A comparison of precipitation downscaling procedures to guide studies of climate change impacts on flooding and water resources (Science & Technology Project 9039)

Eylon Shamir, eshamir@hrcwater.org, Hydrologic Research Center, San Diego &
Eve Halper, ehalper@usbr.gov, Bureau of Reclamation, Phoenix Area Office
References:


Presentation Outline

1. Study Motivation and Objectives
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3. Study Area and Hydrology
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5. Climate Models: Precipitation Projections
6. Hydrologic Modeling Frameworks including Weather Generators
7. Projected Hydrologic Impacts
8. Concluding Remarks and Acknowledgements
Motivation:

Basin-scale hydrologic assessments often face the dilemma of having to choose between Statistical Downscaling (SD) and Dynamic Downscaling (DD) approaches.

- SD simulations are easier to obtain and there are several readily available datasets that include simulations for many Global Climate Models (GCM) simulations.
- DD simulations require a high level of expertise to produce and are available for only a few GCMs.
What is “downscaling” anyway?

• Global Climate Model (GCM) simulation is coarse, about 1 degree latitude x 1 longitude

• In order to use GCM simulations for hydrologic modeling, it must be *downscaled*
Statistical vs. Dynamical Downscaling

Downscaling: create higher spatial resolution information at regional and local scales

**Statistical downscaling (SD):**
Develops statistical (empirical) relationships between atmospheric forcing data and surface variable of interest. Then applies those relationships to future projections from global models.

**Assumptions**
- Statistical relationship between predictor and predictand does not change over time [stationarity].
- Predictor carries the climate change signal.
- Strong relationship between the predictor and predictand.
- GCMs accurately simulate the predictor.

**Dynamical downscaling (DD):**
Uses a regional climate model (RCM) to explicitly represent physical processes in the atmosphere.

**Assumptions**
- The Regional Climate Model (RCM) adequately simulates the variable of interest
  - Convective storms
  - Orographic enhancement of precipitation
  - Extreme events
  - Snowfall/rainfall
  - Mesoscale (regional) processes
Study Objectives and Background:

- Investigate the differences between statistical and dynamical downscaling of climate model and their implications in arid basins.

Two Case Studies:
- Upper Santa Cruz River (Water Resources, Riparian Vegetation)
- Alamo Lake and Bill Williams River Watershed (Reservoir Management, Flood Control, Recreation, Fish and Wildlife)
Why this location?

*Alamo Dam and Bill Williams River Watershed*

- Alamo Dam is immediately upstream of Lake Havasu, where water is diverted into the Central Arizona Project (CAP) aqueduct.
- Alamo Lake is operated by the Army Corps of Engineers.
- Reclamation’s Boulder Canyon Operations Office is interested in the impacts of changes in precipitation on the operation of Alamo Dam and the outflow downstream to the Colorado River and the Central Arizona Project (CAP) intake.
Bill Williams River Basin - Alamo Lake

- BWR: A tributary (5,393 mile$^2$) of the Colorado River that drains into Lake Havasu in west-central Arizona.
- Alamo Dam, 36 miles upstream Lake Havasu, was built in 1968 as a multi-purpose facility with a primary objective of controlling flooding downstream of the dam.
Precipitation → Streamflow
Precipitation Projections

- Precipitation historic runs 1950-2005
- All projections use RCP (Representative Concentration Pathway) 8.5, 2006-2100

**Dynamically Downscaled: (WRF Regional Climate Model)**
- NORTH AMERICAN COORDINATED REGIONAL CLIMATE DOWNSCALING EXPERIMENT
- (NA-CORDEX) [HTTPS://NA-CORDEX.ORG/](https://NA-CORDEX.ORG/)
- HadGEM2-ES WRF 3-hour 25km²
- MPI-ESM-LR WRF 6-hour 25km²
- GFDL-ESM2M WRF 3-hour 25 km²
- WRF Reanalysis 6-hour 25km² (1979-2015)

**Statistically Downscaled: (LOcalized Constructed Analogs [LOCA]),**
- (Pierce et al 2016)
- HadGEM2-ES LOCA Daily ~6km²
- MPI-ESM-LR LOCA Daily ~6km²
- GFDL-ESM2M LOCA Daily ~6km²
- Livneh 1915-2005 Daily ~6 km²
- (Livneh et al., 2013)

