Technical Description of the National Water Model Implementation WRF-Hydro

Developed by large integrated NWC, NCAR and academic development team

The National Water Model (NWM) is a hydrologic model that simulates observed and forecast streamflow over the entire continental United States (CONUS). The NWM simulates the water cycle with mathematical representations of the different processes and how they fit together. This complex representation of physical processes such as snowmelt and infiltration and movement of water through the soil layers varies significantly with changing elevations, soils, vegetation types and a host of other variables. Additionally, extreme variability in precipitation over short distances and times can cause the response on rivers and streams to change very quickly. Overall, the process is so complex that to simulate it with a mathematical model means that it needs a very high powered computer or super computer in order to run in the time frame needed to support decision makers when flooding is threatened.

The NWM complements current hydrologic modeling which is done in a simplified manner for approximately 4000 locations across the CONUS by providing information at a very fine spatial and temporal scale at those locations, as well as for locations that don’t have a traditional river forecast.

http://water.noaa.gov/about/nwm
The National Water Model

Development Team: NCAR/RAL, NOAA/OWP/NWC, USGS, CUAHSI, Universities
Sponsor: NOAA Office of Water Prediction

Data Throughput:
• Input data per day: 4.45 Terabytes
• Output data per day: 3 Terabytes
• # of river channels: 2.7 million
• # of reservoirs: 1,260
• Total # of computational elements: ~360,000,000

Model Details:
• Number of lines of code: 74,740
• Computer usage: > 100,000 cpu-hours per day

Available online at: http://water.noaa.gov/tools/nwm-image-viewer

System become fully operational beginning Aug. 16, 2016
• Real-time verification since June 2016 (Rwrfhydro)
• Multiple operational products created by NOAA, academia, private sector
• Operational forecast streamflow guidance for currently underserved locations

• Spatially continuous estimates and forecasts of hydrologic states for the nation through, enhanced physical accounting of major water cycle components (snowpack, soil moisture, channel flow, major reservoir inflows, flood inundation)

• Seamlessly interface real-time hydrologic products into and advanced *geospatial intelligence* framework

• Implement an Earth system modeling architecture that permits rapid model evolution of new data, science and technology
WRF-Hydro forms the foundation of the National Water Model

A community-based, robust Earth System Modeling Framework (ESMF)-compliant hydrologic modeling framework supported by the National Center for Atmospheric Research (NCAR) being put into operations by an OWP, NCAR and National Centers for Environmental Prediction (NCEP) partnership

Not dependent on a particular forcing data source or choice of LSM

Able to operate over multiple scales and with multiple physics options

National Water Model Version 1.0: Model Chain

1. NWM Forcing Engine (1 km grid)
2. NoahMP LSM (1 km grid)
3. Terrain Routing Module (250 m grid)
4. NHDPlus Catchment Aggregation (2.7M unique catchments and river reaches)
5. Channel & Reservoir Routing Modules

NWM uses NCAR supported community WRF-Hydro system
NWM: http://water.noaa.gov/about/nwm
WRF-Hydro: https://www.ral.ucar.edu/projects/wrf_hydro
### Operational Cycling of the National Water Model

<table>
<thead>
<tr>
<th>Cycling</th>
<th>Forecast</th>
<th>Meteorological Forcing</th>
<th>Outputs</th>
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<tbody>
<tr>
<td><strong>ANALYSIS &amp; SHORT-RANGE</strong></td>
<td></td>
<td></td>
<td>1-km spatial fluxes (water &amp; energy); 250-m routed fluxes (water); NHDPlus channel routing</td>
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<tr>
<td>Hourly</td>
<td>0 – 21 hrs</td>
<td>MRMS QPE</td>
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<td></td>
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<td>Downscaled HRRR/RAP Blend</td>
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<tr>
<td><strong>MEDIUM-RANGE</strong></td>
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<tr>
<td>Daily</td>
<td>to 10 days</td>
<td>MRMS QPE</td>
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<tr>
<td></td>
<td></td>
<td>Downscaled GFS</td>
<td></td>
</tr>
<tr>
<td><strong>LONG-RANGE</strong></td>
<td>Daily x 16 ensembles</td>
<td>Downscaled &amp; NLDAS2 Bias Corrected CFS</td>
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<tr>
<td>to 30 days</td>
<td></td>
<td>Downscaled GFS</td>
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</tbody>
</table>
National Water Model v1.0 Physics and Related Products (Operational and Experimental)
Model Setup:

