The Application of SWAT for Developing Climate Model Evaluation Metrics within a Hierarchical Framework

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Overview of Presentation

- Description of FACETS project
- Statistical vs. dynamical downscaled methods
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- Role of SWAT within FACETS including use of HAWQS modeling system
- Discussion of example initial SWAT output

Underlying Reason for Study

- **Concern of U.S. Dept. of Energy:** Given the large variety of dynamical and statistical downscaling approaches and products, how do we assess their relative merits and suitability for a given purpose?

FACETS Project

- **FACETS**: Framework for Assessing Climate's Energy-Water-Land nexus by Targeted Simulations
- **Overall goal**: produce and disseminate a suite of metrics and analysis tools that can be used to evaluate different types of climate models and downscaling methods
- **Consortium**: Iowa State Univ., NCAR, Cornell Univ., UCLA, PNNL, Texas A&M Univ.

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FACETS Project

- **Evaluation of climate downscaling techniques**:

1) metrics that include statistical measures of climate model performance (skill)
2) phenomena-based diagnosis of inter-related model biases and multi-scale processes contributing to the phenomena
3) metrics relevant to the energy-water-land (E-W-L) nexus

- **Role of SWAT within FACETS**:

1) translate physical model output into metrics that are directly relevant to the E-W-L nexus
2) produce indicators that provide further insight into factors influencing the performance of specific climate models

Global climate models (GCMs)

- Main tool for projecting future climates.
- Solve fluid dynamical equations for atmospheric and oceanic circulation and thermodynamics. Includes representations of processes that cannot be solved directly (parameterizations).
  - Radiative transfer, land surface processes, sea ice, biogeochemical cycles, etc.
  - GCMs do not directly use observed data as input.
  - Numerical solution methods require dividing the world into a grid. Computational constraints dictate the size of the grid cells, typically 1º to 2º latitude / longitude.

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All of this is less than one grid cell in a global climate model

The need for downscaling

- Climate impacts often take place on scales much smaller than the grid cells of global climate models.
- Coarse resolution models cannot properly include many geographic features and atmospheric processes that have hydrologic consequences (coastal mountains, thunderstorm systems, etc).
  - This is one reason GCMs give too much light precipitation and too little heavy precipitation.
- **Downscaling** is the production of finer-resolution information from coarse-resolution GCM results.

There are two broad approaches to downscaling

- **Dynamical downscaling:** Run a finer-resolution dynamical model (similar to the global model) but over only a limited area of interest.
  - The fine resolution model is supplied with data from the global model at its lateral boundaries.
  - There are several widely-used dynamical downscaling codes.
- **Statistical downscaling:** Develop statistical relationships between model output variables and observed quantities.
  - Many different statistical downscaling approaches exist, using different assumptions and statistical methods.

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Comparison of statistical and dynamical downscaling

- **Statistical downscaling:**
  - \+ Fast, allows many realizations
  - \+ Parsimonious variable set
  - \+ Should match observed climate, at least for training period
  - – Limited by availability of observations
  - – Results may not be physically consistent
  - – Statistical relationships may not apply in future climate
- **Dynamical downscaling:**
  - \+ Basis in fundamental conservation laws
  - \+ Physically consistent
  - \+ Can produce any atmospheric, oceanic or land state variable
  - – Not constrained to reproduce observed climate
  - – Very computation intensive (weeks-months per simulation) with very large output volume (10s-100s of GB)

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The role of SWAT in FACETS

- Evaluation of model results (including downscaled results) usually focuses on a single variable such as precipitation or temperature.
- SWAT can be used to **integrate** model skill for multiple variables at multiple time and space scales.
  - Run SWAT using different sources of downscaled climate data and compare results for streamflow, etc. SWAT also produces results applicable to DOE's interest in the energy-water-land nexus.
- SWAT is not computationally burdensome, but human effort is needed to set up and run SWAT. **HAWQS gives a path to reduce this effort.**

