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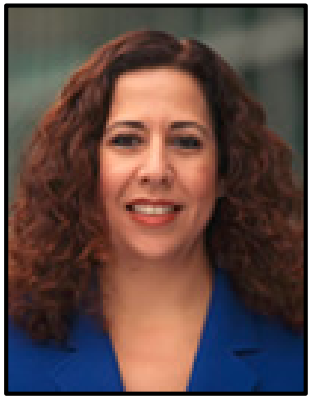
Determining the Temporal and Spatial Scales of Non-Stationarity in Temperature and Precipitation across the Continental United States

March 14, 2019

Welcome and Introductions



Rula A. Deeb, Ph.D.
Webinar Coordinator

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Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Kurt Preston, SERDP and ESTCP
- **Charting a Path for End-Users from the CMIP Ensemble Projections to Facility-Level Risks from Non-Stationarity in Temperature and Precipitation Distributions** (25 minutes + Q&A)
  Dr. Daniel Feldman, Lawrence Berkeley National Laboratory
- **Next-Generation Rainfall IDF Curves for the Virginian Drainage Area of Chesapeake Bay** (25 minutes + Q&A)
  Dr. Xixi Wang, Old Dominion University
- **Final Q&A session**

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  - Key in Ctrl + F5 to do a hard refresh of your browser
- If connecting to computer audio
  - Click the arrow next to the "*Join Audio*" button
  - Select test "*Speaker and Microphone*"
  - Follow prompts
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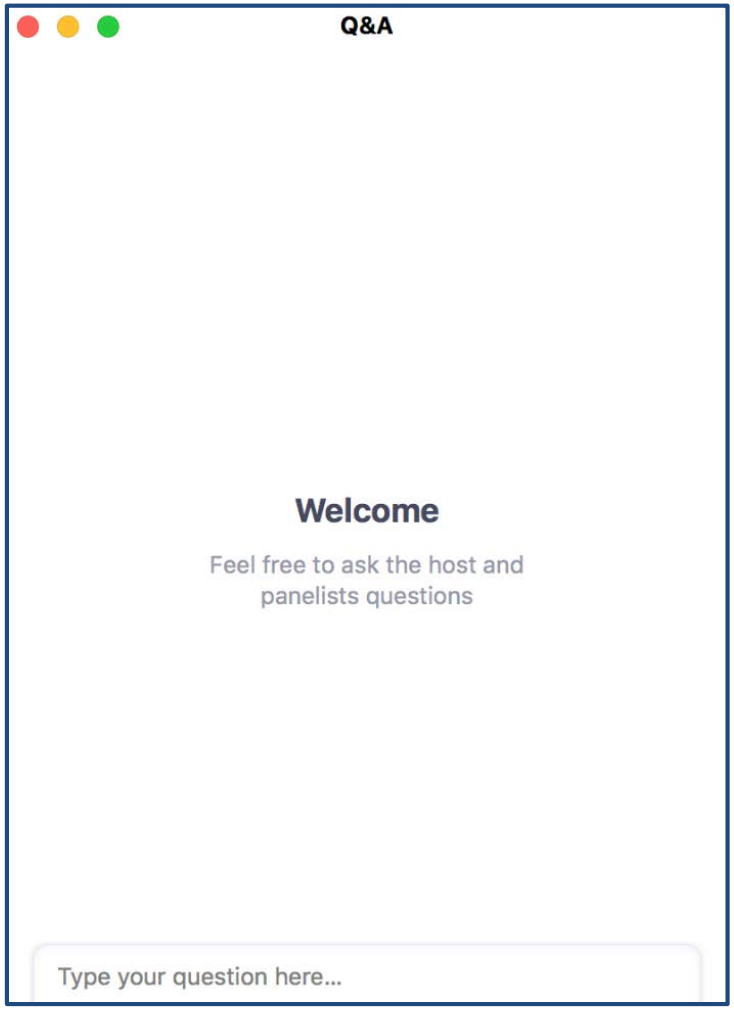
- Make sure to add your organization name at the end of your question so that we can identify you during the Q&A sessions



SERDP and ESTCP Overview

Kurt Preston, Ph.D.
Resource Conservation and Resiliency Program Manager

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SERDP

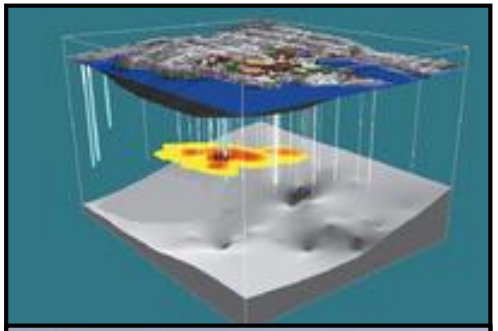
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

