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Estimating Weather-Sensitive Demands for Water: Implications of Climate Change

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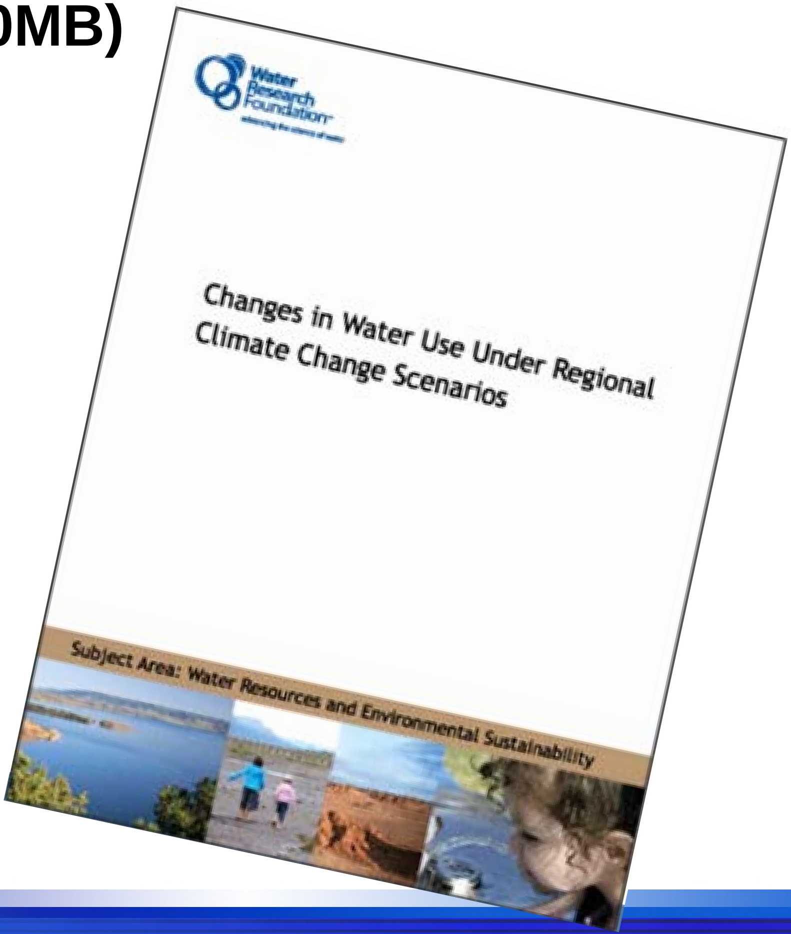
Environmental Engineers & Scientists

Acknowledgments

- Financial Support
  - Water Research Foundation
  - Colorado Springs Utilities
- Participating Utilities
  - Tampa Bay Water
  - San Diego County Water Authority
  - Phoenix Water Services
  - Massachusetts Water Resources Authority
  - Regional Municipality of Durham (Toronto Area, Ontario)
  - Southern Nevada Water Authority
  - Seattle Public Utilities
  - Gwinnett County (Metro Atlanta Area, Georgia)

Final Report is Now Available

- http://www.waterrf.org/Pages/Projects.aspx?PID=4263
- Print and electronic form (~10MB)
- Webinar and Powerpoint



Changes in Water Use Under Regional Climate Change Scenarios

Subject Area: Water Resources and Environmental Sustainability

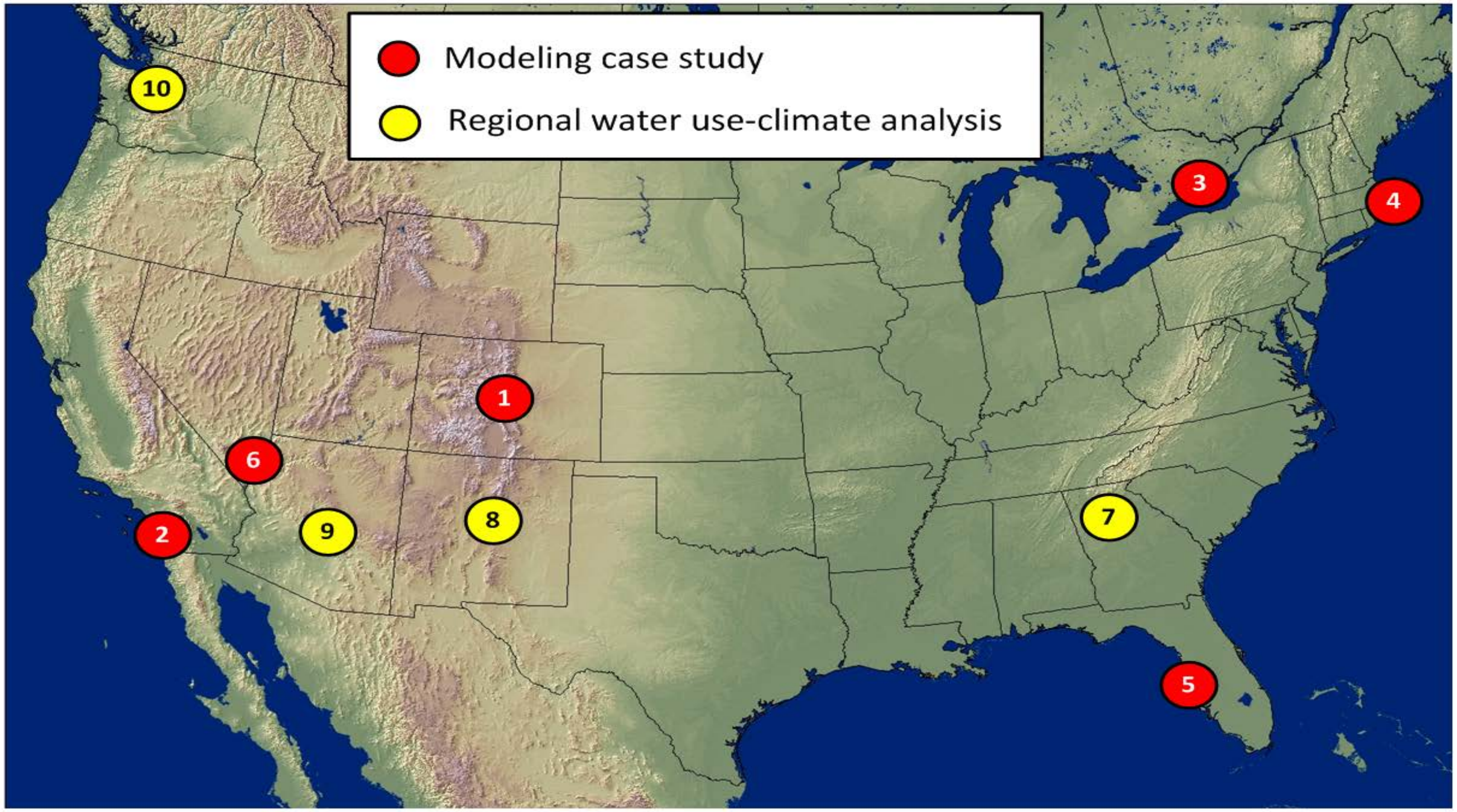
Outline

- Introduction to WRF 4263: Changes in Water Use under Regional Climate Change Scenarios
- Colorado Springs Case Study
- Technical Implications for Demand-Weather Models
  - Data Concerns
  - Model Form Specification
  - Model Variable Selection
- Summary

WRF Project 4263: Changes in Water Use under Regional Climate Change Scenarios

WRF Project 4263: Changes in Water Use under Regional Climate Change Scenarios

- Objective: Increase the adaptive capacity of water utilities to plan and adapt to changing climate
- Used data from participating utilities to
  - Illustrate importance of observed climate in shaping observed seasonal patterns of water use
  - Review weather-demand modeling techniques
  - Identify sources of climate projections that are applicable to weather-demand models
  - Demonstrate techniques for case study utilities



