
- Inflation
- Localization
- Parallelization
- Observation handling
- OSSE
- Diagnostics
- Etc...

Mult-model - NoahMP & Noah
Uncertainty specification - Observation retrieval
HydroDART Flowchart

Have initial states?

Yes

No

Long-term spinup

Have ensemble?

Yes

No

Perturb initial state

Have ensemble streamflow?

Yes

No

Equilibrate

Have observations?

Yes

No

Assimilate

Flowchart:

- Start
- Have initial states?
  - Yes: Long-term spinup
  - No: Have ensemble?
    - Yes: Perturb initial state
    - No: Have ensemble streamflow?
      - Yes: Equilibrate
      - No: Have observations?
        - Yes: Assimilate
        - No: STOP

- LSM States
  - Noah
  - NoahMP

- Hydro States
  - High-res soil moisture
  - Channel flow and stage
  - Groundwater level

- "AssimOnly" States
  - Model parameters
  - Forcing adjustments

- Assimilation States (Restart Files)

- WRF Hydro States

- Perturb States

- WRF Hydro

- DART

- Observations at model time?
  - No: Filter Update States
  - Yes: Observations

- Executables
  - Control files
  - Restart files
  - Forcing files
  - Observation files

- Key
  - Decision
  - Task

- Ensemble members (if created)
Nudging DA: Motivation

- Operational forecasting: IOC
- Lots of available observations from USGS NWIS
  - 2015:
    - 6,000 – 8,000 available stations (.2-.3% of NHD reaches)
    - 15,000,000 – 25,000,000 observations monthly
- State agency data

- Why nudging?
  - Calibration challenges => model biases => improper error covariances
  - (No error covariances => treat symptom not cause)
  - Computationally tractable at national scale
  - Future: hybrid with other DA methods
WRF-Hydro Initial Operating Capability (IOC) System: Model Chain with nudging data assimilation

1. WRF-Hydro Forcing Engine (1 km grid)
2. NoahMP LSM (1 km grid)
3. Terrain Routing Module (250 m grid)
4. NHDPlus Catchment Aggregation
5. Channel & Reservoir Routing Modules
6. USGS stream gages
7. GOES satellites
8. USGS National Water Information System (NWIS)
9. Preprocess: Ingest and QC
10. Stream Nudging Module

Hydrologic Prediction with the Community WRF-Hydro System
WRF-Hydro Nudging: Illustration near a reservoir

USGS 08044500 – W Fk Trinity Rv nr Boyd, TX

- Observations
- Open loop
- Nudging
- Nudging w/o

2015:

May, Jun, Jul, Aug, Sep, Oct, Nov

Streamflow (cms)
% Open Loop Bias Reduction: OL -> Nudge Validation: May-Oct, 2015

% bias reduction
(-Inf, -100]
(-100, 0]
[0, 20]
[20, 40]
[40, 60]
[60, 80]
[80, 100]

Mean Flowrate (cms)
0
50
100
150
200
Thank you.

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WRF-Hydro: http://www.ral.ucar.edu/projects/wrf_hydro/

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