**Raw GCM:**
- HadGEM2-ES (1.85° x 1.25°)
- MPI-ESM-LR (1.85° x1.85°)
- GFDL-ESM2M (2.5° x 2°)
Performance of the Downscaled Models, 1950-2005

Bill Williams Watershed

Cumulative Distribution

Mean (mm/day)

0 0.5 1 1.5 2

0 0.5 1

SD-HAD
SD-MPI
SD-GFDL
DD-HAD
DD-MPI
DD-GFDL
Reanalysis
Observed MAP

Standard Deviation (mm/day)

0 2 4 6 8 10 12

0 0.5 1

Number of daily events greater than zero

50 100 150 200 250

12
Climatological Performance, 1950-2005

Bill Williams River Basin Monthly Mean [1950-2005]

Had-GEM2-ES
- Observed-Liveh
- WRF Reanalysis
- WRF-HAD
- LOCA-HAD
- GCM-HAD

MPI-ESM-LR
- Observed-Liveh
- WRF Reanalysis
- WRF-MPI
- LOCA-MPI
- GCM-MPI

GFDD-ESM2M
- Observed-Liveh
- WRF Reanalysis
- WRF-GFDD
- LOCA-GFDD
- GCM-GFDD

Precipitation mm/month

Months

Precipitation mm/month

Months

Precipitation mm/month

Months
Alamo Lake and Bill Williams River Watershed Modeling Framework
Alamo Lake

- Multi-purpose reservoir:
  - Flood control on the Lower Bill Williams and Colorado Rivers
  - Water supply and conservation
  - Recreation
  - Fish and wildlife enhancement
    - Bald Eagle nest inundation

\[\text{Water Level (ft)}\]
\[\text{Storage (Acre-feet)} \times 10^5\]

\[\approx 600,000\text{ ac-ft}\]
Weather Generator

• A computer program that can produce a large number of time series of “likely to occur” precipitation scenarios

• In arid regions with ephemeral streams, the WG captures the unique spatial-temporal features of the precipitation

• A sufficiently large ensemble of synthetic precipitation time series represents the regional rainfall characteristics, natural variability and uncertainty associated with the observed record

• The probabilistic nature of the WG is appealing for water resources planning and management. It can be used to assess the impact of changes in atmospheric input, water demand, and construction of infrastructure.
Hourly precipitation Weather Generator

Deriving a Statistical Sample for Summer / Winter
Wet Normal Dry

Minimum Inter-arrival Time

Average over the watershed
- Wetness Category
- Season Onset
- Duration of Storm
- Chance of Hourly Precip. to Occur
- Hourly Precip. Magnitude
- Duration until the next storm

Sub-basins
- Wetness Category
- Hourly Precip. Magnitude
- Season Offset
Weather Generator Concept:

Observed Input for Hydrologic Model → Weather Generator → Adjusted Weather Generator

- Dynamical & Statistical Downscaling
- Climate Model Historic Period → Climate Model Future Projection

Hydrologic Model → Impact Assessment
### Projected Wetness Categories: Upper Santa Cruz River Watershed

#### WINTER (November-March)

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<td>Dry</td>
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<td>HAD</td>
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<tr>
<td>MPI</td>
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#### SUMMER (April – September)

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Results: Bill Williams and Alamo Lake

- 7 ensembles generated by the Weather Generator: Historic, 3 DD and 3 SD
- Each ensemble is 100 realizations and each realization is 30 years of hourly precipitation.
- Hydrology and Lake Model
Projected Rainfall → Inflow into Alamo Lake
Alamo Lake -
Low Water Level

Figure 4. Alamo Dam storage allocations and current operation.
Concluding Remarks

- Mid-21\textsuperscript{st} century precipitation projections differ among climate models and downscaling methodologies.

- DD simulations of the MPI and HAD have larger projected changes, compared to their corresponding SD simulations.

- The DD projected changes have contradictory trends: while the MPI projected a drying trend, the HAD projected a wetting trend.

- The projected wetting and drying for the mid-21\textsuperscript{st} century are magnified as precipitation is converted to streamflow and accumulated in Alamo Lake.
Implications for hydrologic assessments

• While the projections in this study did not show clear directional trends, it provides uncertainty bounds that can be useful for future planning of water supply and lake operations.

• These uncertainty bounds are much wider when including the dynamically downscaled models of the MPI and HAD.

• One of the goals of a Reclamation appraisal study is to understand the range of possible outcomes.

• In our study areas, the use of DD projections expands the range of projected impacts.
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