Hydrologic and Water Quality System (HAWQS)

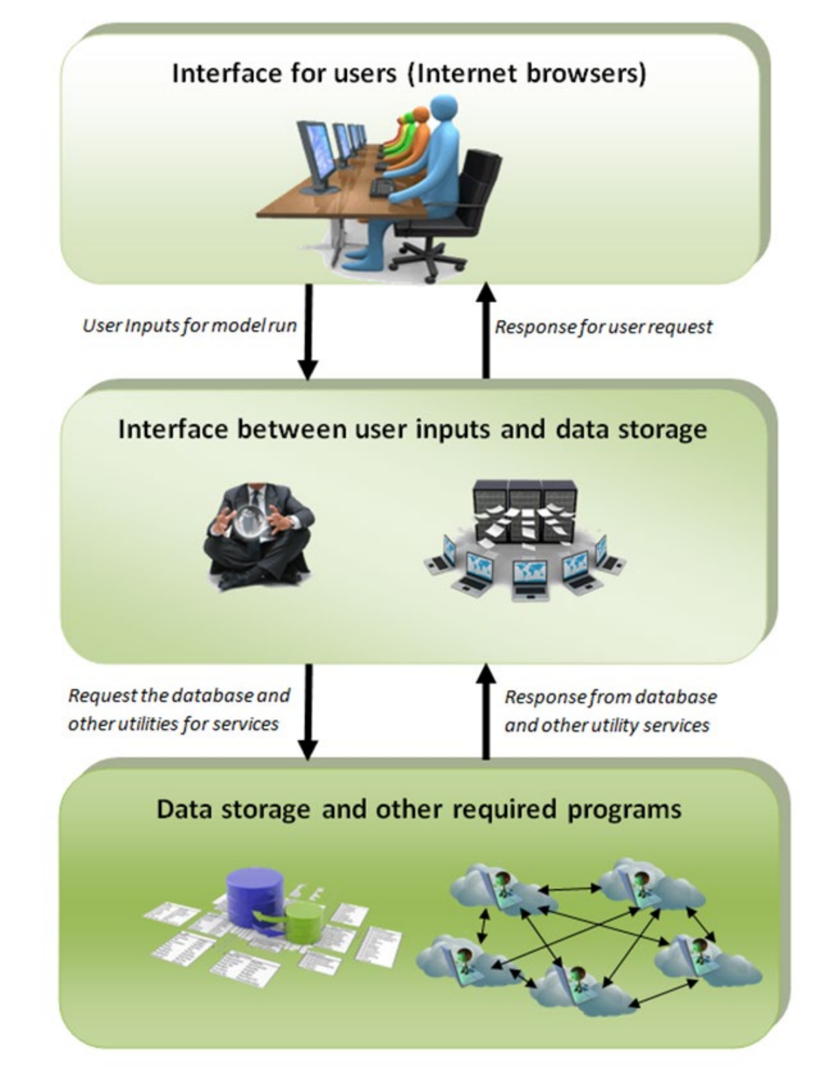
- A national watershed and water quality assessment system for the U.S.
  - Versions also exist for Poland & Brazil (SUPer)
    - SUPer website: https://super.swat.tamu.edu/
- Cooperative project of the:
  - U.S. Environmental Protection Agency
  - USDA-ARS Grassland Soil and Water Research Lab
  - AgriLIFE Research, Texas A&M University
- HAWQS 1.0 released Sept. 2017, currently developing 2.0
- Website: https://epahawqs.tamu.edu/

HAWQS vs. Standard Development of SWAT Simulations

- Automatic data processing
- Internet based interface
- More efficient
  - Speeds up model setup
- Minimal computer requirements
- Multiple user access

HAWQS On-line Structure

- Front-end web and desktop interfaces for users
- Middle-tier servers for handling user requests and responses
- Back-end database holds all SWAT related datasets and SWAT model