- ● 1 Colorado Springs Utilities (CO)
- ● 2 San Diego County Water Authority (CA)
- ● 3 Durham Region (Ontario, Canada)
- ● 4 Massachusetts Water Resources Authority (MA)
- ● 5 Tampa Bay Water (FL)
- ● 6 Southern Nevada Water Authority/Las Vegas Valley Water District (NV)
- ● 7 Gwinnett County (GA) Department of Water Resources
- ● 8 Albuquerque-Bernalillo County Water Utility Authority (NM)
- ● 9 City of Phoenix (AZ)
- ● 10 Seattle Public Utilities (WA)

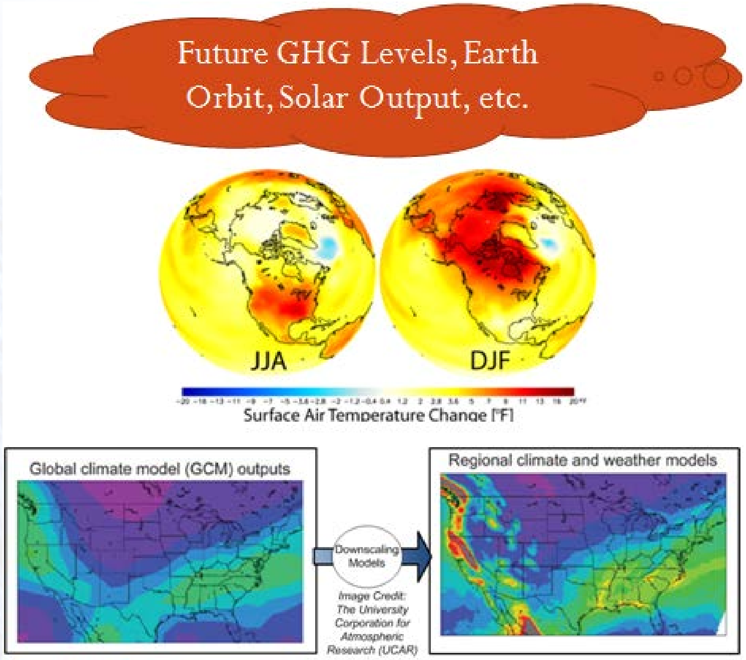
Projected Weather Changes Under Climate Change Scenarios

- Data now available for projected weather variability in response to climate change at geographic scales comparable to moderate-large service areas

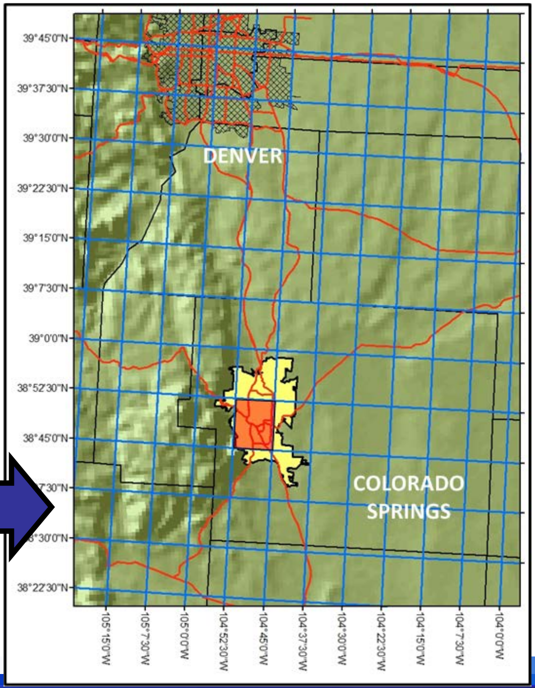
Climate forcing assumptions

Global Circulation Models (GCMs)

