UU Team 2 Integrated Modeling Updates

Climate Modeling
Web Interface
Wasatch Integrated Water Model
Climate Data Access Tool

Steven Burian, Court Strong, Erfan Goharian, Adam Kochanski, and Debadrita Das
Use future climate modeling and downscaling to inform probabilistic scenario development (Strong/Kochanski, UU)

Hydrologic Models

Natural system hydrologic and hydraulic modeling (Burian, UU)

Urban watershed and green infrastructure modeling (SWMM-ET, Pomeroy/Burian, UU)

Water Quality Modeling (SL County, Potential iUTAH)

Outcomes
Expanded information for:
- climate-water science
- water operations
- long-term planning
- infrastructure upgrades

Water System Models

Operations model (Potential iUTAH)

Planning model (Burian, UU; SLC PU)

Demand scenarios (Tim Bardsley, WWA; SLC PU)

http://www.hiddenwaters.org/
Dynamical downscaling

- WRF customized with Great Salt Lake model and urban irrigation scheme

Boundary conditions:
- 6-hourly NCEP Climate Forecast System Reanalysis (CFSR)
- ~38 km resolution
- CMIP5 (~1°)
  - 2025-2035
  - 2055-2065
  - 2085-2095

In production on Yellowstone!
Dynamical downscaling

- WRF Great Salt Lake “slab” model

Differential equation at each grid point
\[
\frac{dT_L}{dt} = -\frac{1}{\rho_w c_w h} F
\]

Cost function
\[
J(h) = \left\{ \frac{1}{n_T} \sum_{t \in \Gamma} \left[ T_L^o(t) - T_L^b(t, h) \right] \right\}^{1/2}
\]

Numerical optimization
\[
\arg \min_h J(h); \text{ subject to } : h \in [0, \infty] \]
\[
h = 5.1 \text{ m}
\]

Strong et al. (2013), JAMES, in prep.
• Developing a “Climate Scenario module” (CSmod) to generate on-demand, stochastic realizations of climate
Statistical downscaling

**CSmod engine:**

**Occurrence:** two-state, 2\textsuperscript{nd}-order Markov chain process

\[ p_{000}(k); p_{100}(k); \]
\[ p_{010}(k); p_{110}(k); \]
\[ k = 1, \ldots, K \]

**Amount:** fit mixed exponential

\[ f[r(k)] = \alpha(k) \beta_1(k) \exp \left[ -\frac{1}{\beta_1(k)} r(k) \right] + \]
\[ \frac{1 - \alpha(k)}{\beta_2(k)} \exp \left[ -\frac{1}{\beta_2(k)} r(k) \right] \]

**Stochastic driver:** spatially-correlated multivariate Gaussian

\[ g(x) = \frac{1}{(2\pi)^{K/2} \sqrt{\det \Sigma}} \exp \left[ -\frac{1}{2} (x - \mu)^T \Sigma^{-1} (x - \mu) \right] \]

Wilks (1999, 2009)
Climate Scenario module

CSmod test: generate synthetic historical precipitation data
Climate Scenario module

**CSmod test:** generate synthetic historical record (1958-2012)

**CSmod future climate:** amount and occurrence functions are re-fit allowing nonstationarity if justified by change in log-likelihood
Integrated Water Resources Management (IWRM)
Case Study
Parley’s Water System
Parleys GoldSim model

GoldSim Player allows you to view, navigate, and run an existing GoldSim model without having to purchase GoldSim Pro.
Player File Dashboard

Parleys Creek Management Tool

Dell Creek Inflow Rate

Demand Rate

Reliability Results

Choose a scenario
- Warm Dry
- Historical Run

Run the Model

Simulation Settings

Mountain Dell Reservoir
- Scenario Results
- Historical Result

Little Dell Reservoir
- Scenario Results
- Historical Result

Reliability
- Scenario Results
- Historical Result

General Mountain Dell Reservoir Characteristics
- Capacity [af]: 3200
- Dead Pool [af]: 800
- Initial Volume [af]: 2000

General Little Dell Reservoir Characteristics
- Capacity [af]: 20000
- Dead Pool [af]: 0
- Initial Volume [af]: 5700
Adjustment

- Change factor approach (CFA):

\[
\begin{align*}
\Delta T &= (T_{GCM,fut} - T_{GCM,base}) \\
\Delta P &= \left( \frac{P_{GCM,fut}}{P_{GCM,base}} \right)
\end{align*}
\]