HAWQS Watershed Delineations

- Designed for continental USA (contiguous 48 states)
  - HAWQS users select outlet of the watershed based on HUC (Hydrologic Unit Code)
  - Currently HAWQS projects are defined based on hydrological boundaries
- HAWQS watershed scale
  - 8 digit HUC (~1,800 sq km)
  - 10 digit HUC (~600 sq km)
  - 12 digit HUC (~100 sq km)

Testing of SWAT within HAWQS

- Typical calibration approach to match observed data
- ~100 sites: flow, sediment, total N and P
- Additional testing has been initiated

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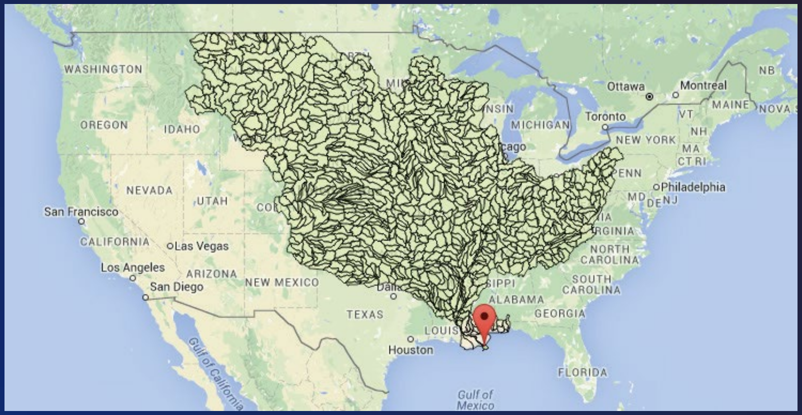
Hydrologic and Water Quality System (HAWQS)

- On-line interface to SWAT that reduces need for pre-processing. Developed by R. Srinivasan at Texas A&M.
- Can execute simulations for a range of watershed sizes throughout CONUS from local-regional scale to huge systems; e.g. Mississippi River (8-, 10- or 12-digit scales).



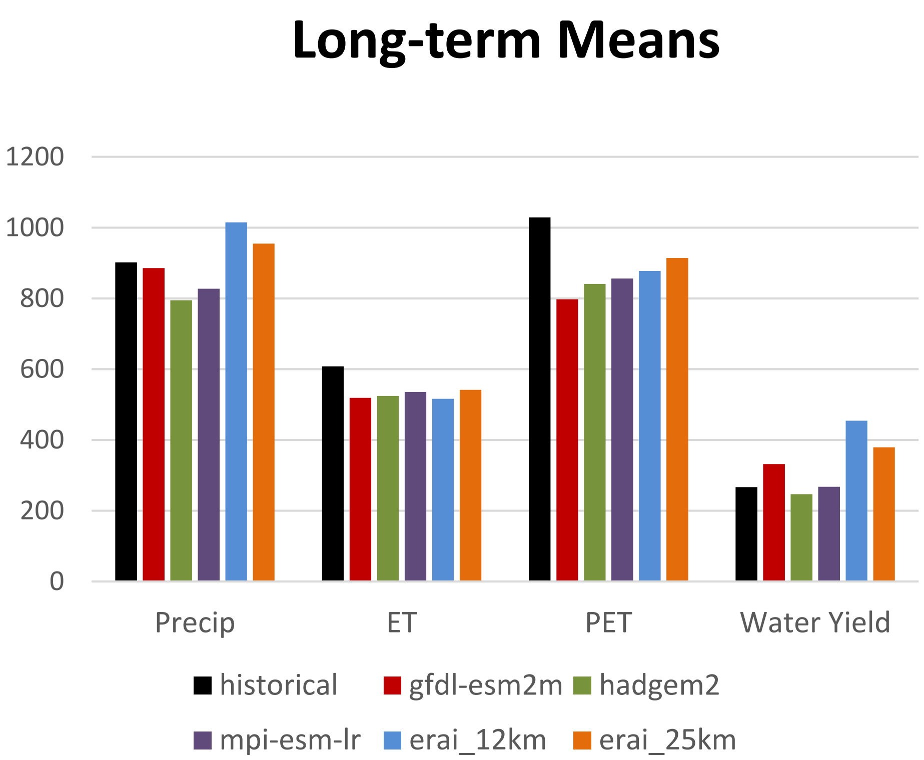
LOCA Statistical Downscaling (Localized Constructed Analogs)