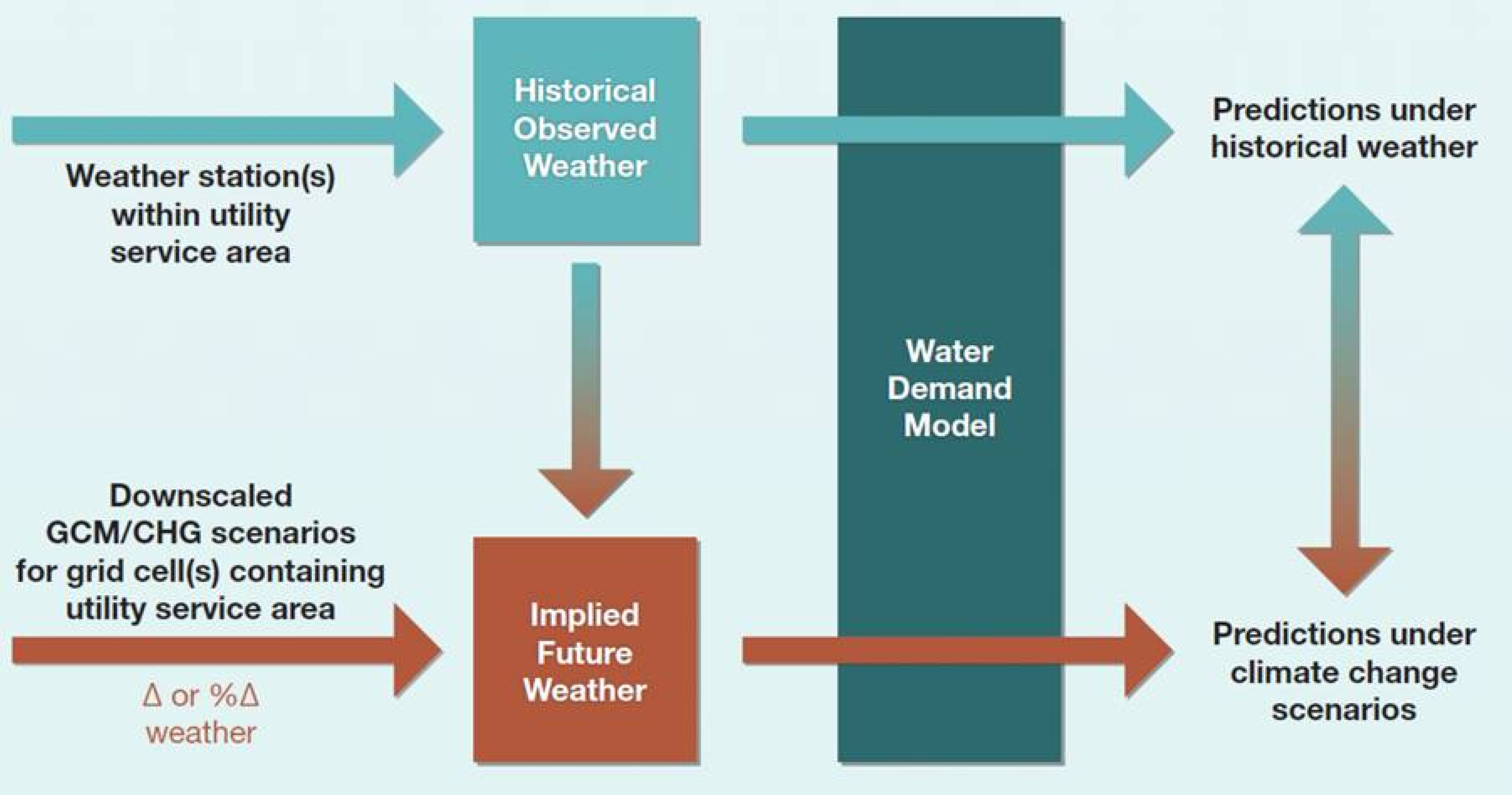
GCM downscaling



Fine-scale weather simulations under climate change scenarios



From Downscaled Climate Change Projections to Demand Impacts



Weather station(s) within utility service area

Historical Observed Weather

Downscaled GCM/CHG scenarios for grid cell(s) containing utility service area

Δ or %Δ weather

Implied Future Weather

Water Demand Model

Predictions under historical weather

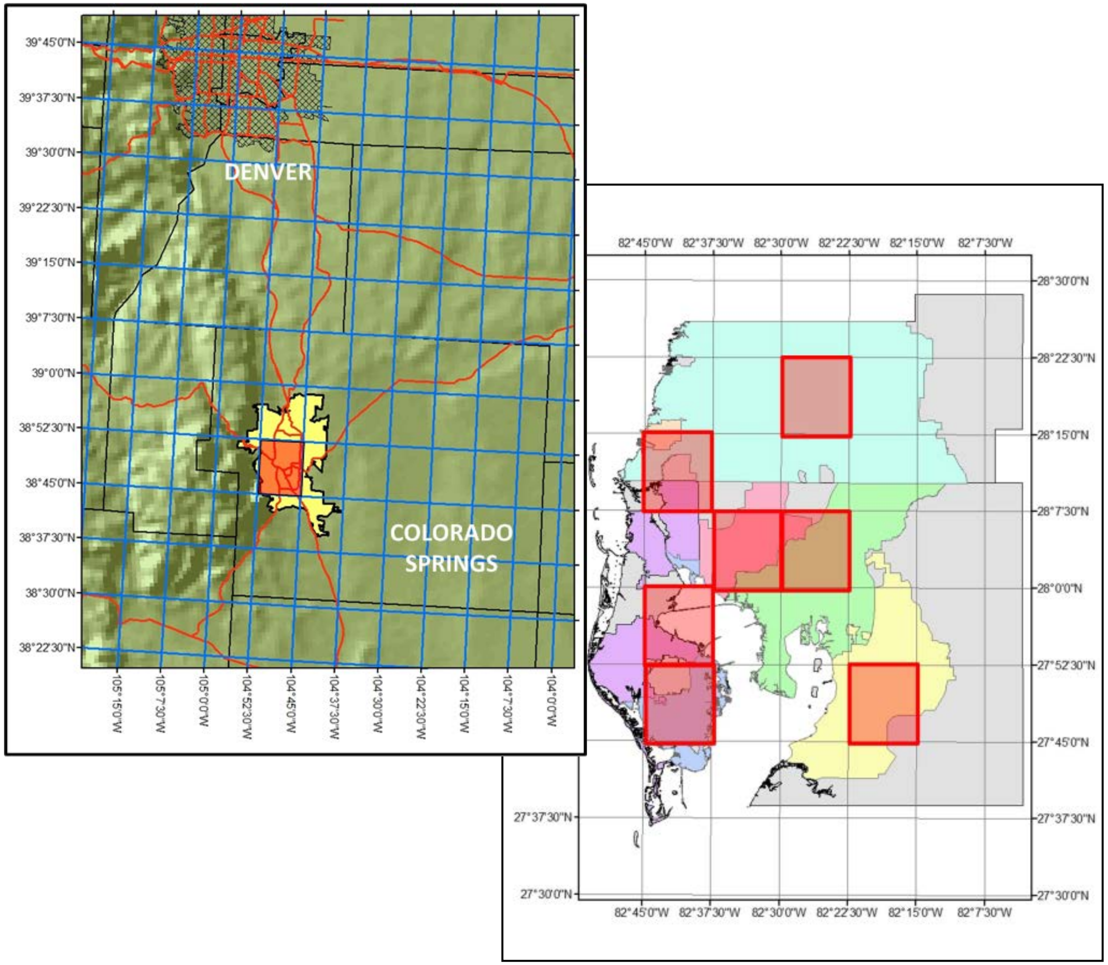
Predictions under climate change scenarios

Selection of Climate Scenarios

- Bias-Corrected Constructed Analog (BCCA) section of the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset
- Daily time scale at 1/8 degree geographic grid resolution
  - Tmin, Tmax, Precip
- Projections for 2 time slices
  - 2055 slice: 2046 through 2065
  - 2090 slice: 2081 through 2100

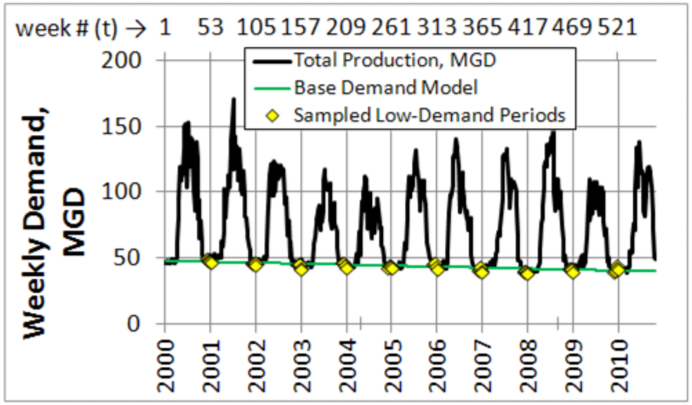
Selection of Climate Scenarios

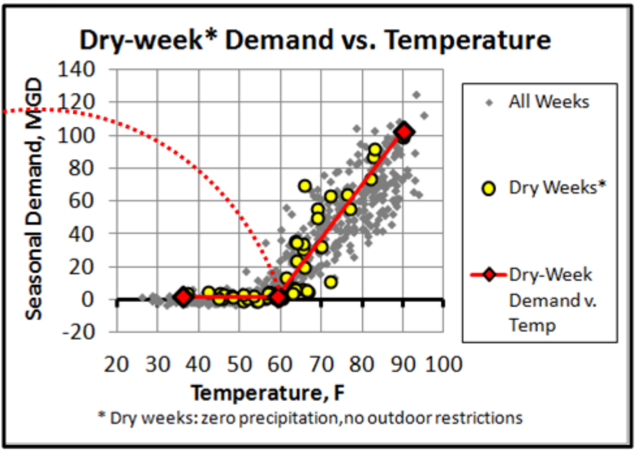
- Select one or more grid cells
- Typically grid cell(s) containing weather station(s) used for historical weather



General Model Development Approach

- **Remove base trend from historical demand**

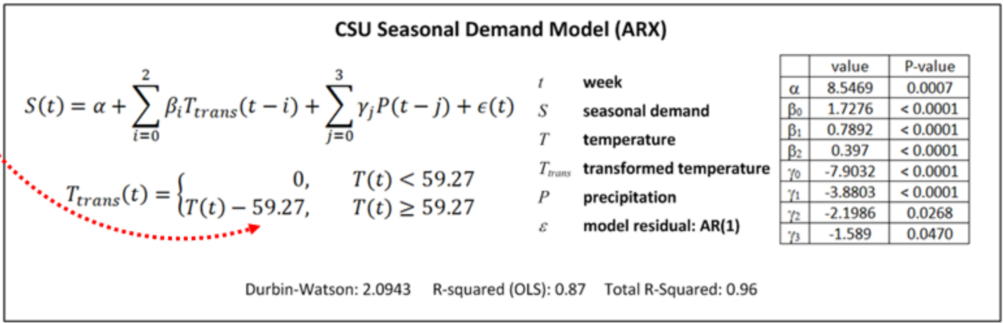




* Dry weeks: zero precipitation, no outdoor restrictions

Breakpoint Temperature: 59.27°F

- **Model remaining seasonal demand as function of weather**
- **Choose weather variables that can be derived from climate projections**