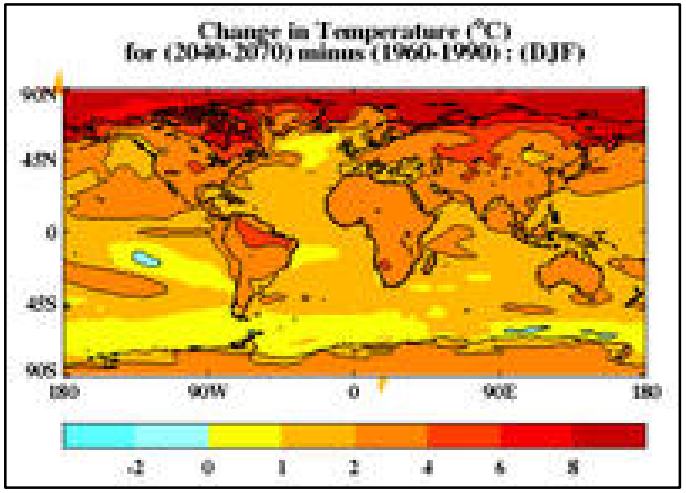
Program Areas

1. Environmental Restoration
2. Installation Energy and Water
3. Munitions Response
4. Resource Conservation and Resiliency
5. Weapons Systems and Platforms



Resource Conservation and Resiliency

- Natural resources
  - Ecological forestry
  - Arid lands ecology and management
  - Cold regions ecology and management
  - Pacific island ecology and management
  - Coastal and estuarine ecology and management
  - Living marine resources ecology and management
  - Species ecology and management
  - Watershed processes and management
- Resilience
  - Vulnerability and impact assessment
  - Adaptation science
  - Land use and carbon management
- Air quality
  - Wildland fire dynamics
  - Fugitive dust



SERDP and ESTCP Webinar Series

Date	Topic
April 11, 2019	Managing Contaminated Sediments: Passive Sampling Methods and In-Situ Treatment
April 25, 2019	Accelerated Corrosion and Ageing Studies
May 9, 2019	Roles of Soil Microbial Communities in Ecosystem Restoration
May 23, 2019	Treatment Options for the Emerging Contaminants 1,2,3-Trichloropropane and 1,2-Dibromoethane
June 6, 2019	Developing and Demonstrating Non-Toxic Paints for Corrosion Protection
June 20, 2019	Developing Adaptation Strategies to Address Climate Change and Uncertainty

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Save the Date!

SERDP • ESTCP
SYMPOSIUM

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

December 3-5, 2019
Washington Marriott Wardman Park

Registration information available soon

Charting a Path for End-Users from the CMIP Ensemble Projections to Facility-Level Risks from Nonstationarity in Temperature and Precipitation Distributions

Daniel Feldman, Ph.D.
Lawrence Berkeley National Laboratory

Agenda

- Coupled Model Intercomparison Project (CMIP) overview
- From CMIP ensemble to facility-level projections
- Avoiding biases in model bias-correction
- Downscaling methods and stationarity assumptions
- Regional and local considerations as CMIP6 data become available

Benefits to DoD

- Changes in temperature and precipitation means and extremes can be damaging to infrastructure and operations
- Nonstationarity at the local and regional level (where it matters) are difficult to assess with coarse climate models
- This project helps users navigate the climate modeling and downscaling landscape to build towards developing local temperature and precipitation distributions for the 21st Century

CMIP Overview

- Surface air temperature, precipitation projections
  - Derived from dozens of climate model runs
  - Different emissions scenarios
- Models exhibit varying levels of skill in reproducing observed global changes
- Models performance is correlated
  - Good where physics is shared
  - Bad where errors are shared