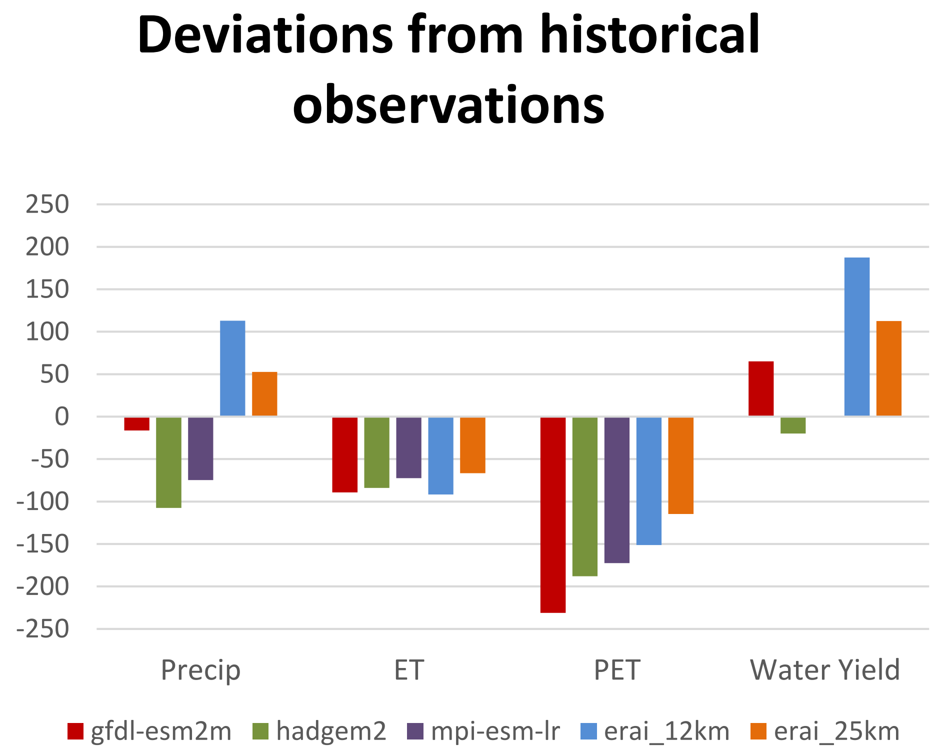
- LOCA: Technique for downscaling climate model projections of the future climate
- Provides better estimates of extreme days, constructs more realistic depiction of the spatial coherence of the downscaled field, and reduces the problem of producing too many light-precipitation days
- **Website**: http://loca.ucsd.edu/

Initial SWAT simulations in support of FACETS

- LOCA downscaled fields from FACETS GCMs (GFDL-ESM2M, HadGEM2-ES and MPI-ESM-LR)
- Dynamically downscaled: ERAI_12km and ERAI_25km (12 and 25 km^2 grids within RegCM4 model)
- Upper Mississippi River Basin and Ohio-Tennessee River Basin
  - Have simulated both baseline periods (1991-2010) and future climate periods using both downscaling methods
  - Only example UMRB baseline (contemporary climate) results discussed here