CSU Seasonal Demand Model (ARX)

$$S(t) = \alpha + \sum_{i=0}^{2} \beta_i T_{trans}(t-i) + \sum_{j=0}^{3} \gamma_j P(t-j) + \epsilon(t)$$

$$T_{trans}(t) = \begin{cases} 0, & T(t) < 59.27 \\ T(t) - 59.27, & T(t) \geq 59.27 \end{cases}$$

t	week
S	seasonal demand
T	temperature
T_{trans}	transformed temperature
P	precipitation
ε	model residual: AR(1)

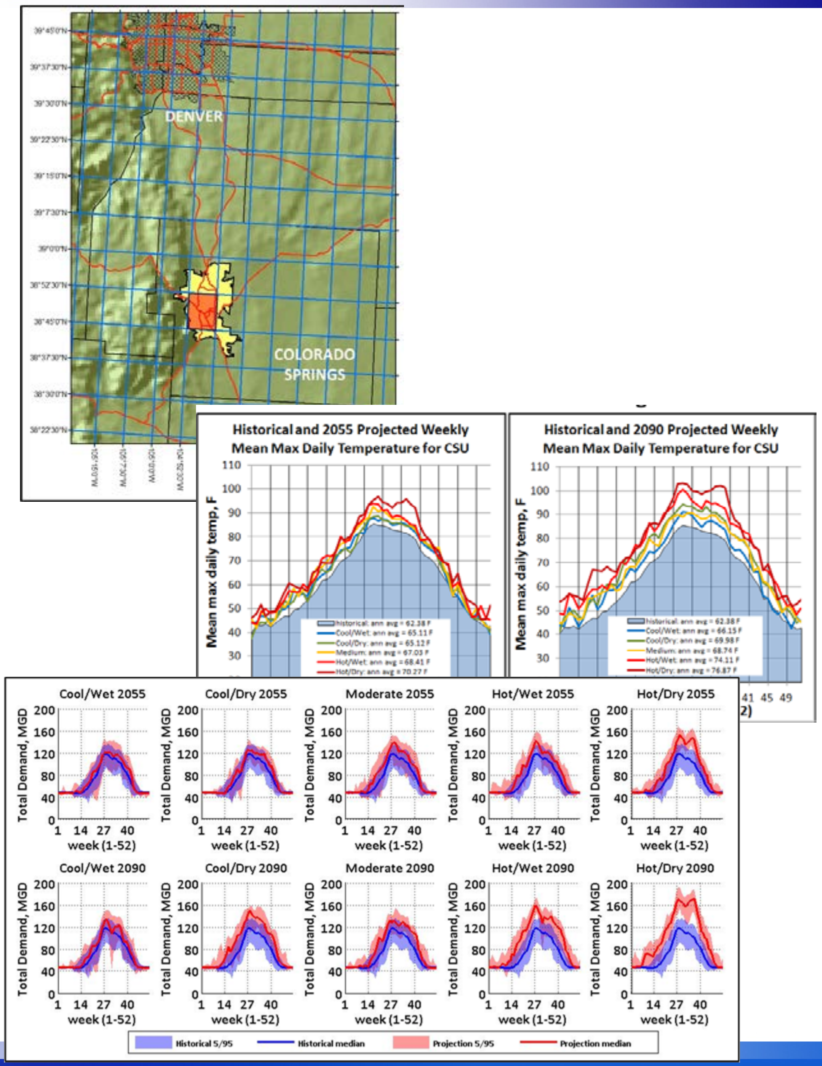
	value	P-value
α	8.5469	0.0007
β_0	1.7276	< 0.0001
β_1	0.7892	< 0.0001
β_2	0.397	< 0.0001
γ_0	-7.9032	< 0.0001
γ_1	-3.8803	< 0.0001
γ_2	-2.1986	0.0268
γ_3	-1.589	0.0470

Durbin-Watson: 2.0943 R-squared (OLS): 0.87 Total R-Squared: 0.96

Colorado Springs Case Study

Colorado Springs Utilities

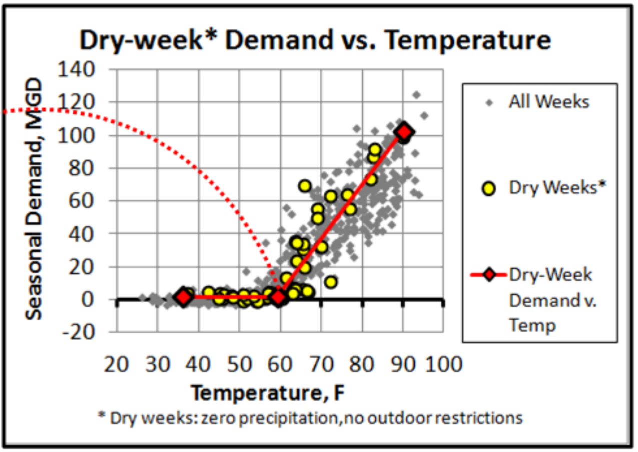
- 10-year historical production record
- Developed model of weekly production as a function of weather
- Applied historical and projected weather to model
  - 30-year historical weather record
  - multiple 20-year projected weather records
- Determined relative (percent) changes in demand from historical weather to each scenario



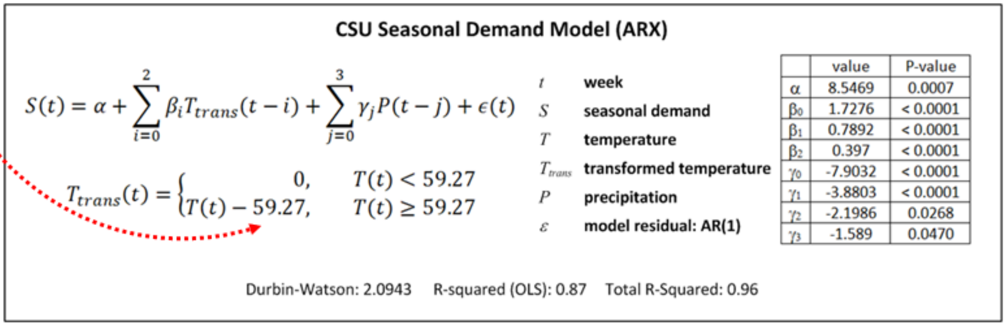
Colorado Springs Model

- Linear base trend with time
- Weekly detrended seasonal demand is function of concurrent and lag values of
  - Weekly average max daily temperature
  - Weekly total precipitation
- Temperature variables transformed
  - Piecewise linear effect of temperature on demand