- **NHDPlusV2-Encompassing Domain**
- **1km NoahMP land model:**
  - USGS-NLCD land cover (2011)
  - NRCS STATSGO, 1km soils
  - Climatological vegetation structure (v1.0)
- **250m routing**
  - Diffusive wave overland flow
  - Saturated subsurface flow
  - NHDPlusv2 catchment-based baseflow parameterization
- **NHDPlusv2 channel routing**
  - Muskingum-Cunge
  - oCONUS manual reach processing....
  - 2.7M river reaches
  - 1260 passive, level-pool reservoirs
NoahMP Column Physics:

Unified Noah/OSU Land Surface Model

Precipitation Condensation

Transpiration

Canopy Water Evaporation

Turbulent Heat Flux to/from Snowpack/Soil/Plant Canopy

Deposition/Sublimation to/from snowpack

Direct Soil Evaporation

Runoff on bare soil

Evaporation from Open Water

Soil Moisture Flux Internal Soil Moisture Flux

Interflow

Gravitational Flow

\[ \Delta Z = 10 \text{ cm} \]
\[ \Delta Z = 30 \text{ cm} \]
\[ \Delta Z = 60 \text{ cm} \]
\[ \Delta Z = 100 \text{ cm} \]

NoahMP development lead by M. Barlage and F. Chen, NCAR
National Water Model v1.0 Physics Configuration

Runoff and Routing Physics:

Overland Flow

Lateral Subsurface Flow

Simplified Baseflow Parameterization

Muskingum-Cunge Channel Flow and Simple Reservoirs
Nudging-based Data Assimilation:

- 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 Agencies...

- 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

Data assimilation team led by J. McCreight, NCAR
**Hydrologic Output**
- River channel discharge and velocity at 2.7 million river reaches
- Reservoir inflow, outflow, elevation
- Ponded water depth and depth to saturation (250 m CONUS+ grid)

**Land Surface Output**
- 1km CONUS+ grid
- Soil and snow pack states
- Energy and water fluxes

**Direct-output and derived products** (e.g. stream flow anomalies)

**Data Services**
- Public-facing NWC website (animation, zoom, point and click hydrographs)
- Data feed to River Forecast Centers
- NOMADS data service (NOAA National Operational Model Archive & Distribution System)
National Water Model v1.0 Physics Configuration

Land Surface Model Outputs:

National Water Model Soil Moisture Guidance
Analysis valid for 2016-11-02 02:00:00 UTC
Model initialized at 2016-11-01 23:00:00 UTC
Land Surface Model Outputs:

Snow Water Equivalent (SNEQV): Being validated with SNOTEL, MODIS SCA, SNODAS, NASA-Airborne Lidar

1 Nov 2016 06Z Medium Range Forecast: Valid 11 Nov 1000Z (colorscale 0-50mm)
Land Surface Model Outputs:

1 Nov 2016 06Z Medium Range Forecast: Valid 11 Nov 1000Z (colorscale 0-25 mm)

Being validated against Ameriflux ET and ‘synthesis’ ET products
Comparison of Medium Range Dispersed Inundation During Hurricane Matthew from Oct 8 06z, f024 (left) and f036 (right)

Maximum depth recorded: ~21 inches

Maximum depth recorded: ~46 inches
Land Surface Model Outputs

Depth to soil saturation (‘shallow water table’): May 24, 2015
Seamless Simulation of Nation’s Hydrologic System

Animation created by:
F. Salas, NOAA/NWC

Legend
Streamflow (cfs)
- 0 - 119
- 119 - 7,520
- 7,521 - 88,700
- 88,701 - 201,900
- 201,901 - 460,000
- 460,001 - 1,200,000