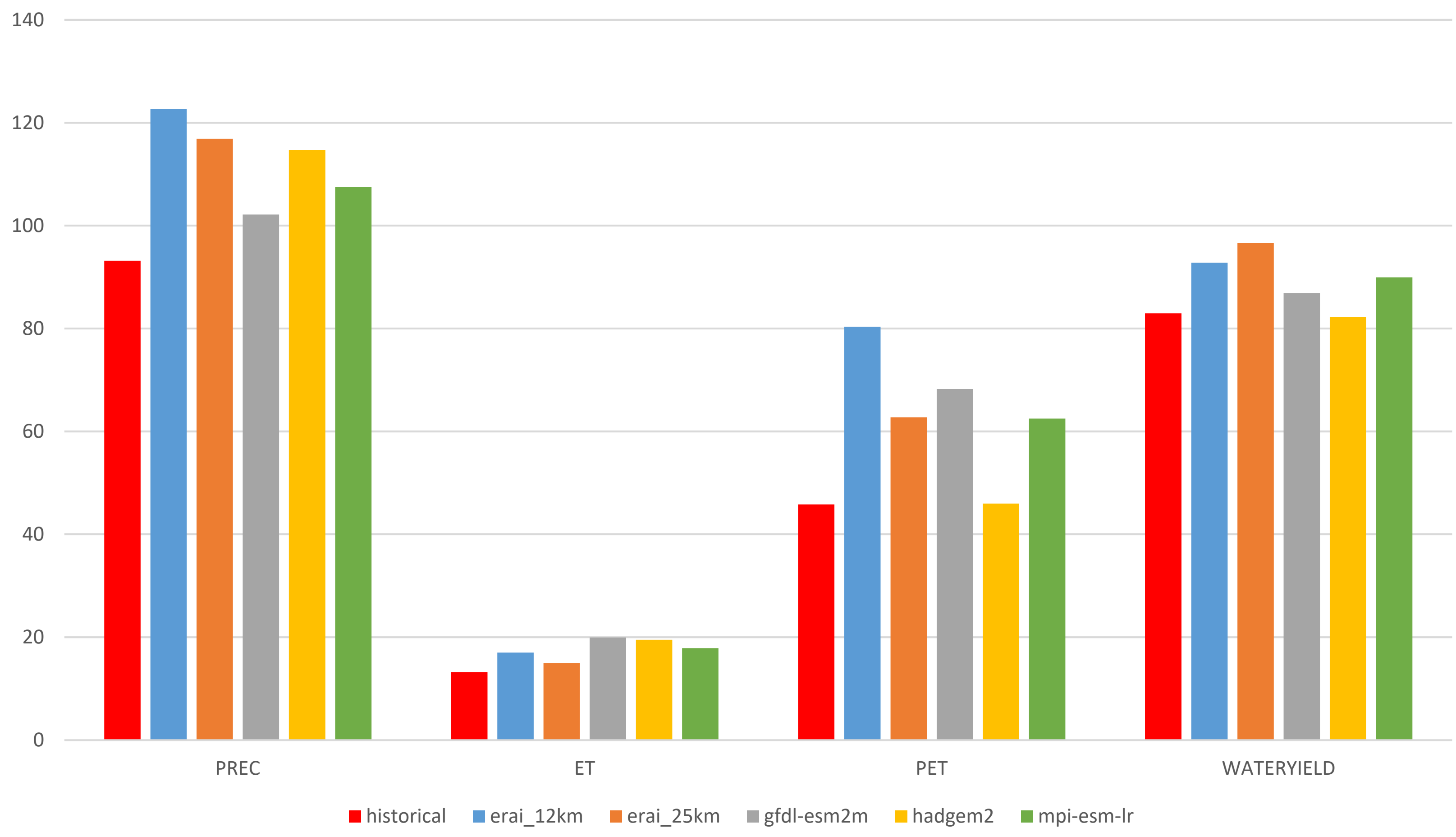
Example SWAT Hydrologic Indicators: UMRB Long-term Means and Deviations from Means