Breakpoint Temperature: 59.27°F



* Dry weeks: zero precipitation, no outdoor restrictions



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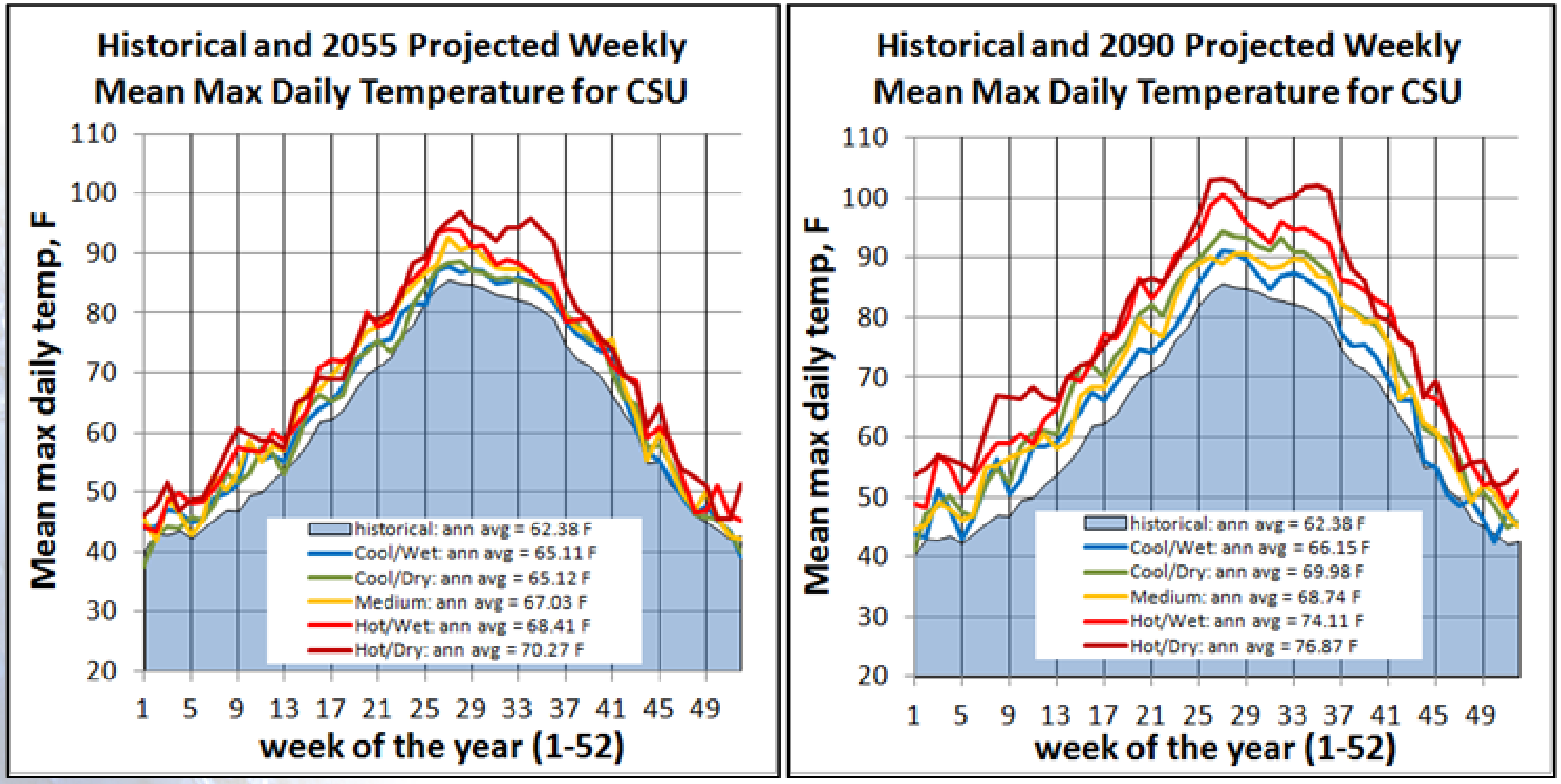
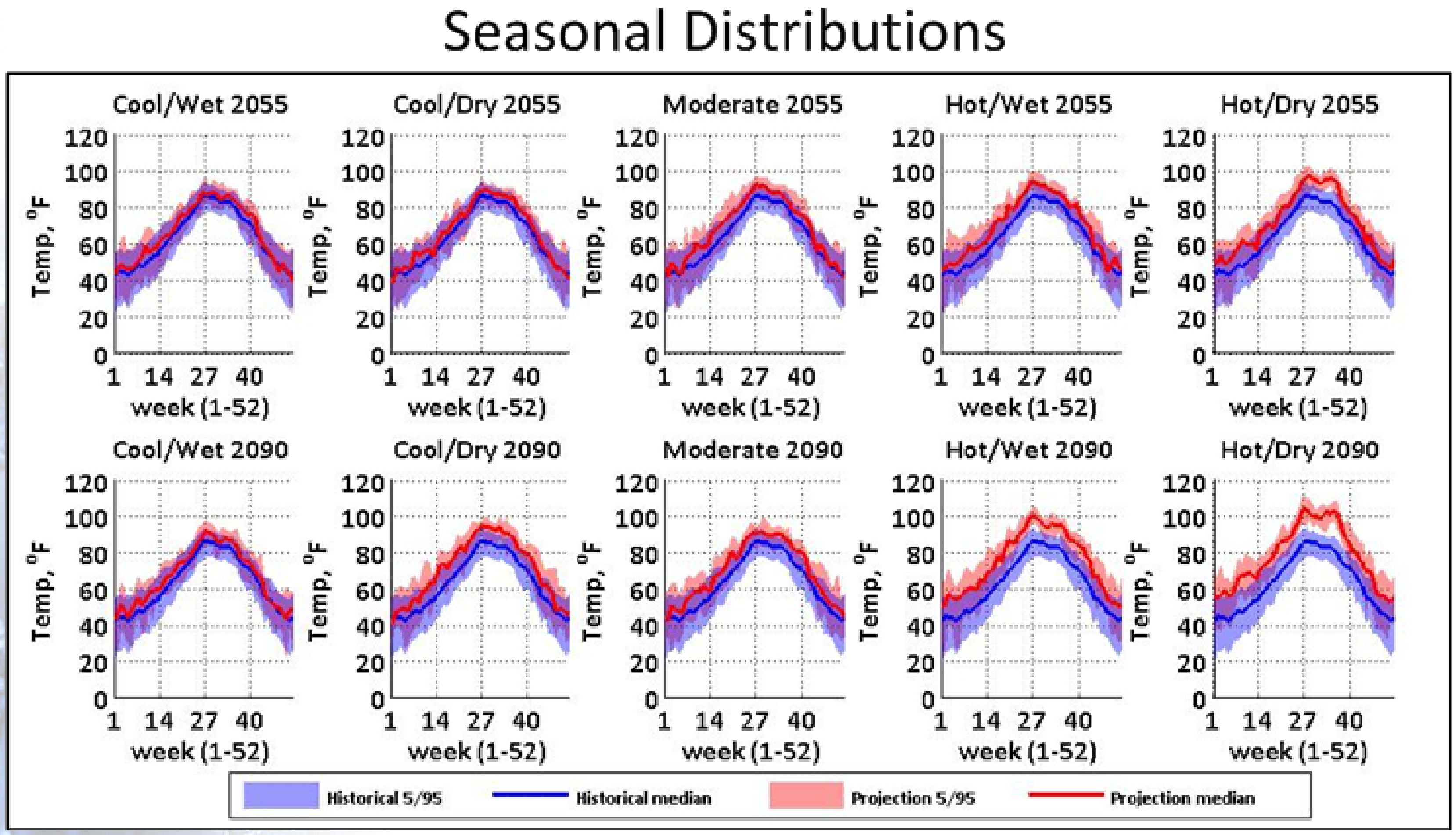
Climate Change Scenarios: Colorado Springs Temperature