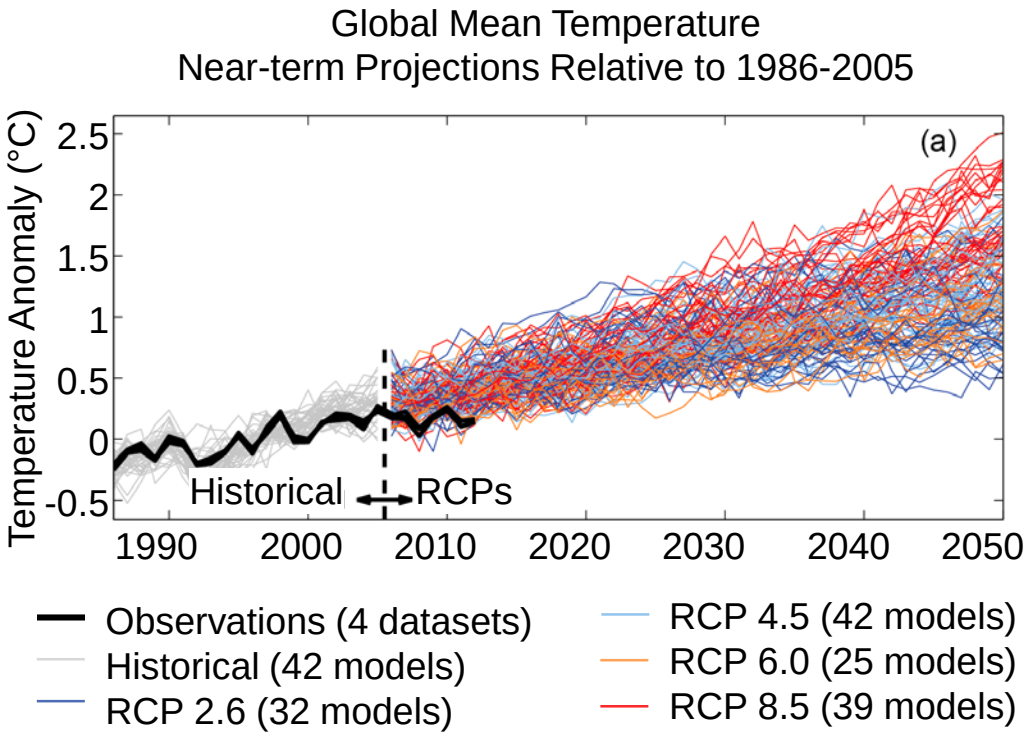


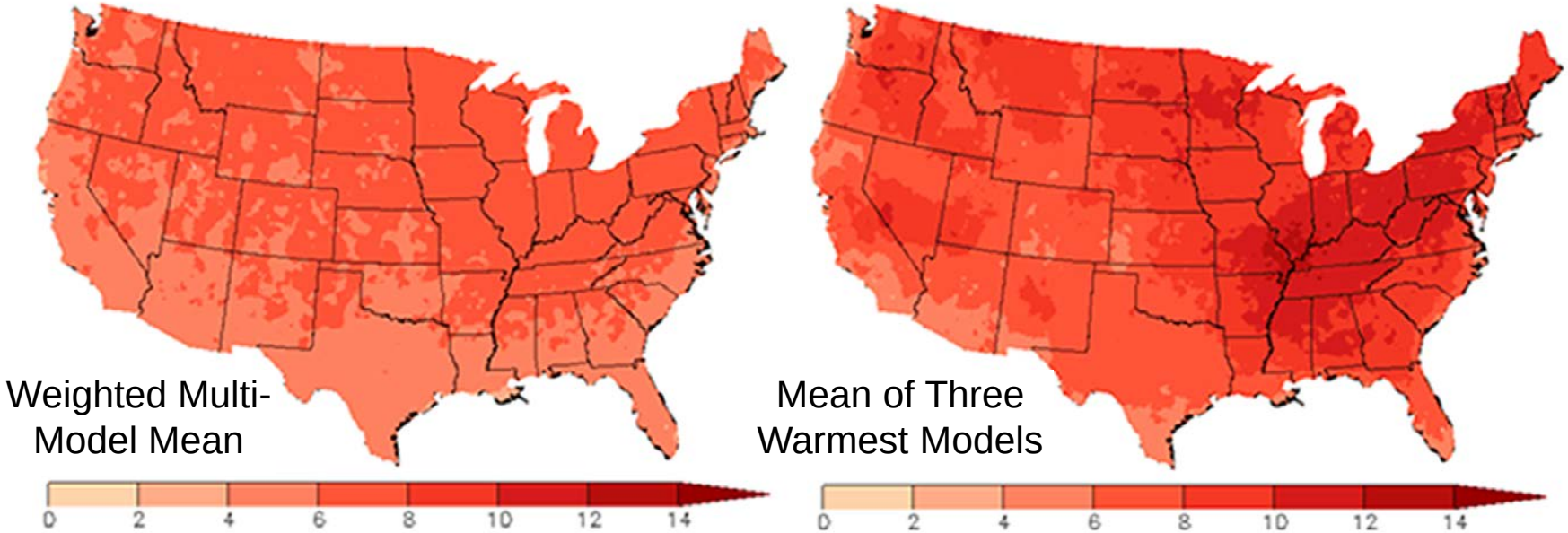
Image Source: IPCC Fifth Assessment Report

Note: RCP = Representative Concentration Pathway

Accounting for Model Spread

Project Change in Warmest Temperature of the Year

Mid 21st Century, Higher Scenario (RCP8.5)