05/01/2015 00:00

Seamless Simulation of Nation’s Hydrologic System
• Rwrfhydro-generated hydrograph products
• Forecasts from Short, Medium and Long Range configuration
• De facto time-lagged ensembles
Hurricane Matthew: Oct. 6, 2016

- NWM streamflow Sept. 20 – Oct. 16, 2016
Hurricane Matthew: Oct. 6, 2016

- NWM streamflow
**Hurricane Matthew: Oct. 6-17, 2016**

**Gauge goes offline...loss of situational awareness from obs...**

**USGS Peak flow value = ~400 cms**

**Medium range forecasts start picking up this event on Oct. 6 (06z) forecast cycle...**

- **NWM Medium Range Forecast Lumber River River valid Oct. 11, 2016**
Hurricane Matthew: Oct. 6-17, 2016

HAND Inundation Courtesy D. Maidment (U. Texas-Austin), F. Salas (NOAA/NWC)

Legend
- Local Flood Reports
- AHPS - Not Flooding
- AHPS - Flooding

WRF-Hydro/National Water Model Evaluation, Verification and Visualization Tools
Rwrfhydro: R package for Hydrological 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
  - Generally model agnostic
- Developed in parallel with NWM v1.0
# Rwrfhydro: R package for WRF-Hydro Model Evaluation

[GitHub Repository](https://github.com/mccreigh/rwrfhydro)

<table>
<thead>
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<th>Dataset</th>
<th>Data type/format</th>
<th>rwrfhydro functionality</th>
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<td>GHCN</td>
<td>point obs</td>
<td>download, format/process, statistics</td>
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National Water Model Forecast Evaluation: Short Range Forecasts

Short Range Prediction Goal:
Provide effective guidance for floods and flash floods

Assess skill of forecast peak flow amount and timing

Based on 40 days of NWM forecasts from WCOSS versus ~1000 USGS Gauges II unregulated stations, May-June 2016

Preliminary Findings
- Errors in peak flow amount center around 0, and are relatively small (i.e., ≤5 cms)
- Median errors in peak flow timing are generally under ~2 hours

Pre-operational Short Range (0-15 hrs) Verification
Upgraded v1.1 Results:
Retrospective Analysis, GAGES-II Reference Basins, NLDAS-2 Forcings

Percent Bias

12% bias above 20%
Upgraded v1.1 Results:
Retrospective Analysis, GAGES-II Reference Basins, NLDAS-2 Forcings

Pearson Correlation
Thanks!

Any Questions: gochis@ucar.edu

NWM: [http://water.noaa.gov/about/nwm](http://water.noaa.gov/about/nwm)

WRF-Hydro: [https://www.ral.ucar.edu/projects/wrf_hydro](https://www.ral.ucar.edu/projects/wrf_hydro)

Rwrfhydro Evaluation Tools: [https://github.com/mccreigh/rwrfhydro](https://github.com/mccreigh/rwrfhydro)
National Water Model Evaluation: Evapotranspiration

Streamflow Bias by Ecoregion

Modeled ET Errors by Ecoregion
Validation against EC-MOD (Xiao 2011)

Modeled ET Errors at Ameriflux Stations

Map showing streamflow bias and modeled ET errors by ecoregion, validated against EC-MOD (Xiao 2011).
IOC Model Evaluation: Evapotranspiration

HydroInspector(Gadget!): National Water Model

Rwrfhydro/SHINY app created by A. Dugger and A. RafieeiNasab, NCAR
National Water Model Evaluation: Snowpack

- National Water Center Snow Data Assimilation System (SNODAS)
- Snow Telemetry Network (SNOTEL)
- NASA Airborne Snow Observatory (ASO)
NWM Version 1.1 Enhancements (LSM)

Activity: Update to the NoahMP multi-layer snow model to modify snow roughness length formulation.
Outcome: Improved characterization of peak snowpack and snow ablation

Snowpack analysis by L. Karsten, NCAR
Upgraded v1.1 Results:
Retrospective Analysis, GAGES-II Reference Basins, NLDAS-2 Forcings

Nash-Sutcliffe Efficiency