Annual and Seasonal Averages

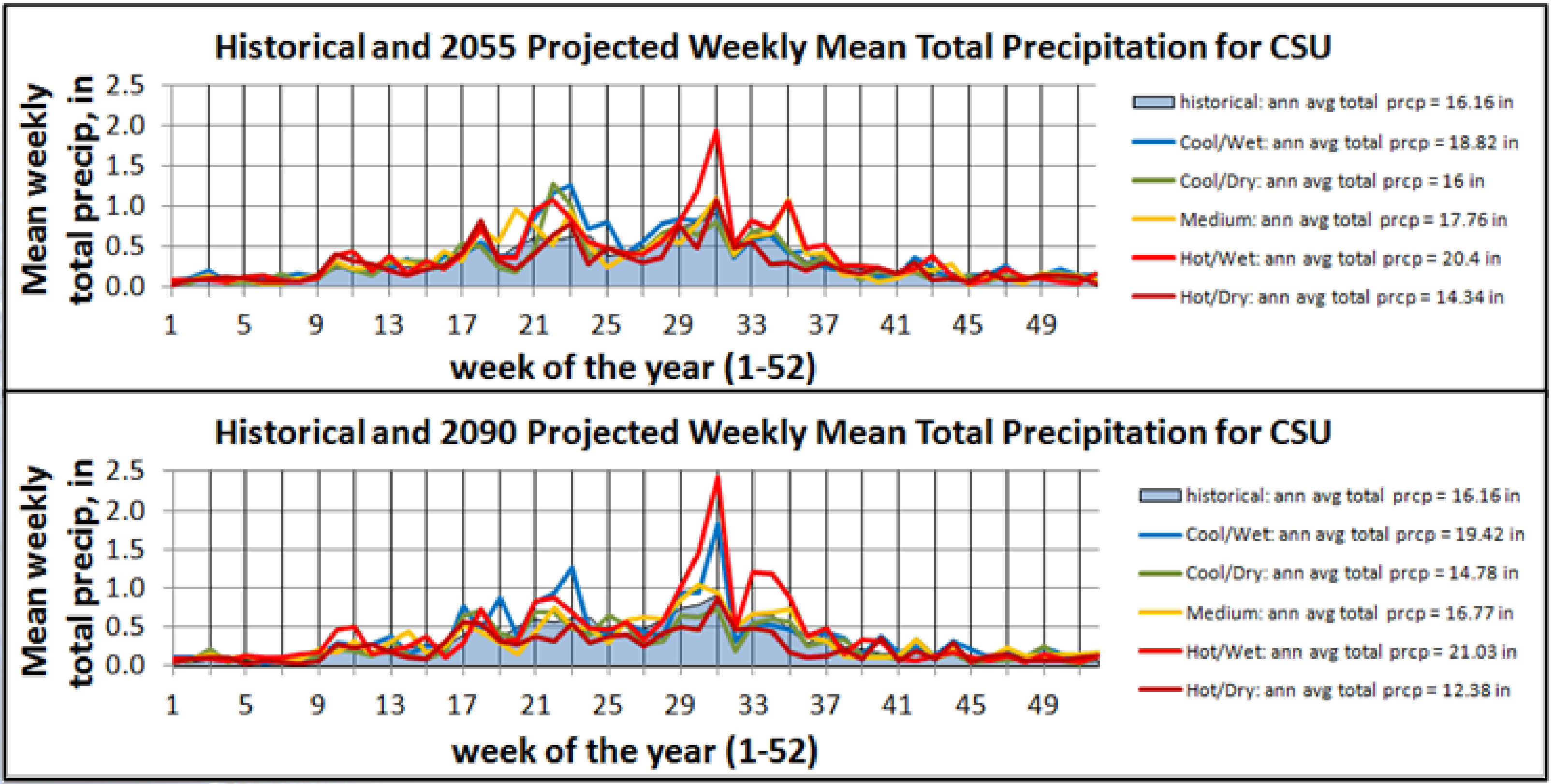


Climate Change Scenarios: Colorado Springs Temperature



Climate Change Scenarios: Colorado Springs Precipitation

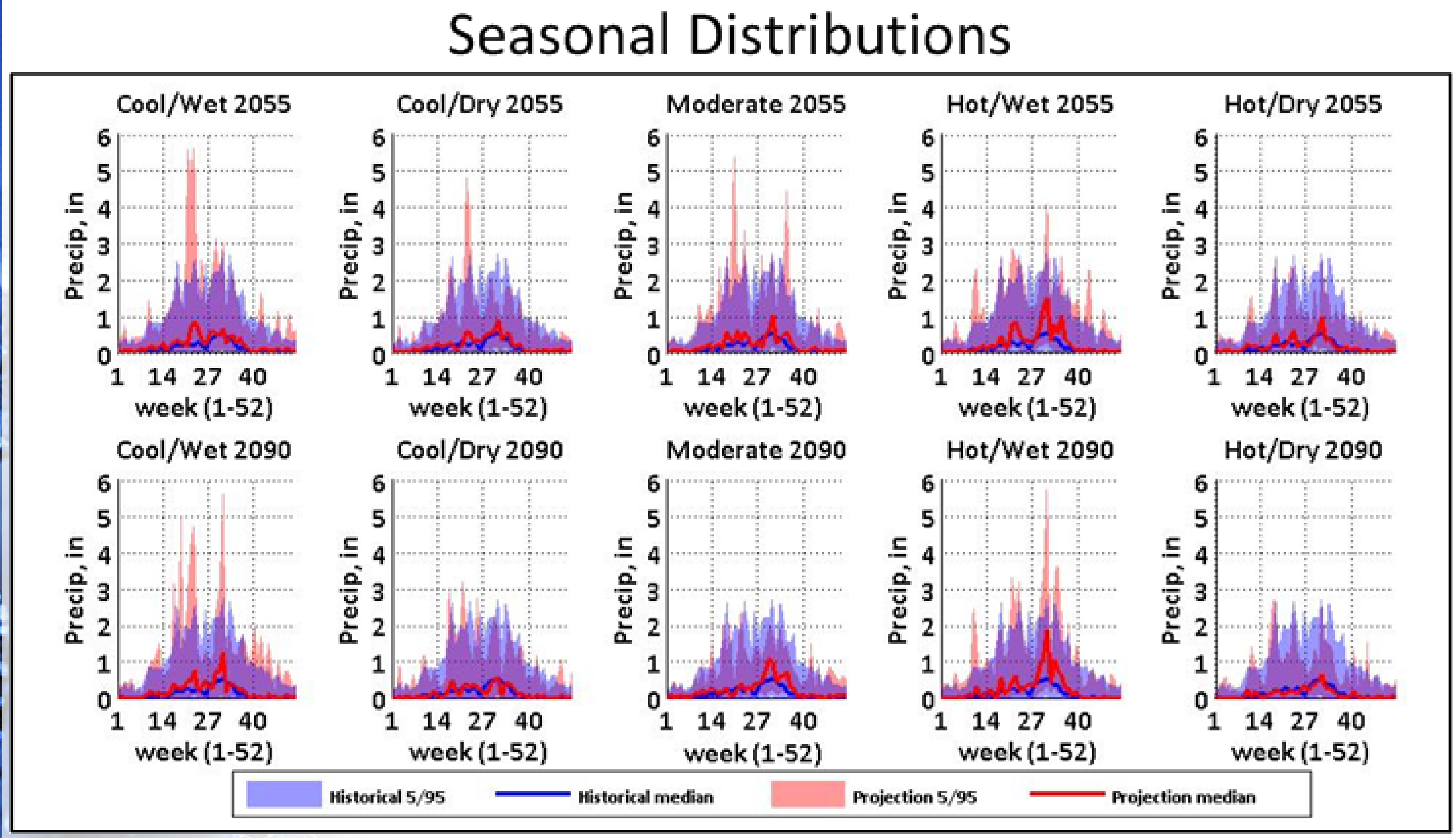
Annual and Seasonal Averages



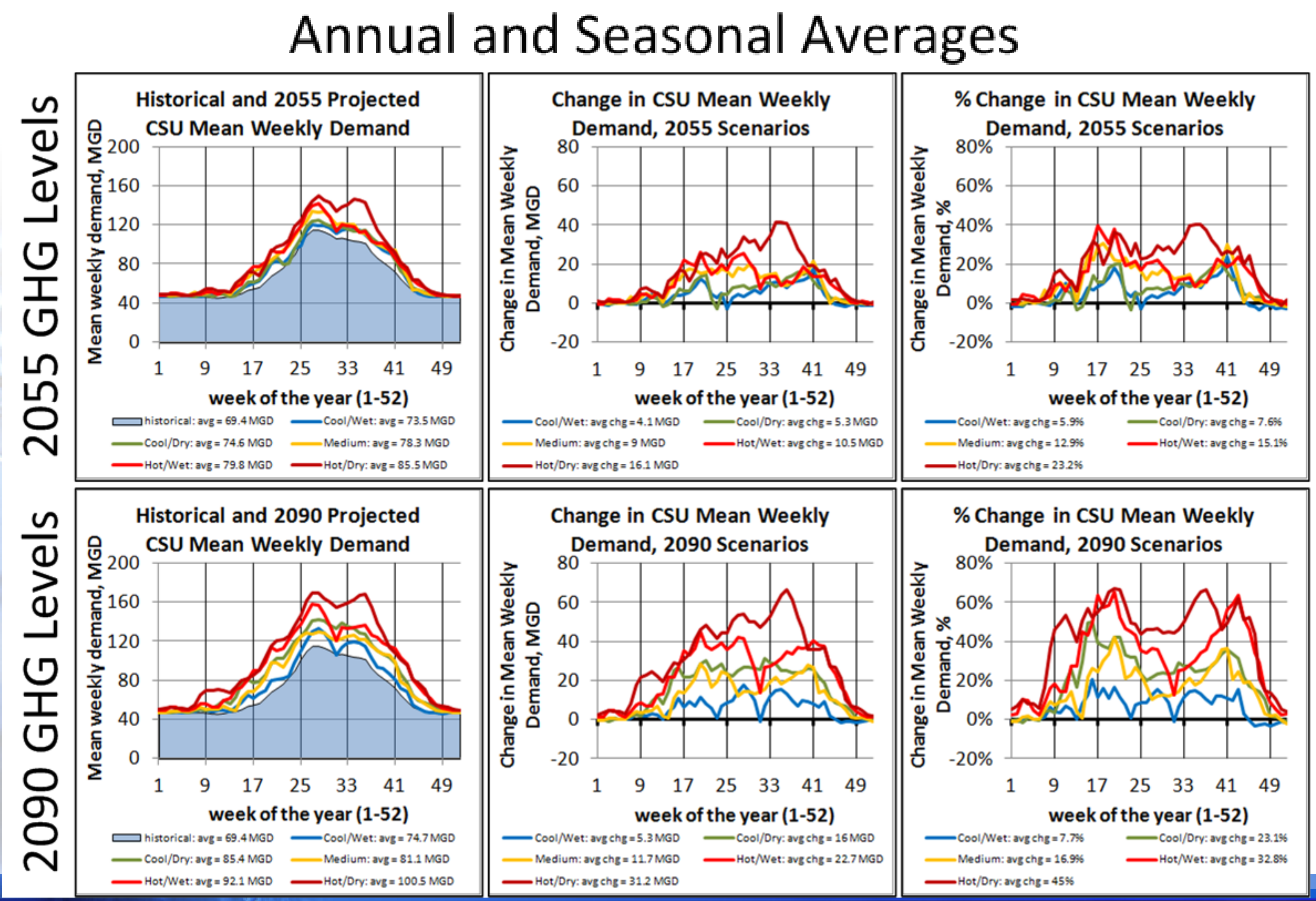
Historical and 2055 Projected Weekly Mean Total Precipitation for CSU

