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# Improving Soil Moisture States in WRF-Hydro Using SWOT Observations

Nicholas Elmer (nicholas.j.elmer@nasa.gov)[1,2], Christopher Hain[2,3], James McCreight[4]

[1]NASA Postdoctoral Program, NASA Marshall Space Flight Center, Huntsville, AL, USA
[2]NASA Short-term Prediction Research and Transition (SPoRT) Center, Huntsville, AL, USA
[3]Earth Science Office, NASA Marshall Space Flight Center, Huntsville, AL, USA
[4]National Center for Atmospheric Research, Boulder, CO, USA

## 1. Background

- Surface Water Ocean Topography (SWOT) mission (Rodriguez 2016; Biancamaria et al. 2016)
  - 2021 launch
  - Wide-swath (120 km), bistatic, Ka-band (36 GHz) radar interferometer
  - Global measurements of channel water surface elevation (WSE) and estimated discharge for rivers with widths greater than 50-100 meters
- Weather Research and Forecasting hydrological extension package (WRF-Hydro) (Gochis et al. 2018)
  - High-resolution hydrologic routing and streamflow modeling framework
  - Couples column land surface, terrain routing, and channel routing modules (Figure 1)
  - Basis of the NOAA National Water Model (NWM; OWP 2019)
- HydroDART (McCreight et al. 2018)
  - Data assimilation system built on National Center for Atmospheric Research (NCAR) Data Assimilation Research Testbed (DART; Anderson et al. 2009)
  - For offline implementation of WRF-Hydro

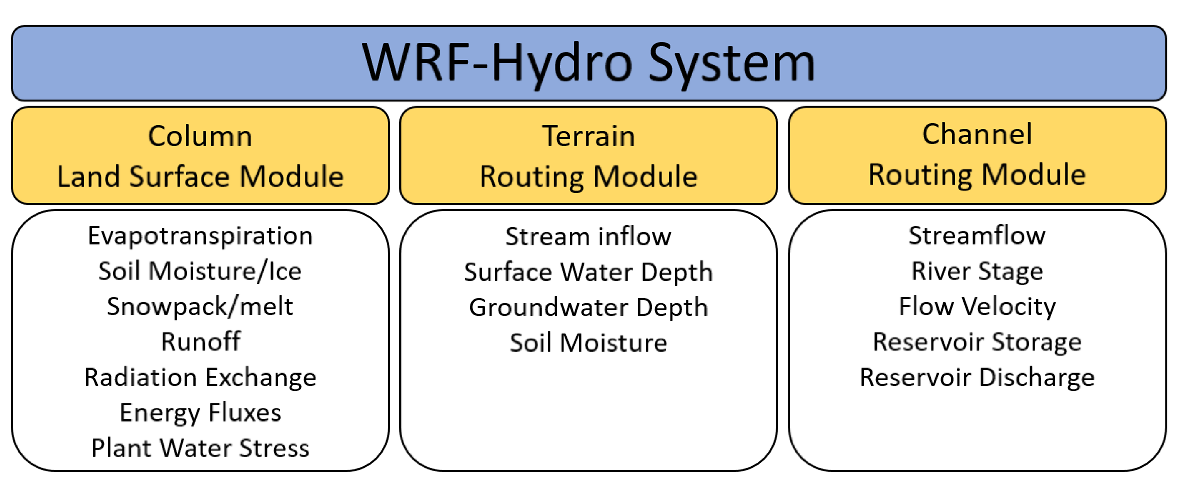


Figure 1. WRF-Hydro modules and output variables (NCAR 2019)

## 2. Motivation

- In situ stream and soil moisture gauges are spatially limited
- SWOT mission will provide global observations at high spatial resolution
- Can SWOT measurements of streamflow improve soil moisture estimates of the land surface?

