Data Adoption Justification Memo (for California's Fifth Climate Change Assessment): Hydrology Projections

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Methods and Prior Relevant Work:

To represent land surface changes such as snowpack and runoff, dynamically and statistically downscaled Global Climate Model (GCM) atmospheric output were used as a forcing for calibrated hydrology models. Two widely used and well recognized hydrology models - Noah land surface model with multiparameterization options (Noah-MP), run via the Weather Research and Forecasting (WRF)-Hydro platform, and the Variable Infiltration Capacity (VIC) macroscale hydrologic model were used to simulate projected land surface conditions.

Noah-MP simulations were performed using the same 3 km x 3 km grid as WRF, while VIC simulations were performed at 1/16th degree resolution (roughly 3 km). The hydrology models were initially calibrated to improve the representation of daily natural streamflow during the historical period using the bias corrected (BC) ERA5 -WRF dataset. Since the hydrology models require a finer time-resolution to run, the BC ERA5-WRF dataset and all of the BC downscaled GCMs were converted from daily time-resolution to 3-hour time-steps using MetSim (the python version of MTCLIM) – a model commonly used in the hydrology community for such purposes (Bennett et al. 2020).

Calibration of the hydrology models was performed for 120 basins throughout California with observed daily natural streamflow data and then the calibrated parameters were extended to ungauged basins throughout California. The general workflow of the calibration follows the methods outlined for the western United States in Bass et al. (2023) and Su et al. (in-press), with details on the methods and results for the California domain outlined in (1). The calibration procedure allows for simulations of runoff, which can be relevant to water resources, hydroelectric power, and flood analysis, that are representative of realistic conditions for the historical and GCM simulations.

After calibration – snowpack, runoff, and additional land surface variables were produced at a daily time-resolution with data paths, with variable naming and unit convention outlined in this document (2). Specifically, the Noah-MP output has been uploaded here (3), and the VIC output here (4), which is publicly available. The downscaled WRF and Localized Constructed Analog version 2 (LOCA2) data, with bias correction to the BC ERA5-WRF dataset, were used as forcings for hydrologic projections. Given computational and model run-time resources, a subset of the full suite of WRF and LOCA2 GCMs were simulated through the hydrology models. The GCMs simulated by the hydrology are outlined in this spreadsheet (5), and include the 4 post-downscaled bias-corrected SSP 3-7.0 WRF GCMs and 13 SSP3-7.0, 4 SSP2-4.5, and 4 SSP5-8.5 LOCA2 GCMs. The LOCA2 GCMs for SSP2-4.5 and SSP5-8.5 were selected to include a wide spread in precipitation and temperature changes, representative of the larger ensemble of GCMs and their range of projections. Hydrology projections from both VIC and Noah-MP include output from 10/1/1954 to 09/30/2100.

QA/QC & Uncertainty:

The hydrology projection data was QA/QC through the calibration process and validation of the hydrology models' ability to represent natural streamflow across the state's basins. In the validation process we assessed the performance of the 120 gauged basins by comparing their simulated streamflow against observational streamflow data [Figs 2-4, in (6)]. This assessment illustrated that both VIC and Noah-MP reasonably captured the historical streamflow across the majority of California's basins, however a few individual basins demonstrated poor performance which could be due to a variety of factors ranging from the forcing data to the hydrologic modeling parameters to the observational data quality. VIC and Noah-MP demonstrate similar performance in representing climatological, monthly, and annual streamflow conditions. While VIC demonstrates slightly better performance in representing daily streamflow conditions, flood events are generally better represented by Noah-MP. We additionally ensured that the historical climatology and mean-state of the downscaled GCMs runoff and snowpack matched the historical simulation of BC ERA5-WRF, which is expected given the bias-correction of the downscaled GCMs to BC ERA5-WRF.

Various sources of uncertainty exist in the hydrology projections. This includes GCM model uncertainty, emission trajectory uncertainty (SSP2-4.5, SSP3-7.0, SSP5-8.5), downscaling method uncertainty (WRF vs LOCA2), and hydrology modeling uncertainty (Noah-MP vs VIC). We are currently assessing what factor results in the greatest uncertainty or variation in runoff projections from these different components of the hydrologic modeling framework; however, analysis of the downscaling methods is limited to only 3 GCMs that were downscaled by both WRF and LOCA2.