- Models can be weighted by historical performance for a target variable
- Model interdependence must also be considered

Image Source: 4th National Climate Assessment

Accounting for Model Spread

- Data points show different models
  - Skill weight is derived from differencing a model vs. historical observations
  - Independence is derived from how correlated model biases are with each other
- No model exhibits high skill and high independence from the others (upper right quadrant)

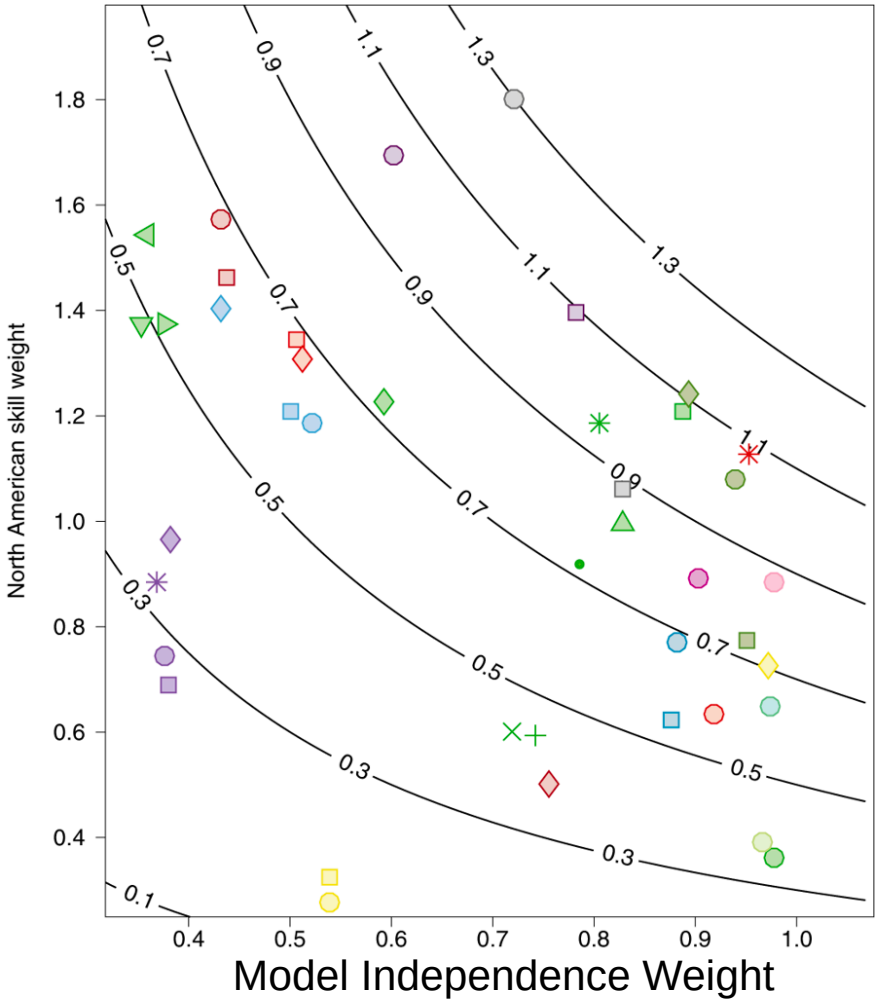
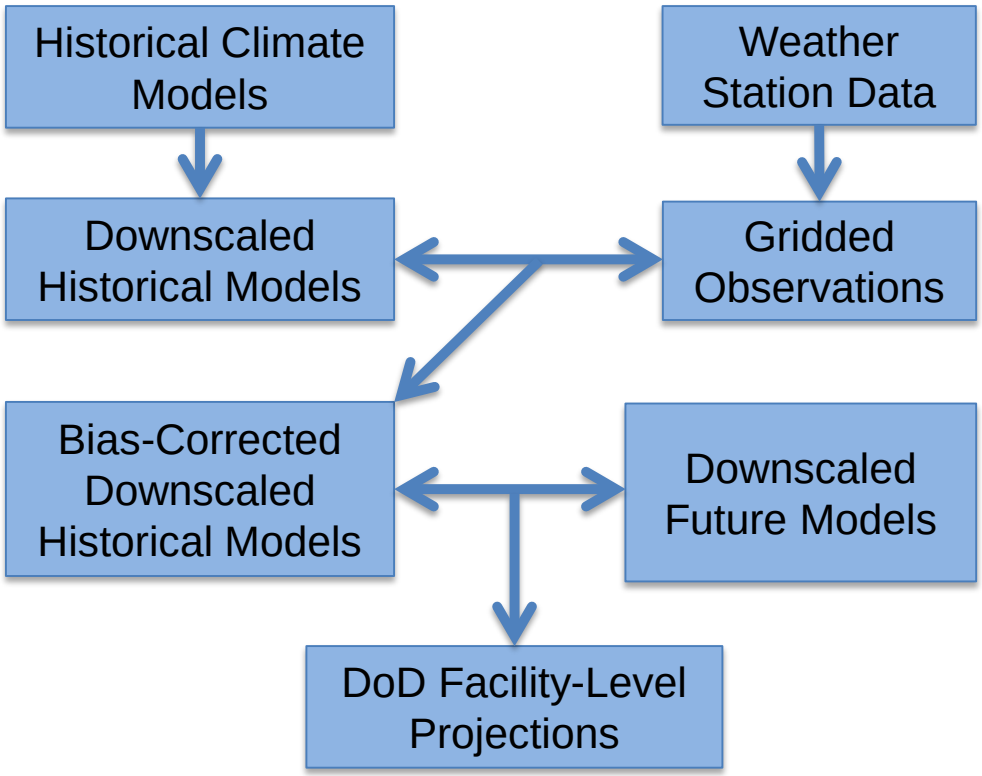