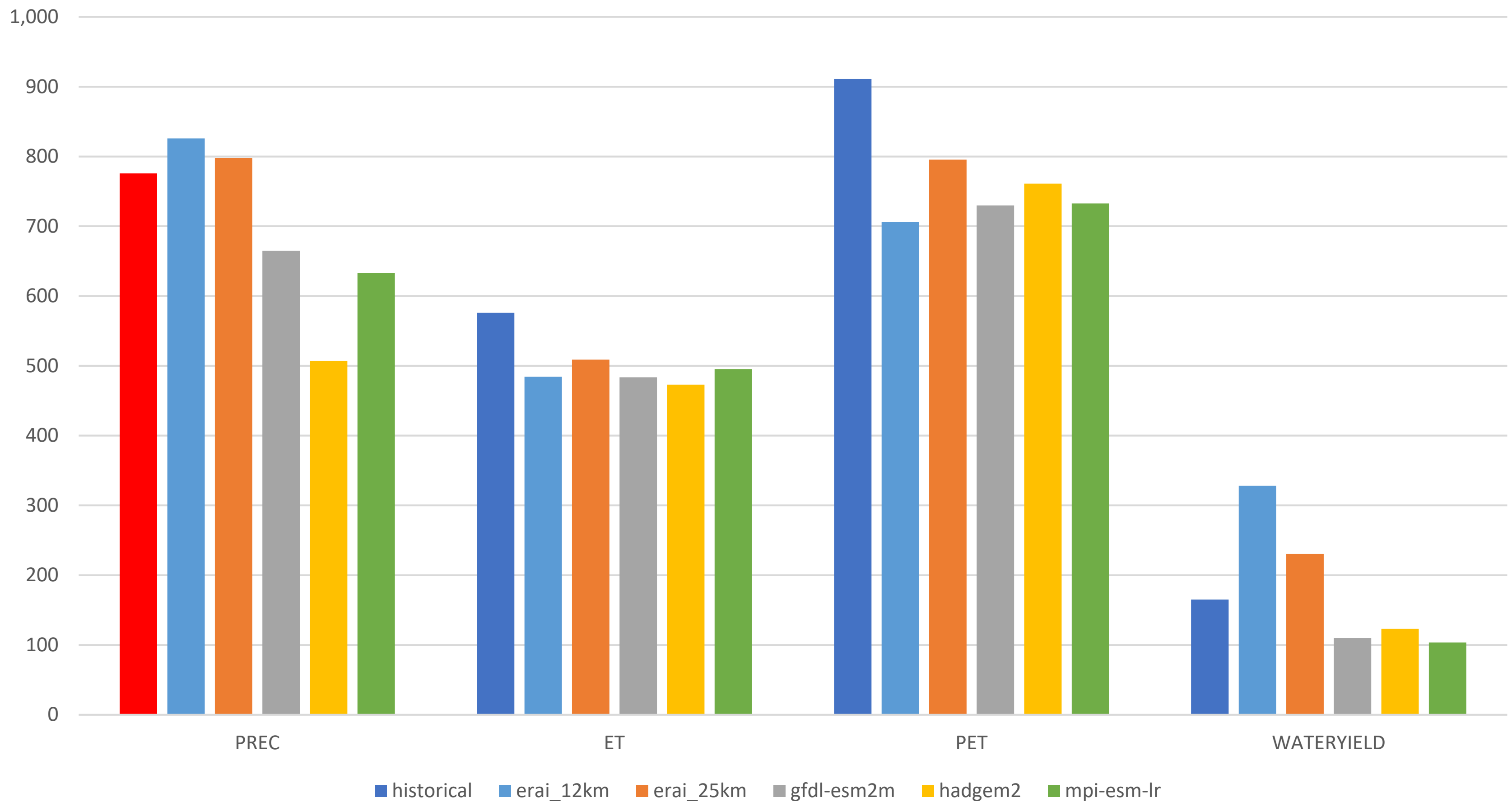
Period is 1991-2010; All values are in units of mm/year