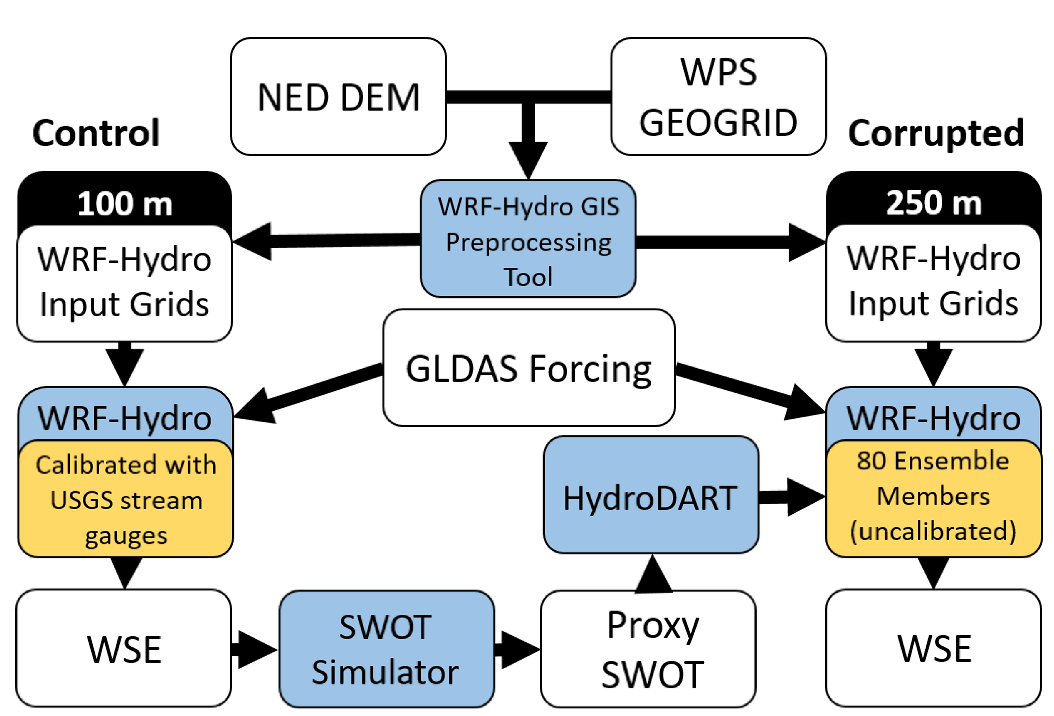


Figure 2. Experiment workflow. Blue boxes indicate models or processing tools, white boxes indicate datasets and model inputs/outputs, and yellow boxes provide brief descriptions.