Image Source: Eyring et al., Nat. CC, 2019

From Global to Local Scales

- Large-scale climate change predictions → local weather impacts
  - Non-trivial task
  - Process involves multiple steps
    - o Bias-correct and downscale models to create local projections.
    - o Need to critically evaluate every process step of the process

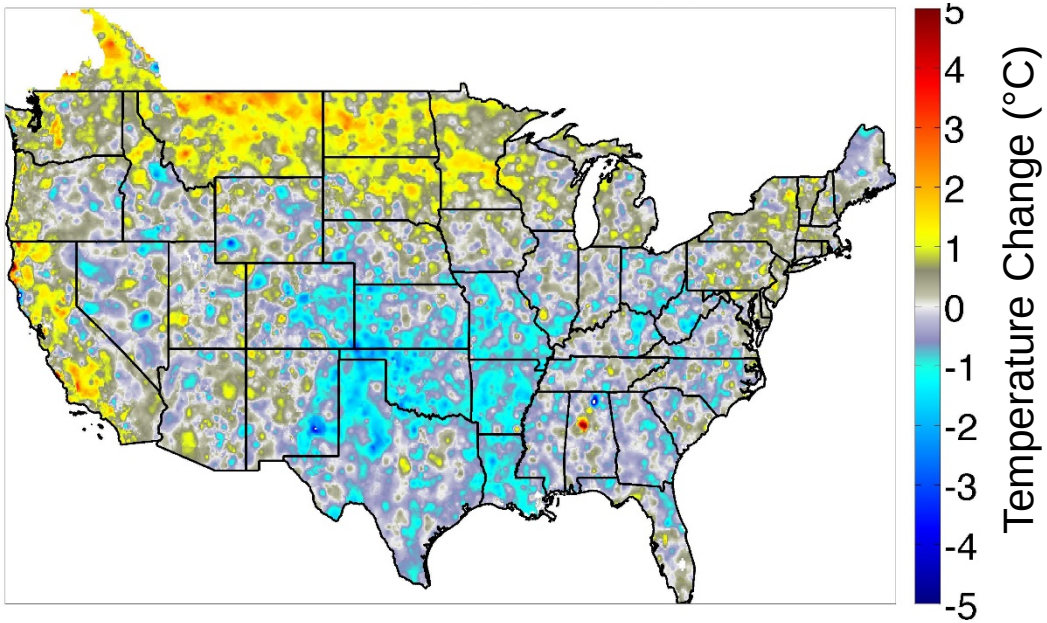


Regression Approach to Construct Distributions

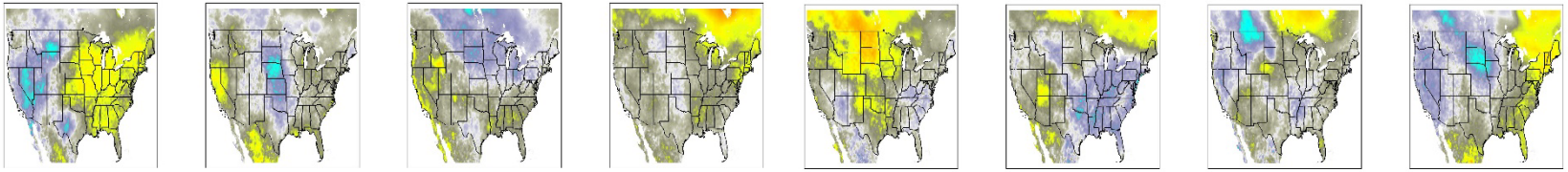
- Use bias-corrected models downscaled with Localized Constructed Analogues (LOCA)
- Weight models based on:
  - Historical performance
  - Independence
- Use weighted model ensemble to develop temperature, precipitation distributions