Historical and 2090 Projected Weekly Mean Total Precipitation for CSU

Climate Change Scenarios: Colorado Springs Precipitation

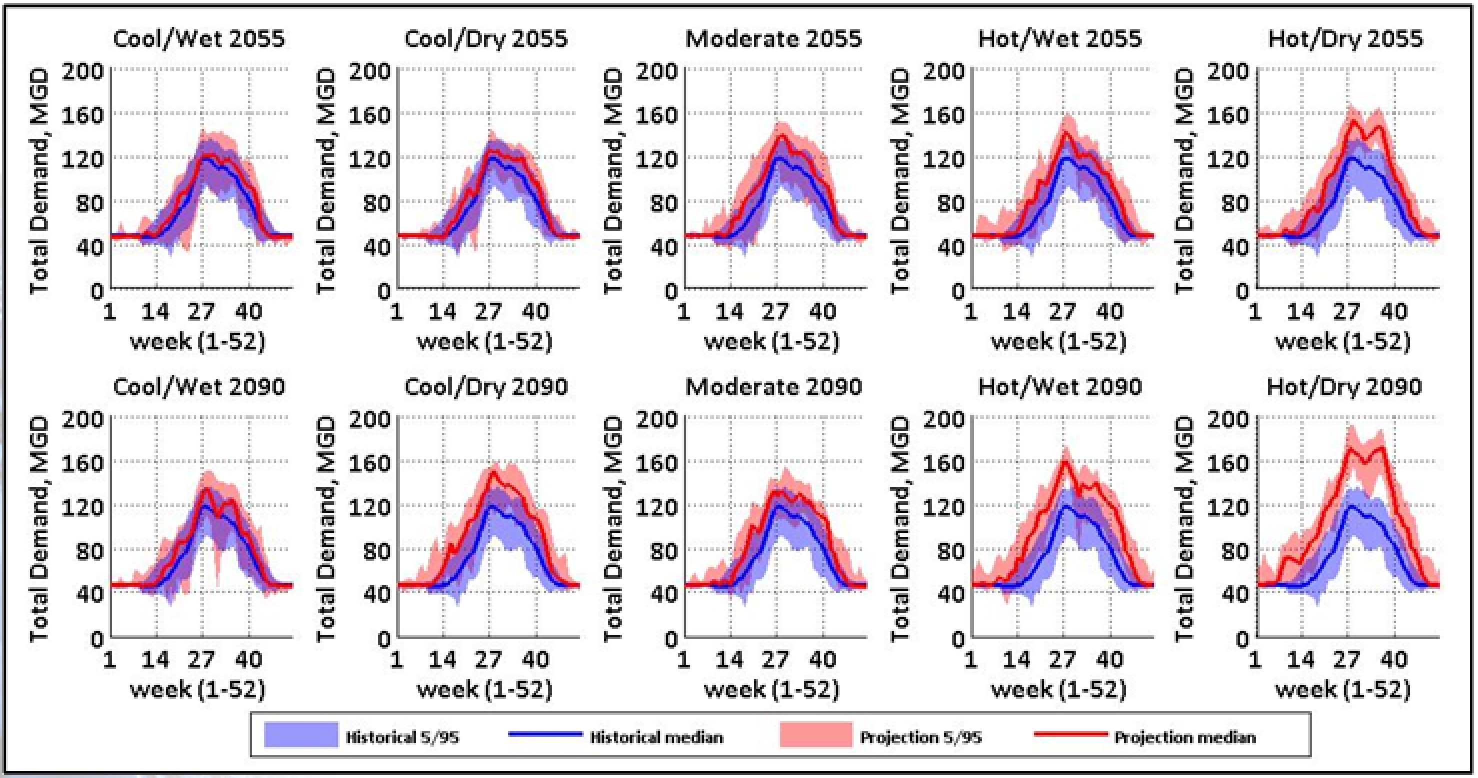


Climate Change Scenarios: Colorado Springs Demand



Climate Change Scenarios: Colorado Springs Demand

Seasonal Distributions



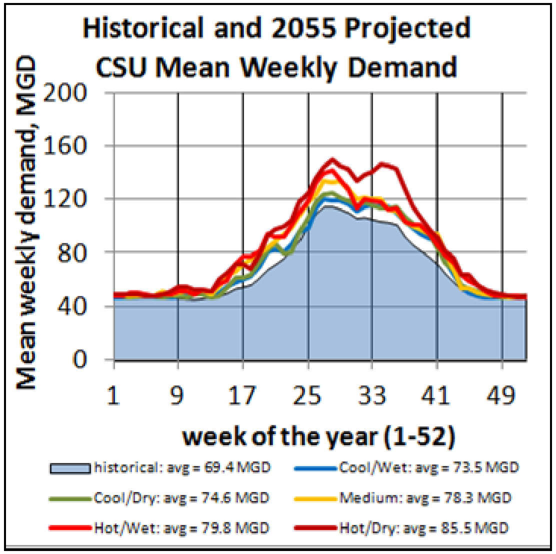
Technical Implications for Demand-Weather Models