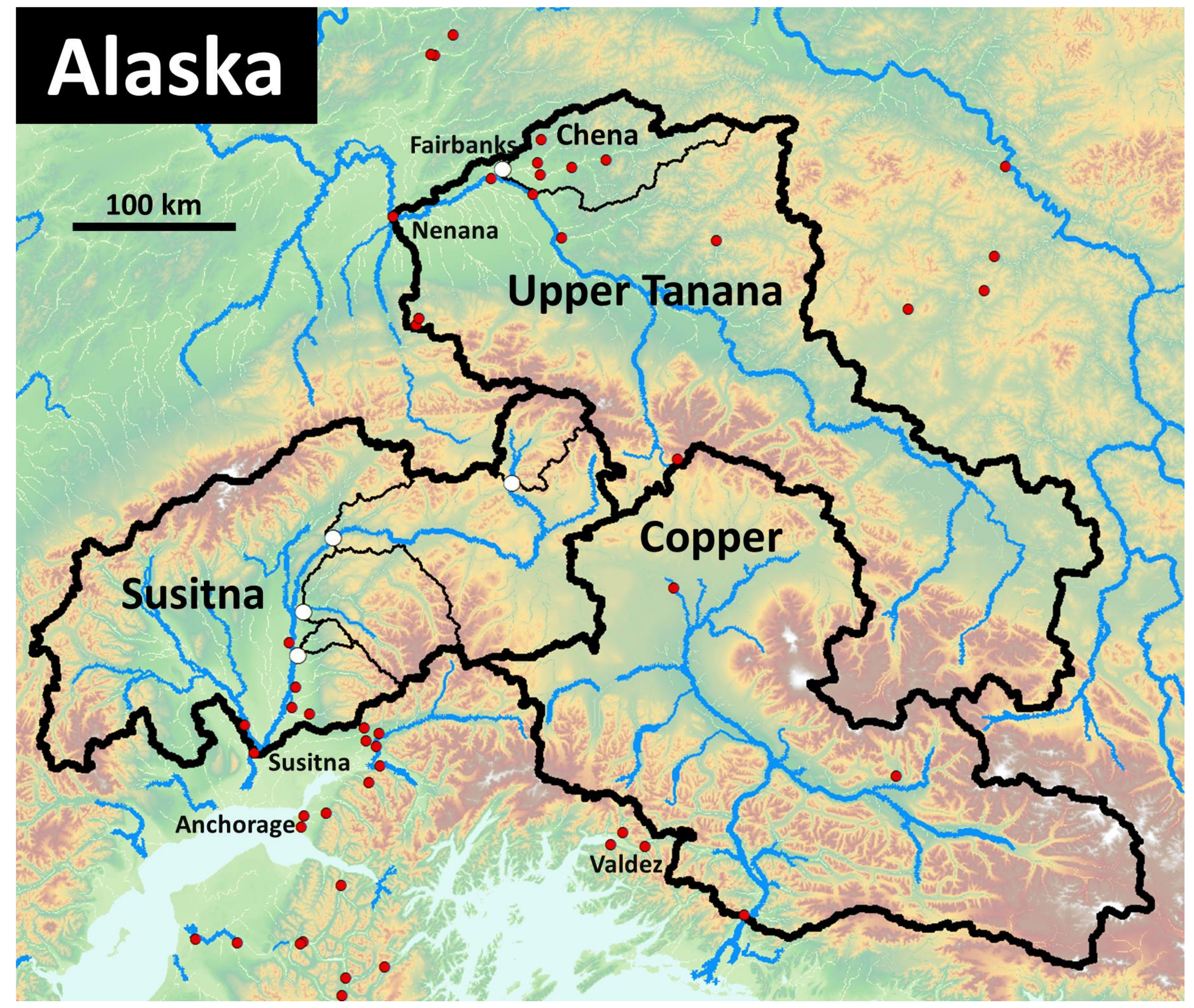


Figure 3. Alaska domain used in this study depicting major basins (thick black lines), minor basins (thin black lines), in situ USGS gauges (red and white dots; white gauge points delineate minor basins), SWOT observable rivers (blue lines), and topography (background).

## 3. Model Configuration

- Alaska domain containing Susitna River, Copper River, and upper Tanana River basins (Figure 3)
- WRF-Hydro v5.0 coupled with 1-km resolution Noah Land Surface Model with Multi-Parameterization options (Noah-MP)(Niu et al. 2011)
- Regridded, 2 arc-second National Elevation Dataset (NED)(USGS 2017) for WRF-Hydro subsurface flow, overland flow, and diffusive wave channel routing (Figure 2)
- Global Land Data Assimilation System Version 2 (GLDAS-2; Rodell et al. 2004) meteorological forcing (0.25° spatial res.) (Fig. 2)
- Control run (100-m WRF-Hydro simulation)
  - 2-year model spin-up (Mar 2009 – Mar 2011) followed by three-year calibration (Mar 2011 – Mar 2014) performed using USGS stream gauges for parameters shown in Table 1
  - Assumed to be free of errors and representative of truth
  - Used to derive proxy SWOT observations (see Section 4 and Figure 4)
- Corrupted runs (uncalibrated 250-m WRF-Hydro simulations)
  - 8-year model spin-up (Mar 2009 – Mar 2017)
  - 80 ensemble members created by randomly varying calibration parameters (Table 1) within valid parameter ranges

| | | | | |
|---|---|---|---|---|
| Clapp-Hornberger B exponent (soil moisture) | Soil moisture maximum | Saturated soil conductivity | Soil infiltration | Soil drainage |
| Retention depth | Saturated soil lateral conductivity | Groundwater maximum depth | Groundwater exponent (bucket model) | Canopy wind (ET) |
| Maximum caboxylation at 25°C | Ball-Berry conductance relationship slope | Snowmelt parameter | | |

Table 1. Parameters used during calibration and ensemble generation.