Model Historical Performance is Mixed

Observed Δ 20-year Return – Maximum Temperature
(1980:2005)-(1950:1979)



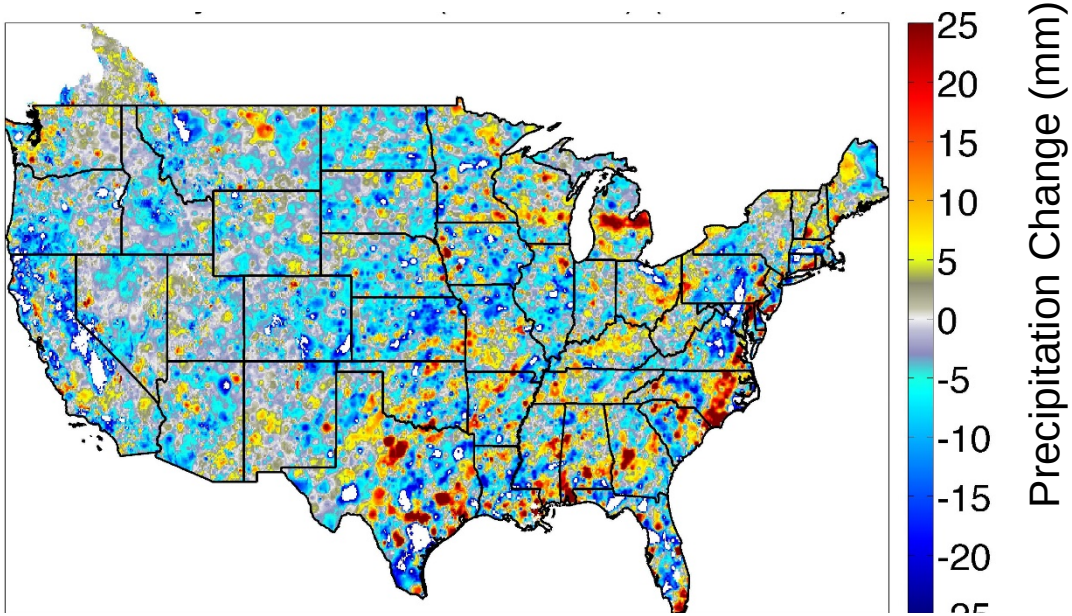
ACCESS 1-0 | CanESM2 | CESM1-BGC | CMCC-CMS | GFDL-CM3 | HadGEM2-CC | HadGEM2-ES | MIROC5



Models less interdependent on temperature than on precipitation

Model Historical Performance is Mixed

Observed Δ 20-year Return – Precipitation
(1980:2005)-(1950:1979)



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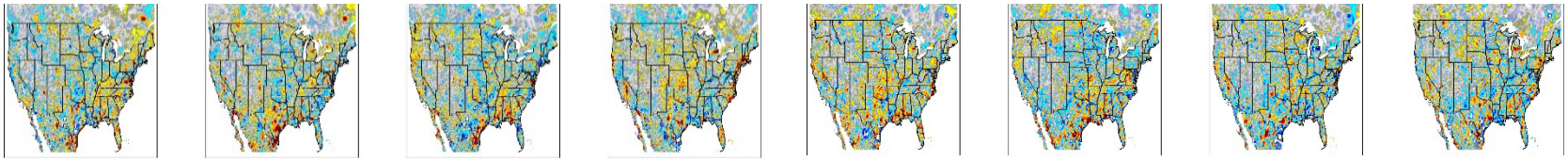