Important Technical Implications for Demand-Weather Models

- When developing weather-demand models for climate change assessments, results impacted by
  - Model time scale
  - Model specification (equation form)
  - Weather variable selection
  - Inclusion or exclusion of fixed-effect seasonal instruments (e.g. dummy variables, oscillating seasonal functions)
  - Choice to model sectoral (retail) demand versus total production demand
  - Inclusion/exclusion of economic variables

Model Time Scale

- Impacts of climate change on demand will arise primarily at seasonal and sub-seasonal level
  - changes in seasonal norms
  - changes in short-term variability
- Demand must be modeled at seasonal or sub-seasonal time scales
  - Monthly, Weekly, Daily
- Constraint: length of demand record
  - Shorter records may require shorter time scales to provide sufficient data



Demand Data Selections

- **Production data vs. retail (billing) data**
  - **strengths and weaknesses of each**

	Production Data: daily, weekly, or monthly production	Retail Data: aggregate meter readings for individual customers
Easy to align with weather observations?	**Yes: fine, regular time scale**	**No: coarse, irregular time scales**
Easy to classify by customer sector?	**No: only represents total use**	**Yes: from customer classifications**
Accounts for unmetered consumption and water loss?	**Yes (implicitly)**	**No**
Relatable to economic conditions and efficiency metrics?	**Yes, but primarily non-sector-specific conditions/metrics**	**Yes, and particularly to sector-specific conditions/metrics**

Weather Data

- Weather variables must be derivable from both historical and projected weather data
- Weather variables should have physically rational impact on demand

Total Precipitation	Length of Cold/Warm or Wet/Dry Spells
Mean Max Daily Temperature	(Consecutive Time Periods
Total ET	Above/Below Threshold)

- Contemporaneous, lag values as needed

Weather Data

- **<u>Avoid</u> fixed-effect seasonal variables (seasonal dummies, harmonics, etc.) derived from historical weather**
  - **Often used to decouple historical climate from actual weather**
  - **Propagate historical repeating water use patterns onto future climates that may differ considerably**
  - **Treating future weather as perturbations from historical climate may not be adequate**
- **Instead, try to use actual weather measurements as the seasonal instrument**

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable)

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is

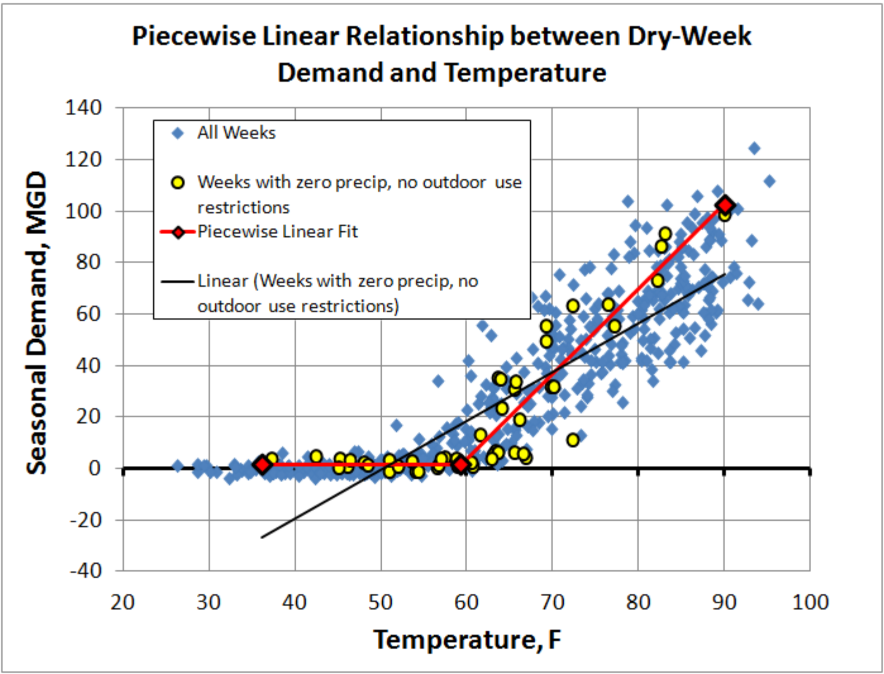
that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*,

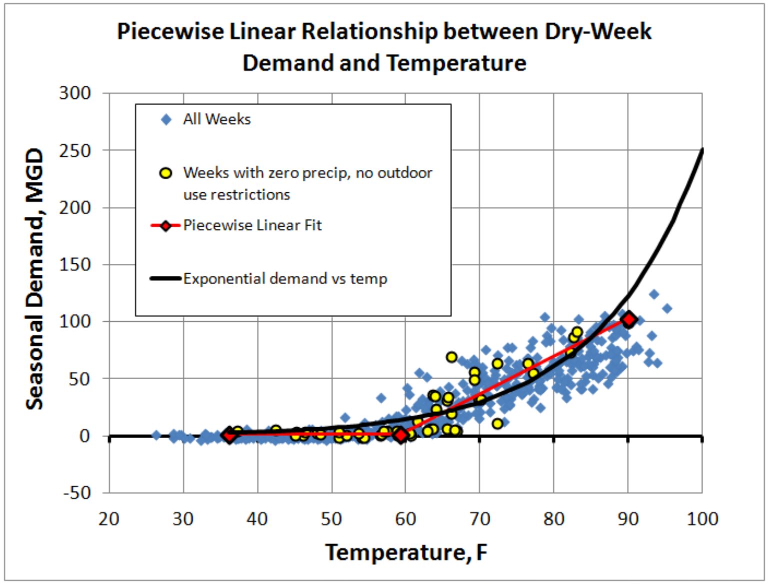
Model Form

- Identify and include nonlinear relationships between demand and weather as necessary
- Temperature vs demand for Colorado Springs is a perfect example: linear demand vs temperature would have
  - Overestimated mid-temperature demand
  - Underestimated cold-and high-temperature demand
  - Unrealistically suppressed projected summer demand impacts



Extrapolation Concerns

- Weather conditions under climate change scenarios may (likely will) extend beyond the historical range
- Nonlinear relationships that seem reasonable within historical weather conditions may lead to unexpectedly extreme results
- Even in linear relationships, weather variable specifications can be sensitive to small changes in climate
  - e.g. large changes in threshold variables (durations of hot or dry spells) from small changes in normal weather
- Monitor weather model behavior outside the historical range… is it still reasonable?



Summary

Demand Models for Climate Change Studies: Important Technical Considerations

- Time scale should be fine enough to allow simulation of seasonal/sub-seasonal impacts.
- Choice of demand variable (production vs. sales) depends on need to address economic, sector-specific impacts.
- Weather variables must be derivable from both historical and projected data sources.
- Seasonal variables (dummies, harmonics) that directly account for historical normal seasonality should be avoided… weather itself should serve as the seasonal instrument.
- Nonlinearity in weather-demand relationships should be sought and represented in models when encountered.
- Models must not just reproduce historical conditions well… they must also be reasonable when presented with weather conditions outside historical ranges.

Thank You!

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