Coupling of parallelized surface water and groundwater models for statewide hydrologic modeling

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1. Introduction

New Mexico is one of the driest states and faces water security challenges that are expected to worsen due to the changing climate.

Union of Concerned Scientists (UCS, 2016) expressed their concerns and argued that we need "to prepare for the expected impacts of these climate trends," However, to the best of the author's knowledge, New Mexico still does not have a high, resolution statewide physically-based model that is capable of simulating and predicting the future availability of surface water and groundwater resources.

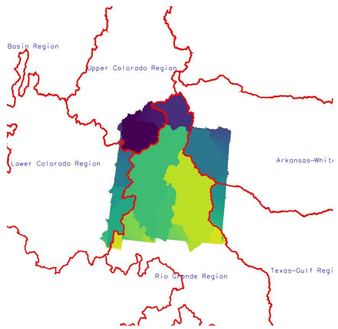
We present a coupled distributed modeling framework of parallelized surface water and groundwater models to address these challenges.

2. Methods and Data

We are using calibrated models for the study including a global VIC model and two modflow 6 models.

I. VIC Model

- Downscaled the calibrated VIC model from Yang et al. (2019) from a lower resolution (1/16°) to a higher resolution (1/32° ≈ 3.375 km).
- Using resampled and interpolated meteorological forcings obtained from PRISM Climate Group and gridMET and MTCLIM.
- Soil and Vegetation parameters from Yang et al. libraries.



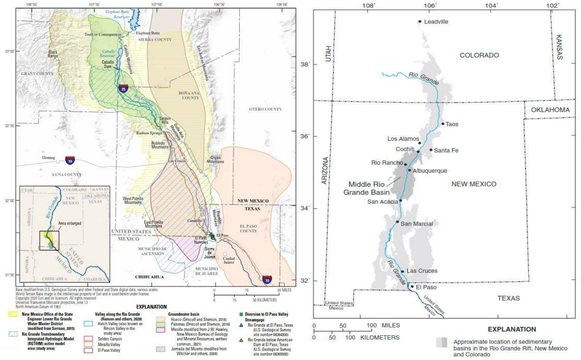
- The model follows the hydrological boundary of the state of New Mexico.
- Input files prepared in GRASS GIS using shell scripts for interpolation and downscaling of soil, vegetation, and meteorological forcings.

II. MODFLOW6 Models

- Using two calibrated models:

1. RGTIHM Lower Grande One Water Hydrologic Model (Ritchie et al., 2022) recreated in MF6 using FloPy:
    1. 14500+ wells, 9500+ reaches, 9 geological layers.
    2. 74 years (1796 stress period) simulation with NWT solver

2. Middle Rio Grande MODFLOW2000 model by McAda and Barroll (2000) converted into MF6 using mfto6 converter. The simulation period is 100 years with 51 stress periods and transient simulation with PCG solver.



3. Parallel Simulations

- ***VIC model:*** Simulated in parallel using the VIC5 package and DoParallel library in R-VIC to simulate water and energy balance from 1991 – 2020.

- ***MODFLOW6:*** For mf6, the model was split using METIS for optimized load distribution.
- The parallel RGTIHM model was run for 74 years using MPI.

The table below presents the average runtime of 5 runs for both serial and parallel.

Model	Runtime (Serial)	Runtime (Parallel)	Efficiency
mf6	110 mins	45 mins	40.7% (np=6)
VIC	69 mins	24 mins	95.8% (np=4)

4. Work in progress

This modeling framework is developed to:

- Assess the statewide water availability in climate change scenarios
- Assess drought susceptibility through the drought vulnerability Index (DVI).

The next steps in the project are:.

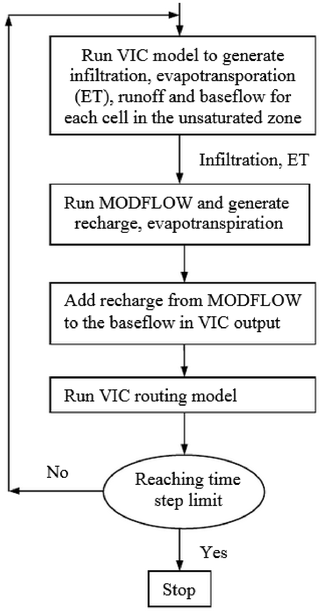
I. Coupling of VIC and MODFLOW

We plan to couple both models;

- For a timestep,

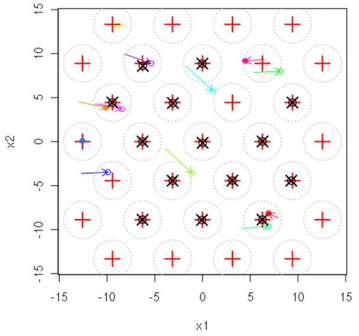
VIC I/O ⇌ MODFLOW I/O

- Coupling methodology adopted from Jin and Sridhar (2010) is shown in the flowchart.



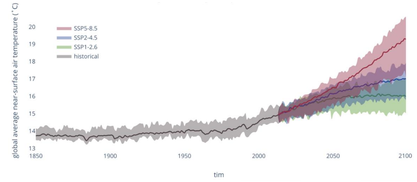
II. Distributed Parallel Calibration

- Run the parallel models multiple times with distributed computing.
- Different sets of objective functions to calibrate the model.
- Model calibration and optimization using Isolated-speciation-based particle swarm optimization (ISPSO).



III. Climate Change Modeling

We plan to simulate the changes in the water budget components especially the snowmelt, surface runoff, and soil moisture in the vadose zone in climate change scenarios.
We will assess these changes in several climate change scenarios from SSP1-2.6 to SSP5-8.5, using CMIP6 data and projections.

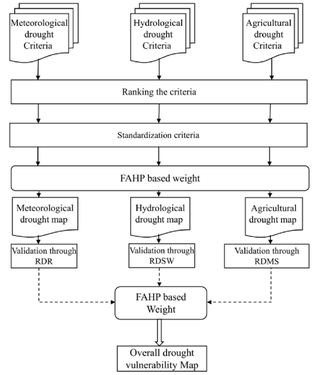


IV. Drought Vulnerability Index (DVI)

- Simulate changes in water budget components: snowmelt, surface runoff, and soil moisture in the vadose zone.

- Assess changes under various climate change scenarios from SSP1-2.6 to SSP5-8.5.

- Utilize CMIP6 data and projections as shown in the flowchart.



5. Implications

The new distributed modeling framework will be general and scale agnostic such that it can be utilized for similar hydrologic modeling efforts for other states or even CONUS.

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GRASS GIS — GRASS GIS has been adopted and utilized throughout the project for geospatial data analysis, input preparation and output assessment.