## 4. Methodology

- SWOT orbit was simulated using expected orbit parameters
- At each SWOT overpass, WSE was calculated for every channel reach within SWOT swath extent and with stream order ≥4 (estimate of rivers with widths > 50 m)
- Randomly generated noise (σ=0.25 m for WSE) was added to mimic SWOT instrument and algorithm errors
- Result is proxy SWOT observation at each channel grid point within the simulated SWOT orbit (Figure 4)
- Proxy SWOT WSE assimilated into WRF-Hydro using HydroDART to update Noah-MP soil moisture states.

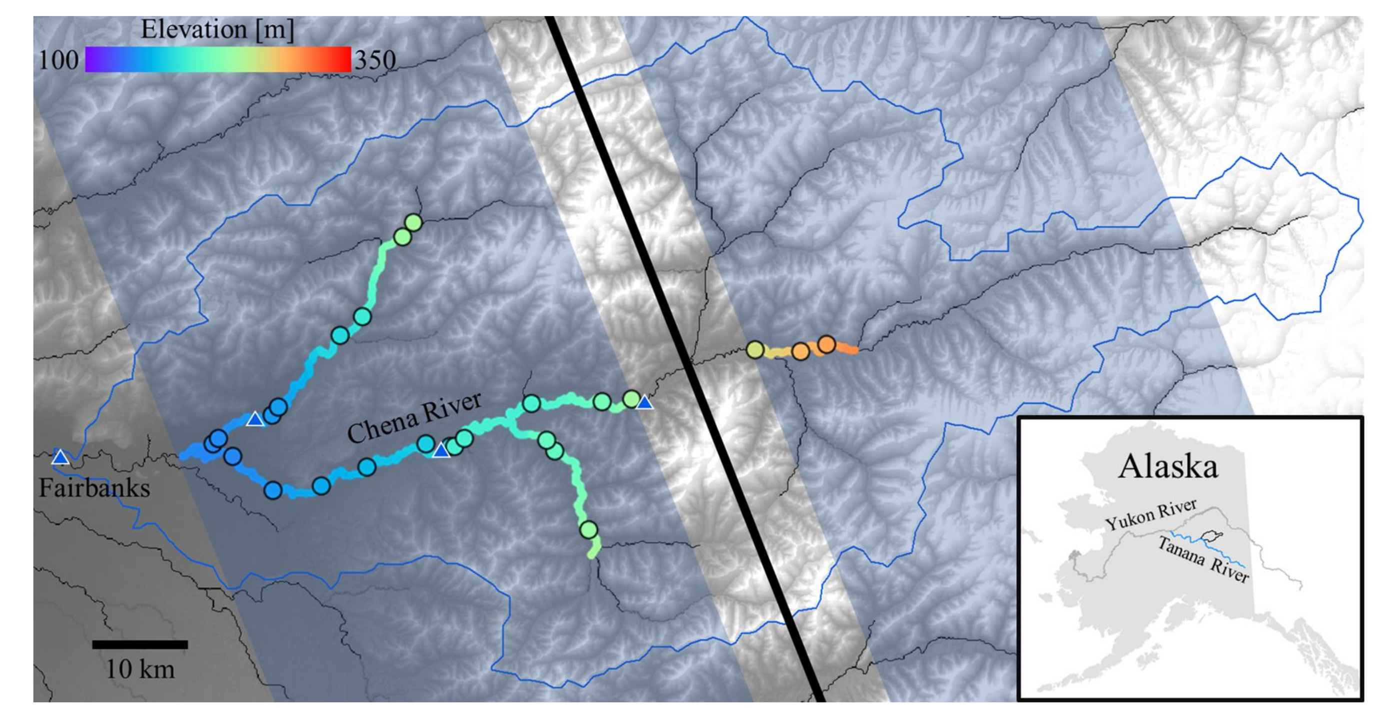


Figure 4. WRF-Hydro-derived synthetic SWOT elevations (colorbar) for the Chena River watershed (outlined in blue) for a simulated SWOT overpass (swath shaded in blue; nadir track shown by the thick black line). Randomly sampled virtual gauges (colored circles outlined in black), current USGS stream gauge sites (blue triangles), and terrain (grayscale; NED DEM) are also shown.