Example SWAT Hydrologic Indicators: UMRB Standard Deviations



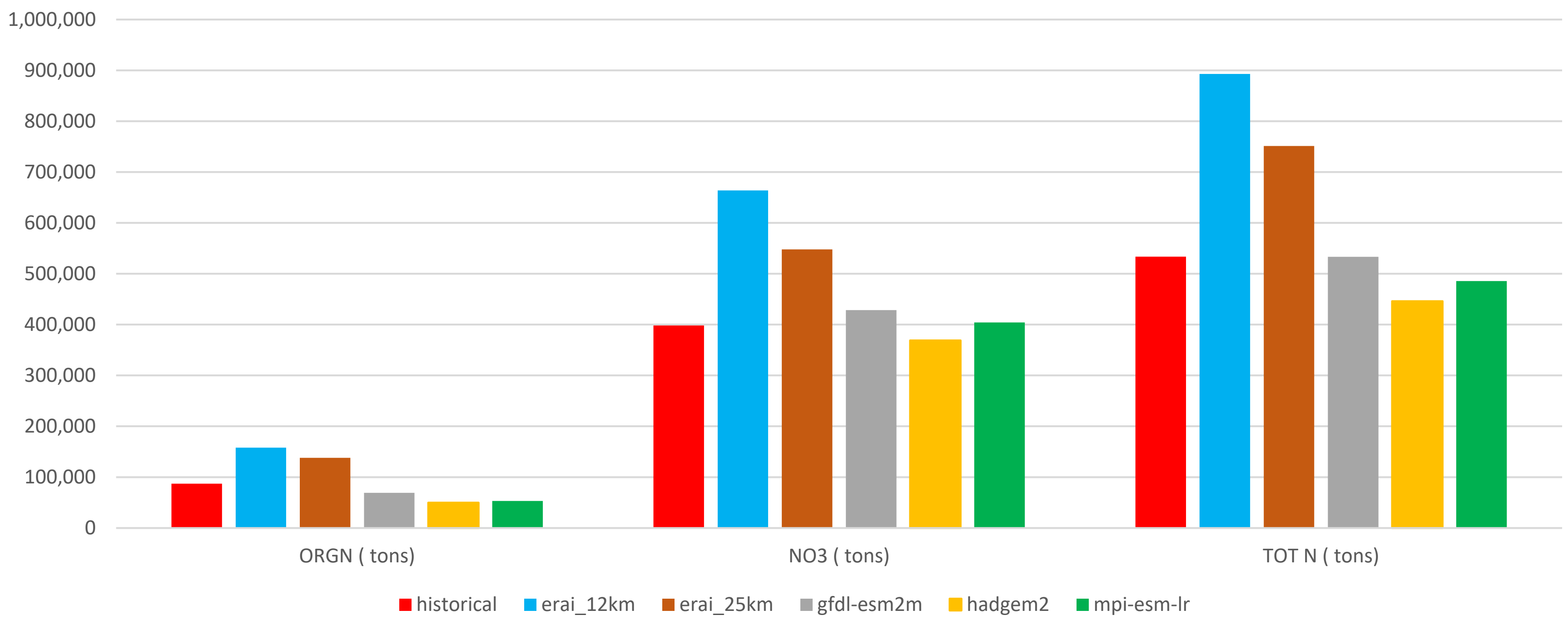
Period is 1991-2010; All values are in units of mm/year

Example SWAT Hydrologic Indicators: UMRB Minimum Values



Period is 1991-2010; All values are in units of mm/year

Example SWAT UMRB Nitrogen Indicators



More Work Needed Regarding Development of SWAT Metrics

- Exact suite of SWAT metrics that will be developed as part of FACETS still need to be determined

- Interest in capturing phenomena such as low level jets (Midwest region) or atmospheric rivers (west coast) via SWAT metrics

- Mississippi River Basin model developed in HAWQS will be focus of next phase of SWAT work