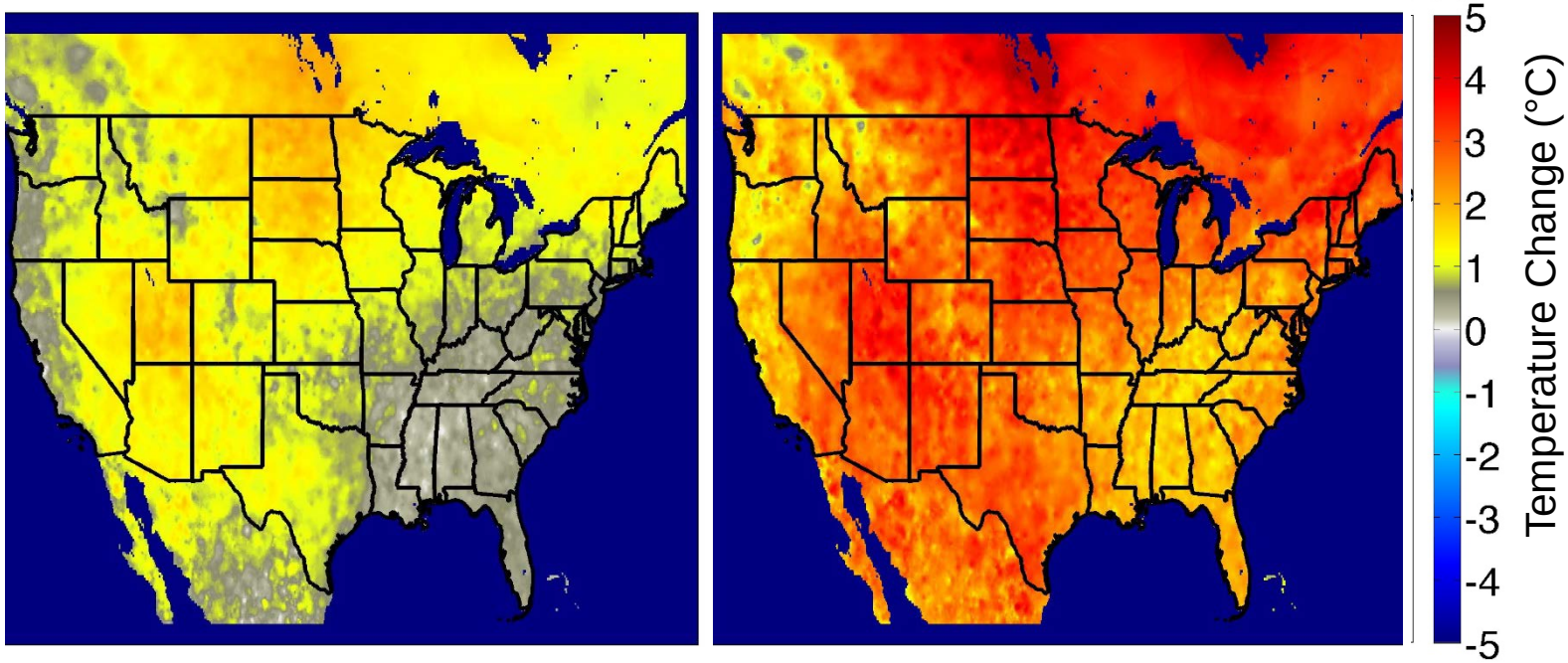
Models less interdependent on temperature than on precipitation

Return Values

Temperature

Observed Δ 20-year Return – Maximum Temperature

RCP 4.5 RCP 8.5



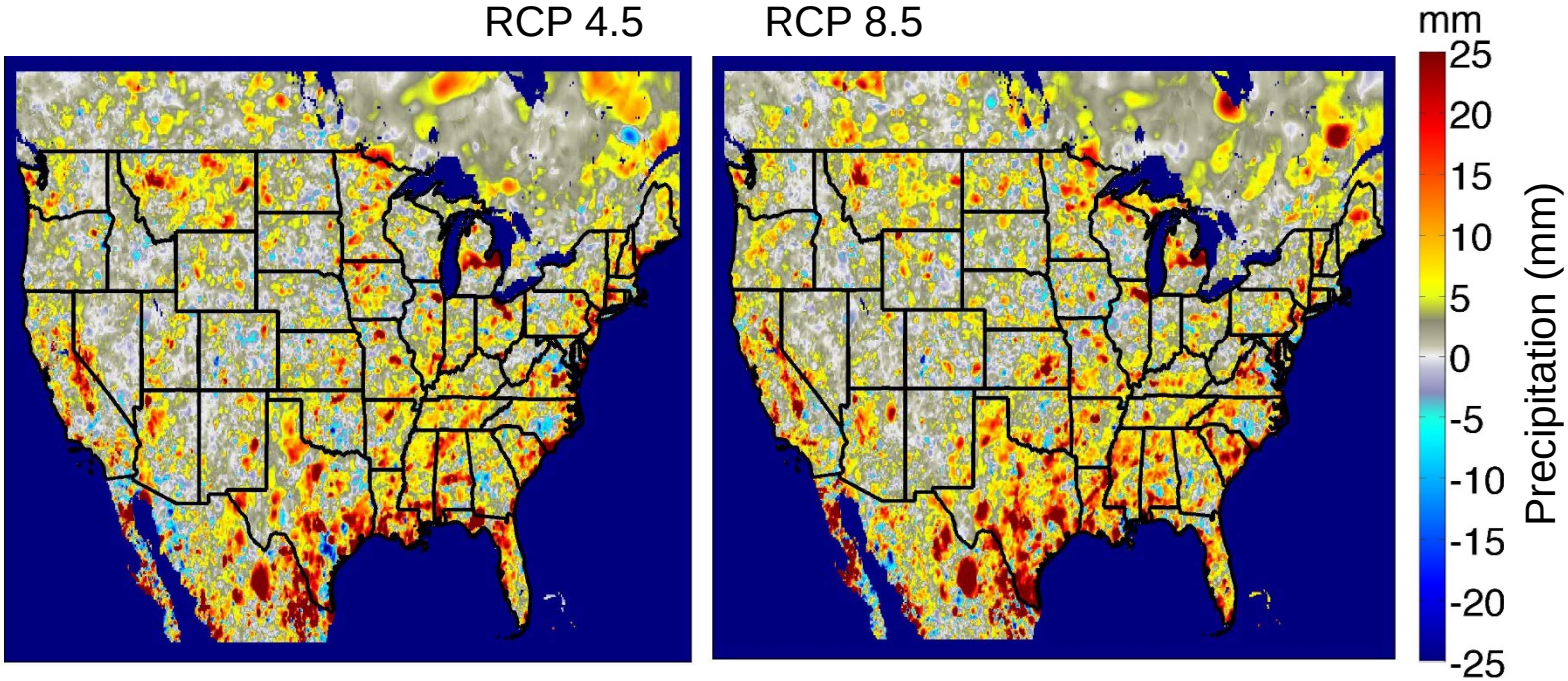
- Using this framework, change in daily temperature 20-year return values change from 1980-2005 to 2056-2085
  - 3+ degrees warmer with RCP8.5 vs. RCP4.5