Guidance or Caveats on Best Practices for Use of Data Products:

To ascertain the climate change impact on hydrology, we recommend making use of the LOCA2 SSP3-7.0 data which includes the largest ensemble of GCMs simulated by both Noah-MP and VIC (13 GCMs) or alternatively focusing on how hydrology changes with warming levels which can make use of projections from the three unique SSPs. Assessing both Noah-MP and VIC data allows investigation into the hydrologic model uncertainty and an opportunity to identify if one model better captures the hydrology of the region. Prior to performing evaluations of projected changes, we generally suggest stakeholders, focusing on a specific basin or region, evaluate the accuracy of the hydrology models for their variable of interest (e.g. flow or snowpack). If capacity is limited in terms of data process or ability to evaluate the hydrologic models, choosing one set of data, either VIC or Noah-MP is acceptable use of the data.

Finally, the first member of each GCM was simulated. This purposely represents a random GCM member. Those evaluating hydrology projections, should be aware that each GCM member is influenced by internal variability that can influence an individual GCMs estimate of extreme drought or flood conditions. Nonetheless, the 13 GCMs for SSP3-7.0 provide a substantial amount of data to assess the changing statistics of snowpack and runoff across the state (390 years to assess conditions in a future 30-year time-horizon such as mid- or end-of-century conditions).

Paths to the data output and an outline of the data output from each hydrology model is provided in this document (7). Please note that the variables output, and their naming convention differ slightly for Noah-MP and VIC. Most notably, total runoff is output by Noah-MP as RNFRATE, while total runoff from VIC must be summed from RUNOFF and BASEFLOW. The gridded total runoff can be aggregated to obtain the total streamflow (e.g., ft3/s or m3/s) at the outlet of a basin of interest (e.g., Bass et al. 2023). Specifically, streamflow can be obtained by masking the gridded runoff across the outline (e.g., shapefile) of a basin, taking the mean runoff across the masked basin, and then multiplying the mean runoff by the drainage area of the basin to obtain a volume over time.

Forthcoming Publications

We are currently developing a manuscript that outlines the hydrology methods and results from our hydrologic modeling effort. The forthcoming publication focuses on mean-state and extreme changes in snowpack and runoff across key basins for the state of California. Several of the basins the analysis focuses on were expressed to be of interest during stakeholder engagement throughout the CEC, EPIC-funded project.

References

Bass, B., Rahimi, S., Goldenson, N., Hall, A., Norris, J., Lebow, Z.J. (2023). Achieving Realistic Runoff in the western US with a Land Surface Model Forced by Dynamically Downscaled Meteorology. Journal of Hydrometeorology. https://doi.org/10.1175/JHM-D-22-0047.1.

Bennett et al., (2020). MetSim: A Python package for estimation and disaggregation of meteorological data. Journal of Open Source Software, 5(47), 2042, https://doi.org/10.21105/joss.02042

Su, L., Lettenmaier, D.P., Pan, M., Bass, B. Improving Runoff Simulation in the Western United States with Noah-MP and VIC. EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-2164, 2023.

Written-out quick links in same order as in text:

(1) Documentation for Hydrologic Models used in CEC Group 1: https://wrf-cmip6-noversioning.s3.amazonaws.com/ben_temp/d03_3km/CEC/0_Hyd_Model_Documentation/CEC_Noah_MP_VIC_Hydrology_Model_Description.pdf

(2) Document describing the data output from the Noah-MP and VIC hydrology simulations: https://wrf-cmip6-noversioning.s3.amazonaws.com/ben_temp/d03_3km/CEC/0_Hyd_Model_Documentation/CEC_Noah_MP_VIC_Hydrology_Output_Description.pdf

(3) NOAH data output: https://wrf-cmip6-noversioning.s3.amazonaws.com/index.html#ben_temp/d03_3km/CEC/2_NOAH_MP_SIMULATIONS/

(4) VIC data output: https://wrf-cmip6-noversioning.s3.amazonaws.com/index.html#Iusu/CEC/VIC_SIMULATIONS/GCMs/

(5) Spreadsheet outlining selected hydrology simulations: https://wrf-cmip6-noversioning.s3.amazonaws.com/ben_temp/d03_3km/CEC/0_Hyd_Model_Documentation/Selected_Hydrology_Simulations.xlsx

(6) Figures 2-4 in the linked document show assessment of the performance of the 120 gauged basins by comparing their simulated streamflow against observational streamflow data: https://wrf-cmip6-noversioning.s3.amazonaws.com/ben_temp/d03_3km/CEC/0_Hyd_Model_Documentation/CEC_Noah_MP_VIC_Hydrology_Model_Description.pdf

(7) Document providing Paths to the data output and an outline of the data output from each hydrology model [same as (3)]: https://wrf-cmip6-noversioning.s3.amazonaws.com/ben_temp/d03_3km/CEC/0_Hyd_Model_Documentation/CEC_Noah_MP_VIC_Hydrology_Output_Description.pdf