- \( \Delta T \) and \( \Delta P \) are monthly change factors (CFs) of temperature and precipitation
Changes in Mean Annual Temp & Precip
comparing Oct 2035- Sep 2065 to Oct 1980- Sep 2010
Climate Scenario results

Reservoirs History

- Little Dell (cfs)
- Historical
- Warm Wet
- Warm Dry
- Middle
- Hot Wet
- Hot Dry

Time

1965
1990
1995
2000
2005
2010
Development Plans

\[ y = 2E^{-07}x^3 - 7E^{-06}x^2 + 0.0004x + 0.9 \]

\[ R^2 = 0.99643 \]

Percent change in Mt Dell Capacity vs. Reliability.
Water Conservation or Population Growth?

The graph shows the relationship between Reliability and the Percent change of demand. The equation fitted to the data is:

\[ y = 1 \times 10^{-5}x^3 - 1 \times 10^{-5}x^2 - 0.009x + 0.899 \]

with a coefficient of determination \( R^2 = 0.99591 \).
Web Interface (Collaboration with BYU)
Connection Between Web and Server

Web

CKAN

Python

Excel

input

Python

Run

Model

# Importing Required Libraries
from tempfile import TemporaryFile
from xlwt import Workbook
import numpy as N
from mmap import mmap, ACCESS_READ
from xld import open_workbook
import subprocess

# Requesting the Dashboard data from Users
# These data will come to the model from web site in final model
# Instead of asking user

# Scenario Number
sc_number = raw_input("Scenario number(1.Historical, 2.Warm Wet, 3.WarmDry, 4.Middle, 5.Hot Wet, 6.Hot Dry): ")

# Little Dell Properties
init_lit = raw_input("Initial volume of Little Dell (default: 5700af): ")
capacity_lit = raw_input("Maximum capacity of Little Dell (default:20000af): ")

# Writing the single values in worksheet
sheet1.row(0).set_cell_number(1,sc_number)
sheet1.row(2).set_cell_number(1,init_lit)
sheet1.row(3).set_cell_number(1,capacity_lit)
sheet1.row(4).set_cell_number(1,deadpool_lit)
sheet1.row(6).set_cell_number(1,init_mt)
sheet1.row(7).set_cell_number(1,capacity_mt)
sheet1.row(8).set_cell_number(1,deadpool_mt)

# Writing the ratio arrays
for a in range(12):
sheet1.row(11+a).set_cell_number(1,dc_ratio[a])
sheet1.row(11+a).set_cell_number(2,lc_ratio[a])
sheet1.row(11+a).set_cell_number(3,mks_ratio[a])
sheet1.row(11+a).set_cell_number(7,dem_ratio[a])

# Saving the Excel file
book.save('dashboard.xls')

# Running the GoldSim through the CML
subprocess.call("C:\Program Files (x86)\Goldsim 11.0\GSimPlayer.exe -r -x Parleys_Creek_V11.gsp",shell=True)
Comprehensive Knowledge Archive Network (CKAN)

- Web-based open source data management system for the storage and distribution of data
- CKAN provides a rich API for querying and accessing dataset information.

- Publish and Manage Data
- Search and Discovery
- Geospatial
- Community
- Visualize
- Themable
- Store
- History
- API
Visualize

Supports:
• line,
• spline,
• area,
• column,
• bar,
• pie,
• Scatter
• Etc…
Salt Lake City

Wasatch front

Farmington Bay

Jordan River
Wasatch Integrated Water Model

Farmington Bay

Jordan River

Salt Lake City

Wasatch Front
Parleys Creek
Climate

Hydrologic

Reservoirs system

SD

Flow Module (GS)

WRF and CMIP

HSPF, GSSHA and UEB

SWMM

RHESSys

Ecology

Stormwater

Demand

Water Supply

GoldSim
Climate Data Access Tool for Analysis of Water Resources

User Interface (Input)
- Observation File
- Determine the time slices

Core of Tool
- Find most accurate GCM
- Find minimum GCM
- Projection of future climate

Result
- Extreme climate condition for specific location
- Download result in SWMM or GSSHA input format

Analysis and Visualization
Method

• Download climate data for the required grids (daily and monthly) for all models in NetCDF (NOT AUTOMATED)