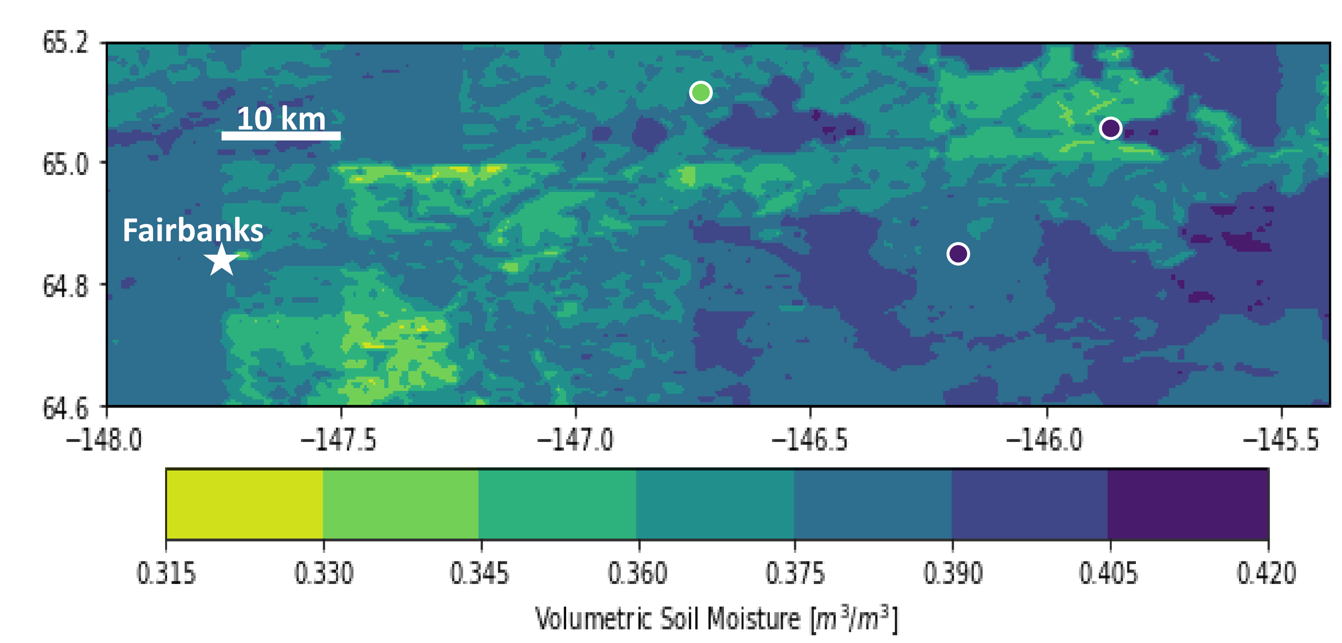


Figure 5. 0000 UTC 14 May 2017 Chena River watershed 0-10 cm volumetric soil moisture simulated by open-loop (no data assimilation) WRF-Hydro and USDA Natural Resources Conservation Service (NRCS) Snow Telemetry (SNOTEL) 5 cm soil moisture measurements (filled circles).

## 5. Preliminary Results (Chena River)

- Open loop WRF-Hydro 0-10 cm volumetric soil moisture is of similar magnitude as SNOTEL observations
- Point-by-point comparison is poor, likely a result of no calibration and no data assimilation being performed

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## 6. Next Steps

- Expand analysis to full domain to include upper Tanana, Susitna, and Copper River basins
- Complete simulations with assimilated proxy SWOT WSE
- Fine-tune radius of influence for updating soil moisture states
- Integrate Soil Moisture Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) soil moisture observations for improved spatial validation.

## 7. Future Work

- Integrate Centre National D'Etudes Spatiales (CNES) SWOT Hydrology Simulator to create proxy SWOT WSE to account for dark water and geolocation errors
- Assimilate both SWOT and SMAP observations

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