• Write R code to calculate which model predictions are closest to the observations

• Determine monthly change factors for every model

• Use these change factors to determine which models project extreme conditions
Potential Climate Analysis Tools

• Intensity: Mean, Maximum, Moving Average, …

• Events and Duration: Average Duration, Interevent, mean event Depth, …

• Frequency Analysis: Probability distribution, return period, Exceedence probability, …

• Drought: Dry proceeding days, longest drought, …

• Spatial Analysis

• Indices: Standard Precipitation Index, Palmer Drought Index, Extreme Precipitation Index

• etc

• Time series
  • Hourly
  • Weekday
  • Monthly
  • Annual
Main Idea

• This package can determine which model (GCM) is most appropriate (based on historical projection and observation) for each part of the USA and prepare an assembled model for future use.

• This package can present a good estimation of future extreme climate condition for each part of the USA and prepare an assembled model for future use. (now we are working on three different parts: Salt Lake City, NYC and Toledo)

• The result can be used for different water models like SWMM, GSSHA and HSPF
R-Code

```r
R version 3.0.1 (2013-05-16) -- "Good Sport"
Copyright (C) 2013 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()', 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> library(ncdf)
> ncd1<-open.ncdf("ext_pr(1950-2099).nc")
> ncd2<-open.ncdf("obs_pr(1950-1999).nc")
> pr1<-get.var.ncdf(ncd1,"pr")
> pr2<-get.var.ncdf(ncd2,"Prp")
> closest<- -999
> modelnumber<-0
> sum<-0
> dim(pr1)
> [1] 1800 234
> dim(pr2)
> [1] 600
> closestmodel<-function(pr1,pr2,n)
> for(i in 1:n)
> sum<-sum(abs(pr1[i,1]-pr2[i,1]))
> if(sum<closest)
> closest<-sum
> modelnumber<-i
> changefactorfn<-function(pr1,pr2,nofyrs,startcurrent,starthistoric)
> arr<-c(12,2)
> for(i in startcurrent:nofyrs)
> arr[i,0]+pr1
> for(i in starthistoric:nofyrs)
> arr[i,1]+pr2
> arr<-c(arr
> for(i in 1:12)
> arr[i,1]/arr[0,1]/arr[1,1]
> arr[i,1]
> for(i in 1:234)
> closestmodel(pr1[i,],pr2[i,])
> changefactorfn(pr1[i,],30,1980,2050)
> closest
> [1] 14.562
> modelnumber
> [1] 63
> close.ncdf(ncd1)
> close.ncdf(ncd2)
```
Results
Climate Tool

- Developing the Climate tool for the first case study, Salt Lake City for precipitation (1950-2100) in monthly and daily mode.

- Using disaggregation methods to produce result in hourly scale.
Accomplishments

Conferences:

• Evaluating the reliability of a water supply system based on system dynamics modeling: A Case Study of Salt Lake City, Utah. EWRI Congress 2013 – Cincinnati, OH.

• Assessing climate change risks to a municipal water supply: A pilot project incorporating downscaled climate projections, operational hydrologic modeling, and a systems planning model. 2013 Spring Runoff Conference.

• Assessing climate change risks to a municipal water supply: A pilot project incorporating downscaled climate projections, operational hydrologic modeling, and a systems planning model. 2013 CPASW Climate Prediction Applications Sciences Workshop.

• Strong C. Future precipitation and snowpack along the Wasatch Range, American Water Resources Association Utah Section Annual Conference, Salt Lake City, Utah, 14 May 2013.

Journal paper:

Future

Conferences:
• Web-Based Reservoirs System Management Tool based on Dynamic Simulation for Water Utilities in Salt Lake City, Utah - EWRI Congress 2014 - Portland, Oregon. (Submitted)

• Using Dynamic Simulation to Support Integrated Water Resources Management in Cities - EWRI Congress 2014 - Portland, Oregon. (Submitted)

• Integrated Water Resource Management Tool based on Extreme Climate Change Impact. HIC 2014 - New York, USA. (Not submitted)

Proposal:
• NSF Hydrologic Sciences, Fall 2013, Climate-Vegetation Impacts on Hydrologic Response

Journal paper:
• Impact of climate change on water resources (Salt Lake City, Utah). (in prep)
Any Question?

Thank you