Return Values

Precipitation

Observed Δ 20-year Return – Precipitation

RCP 4.5 RCP 8.5



- Precipitation extremes also change from 1980-2005 to 2056-2085 and roughly scale with emissions scenario
- But how much confidence can we have in these projections?

Revisiting Key Assumptions

Bias Correction

- Model biases
  - Identified through observationally-derived datasets
  - Based on station data
- GHCN provides such data
  - Thousands of time-series of direct observations from discrete weather stations
- Traditional methods to grid data include
  - Bi-linear interpolation
  - Distance-weighting
  - Ordinary kriging

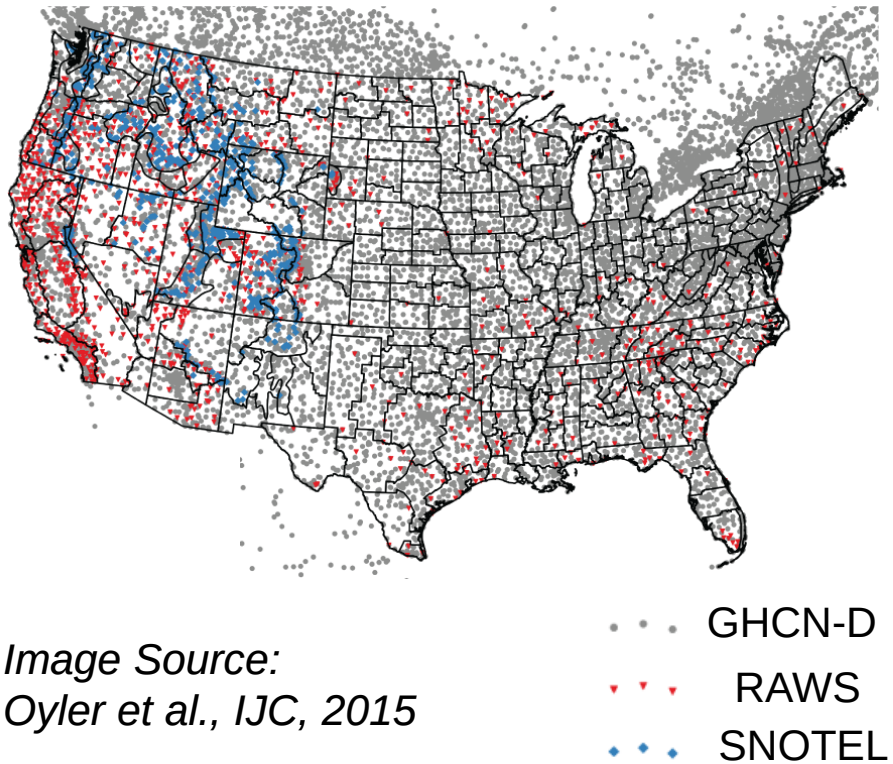


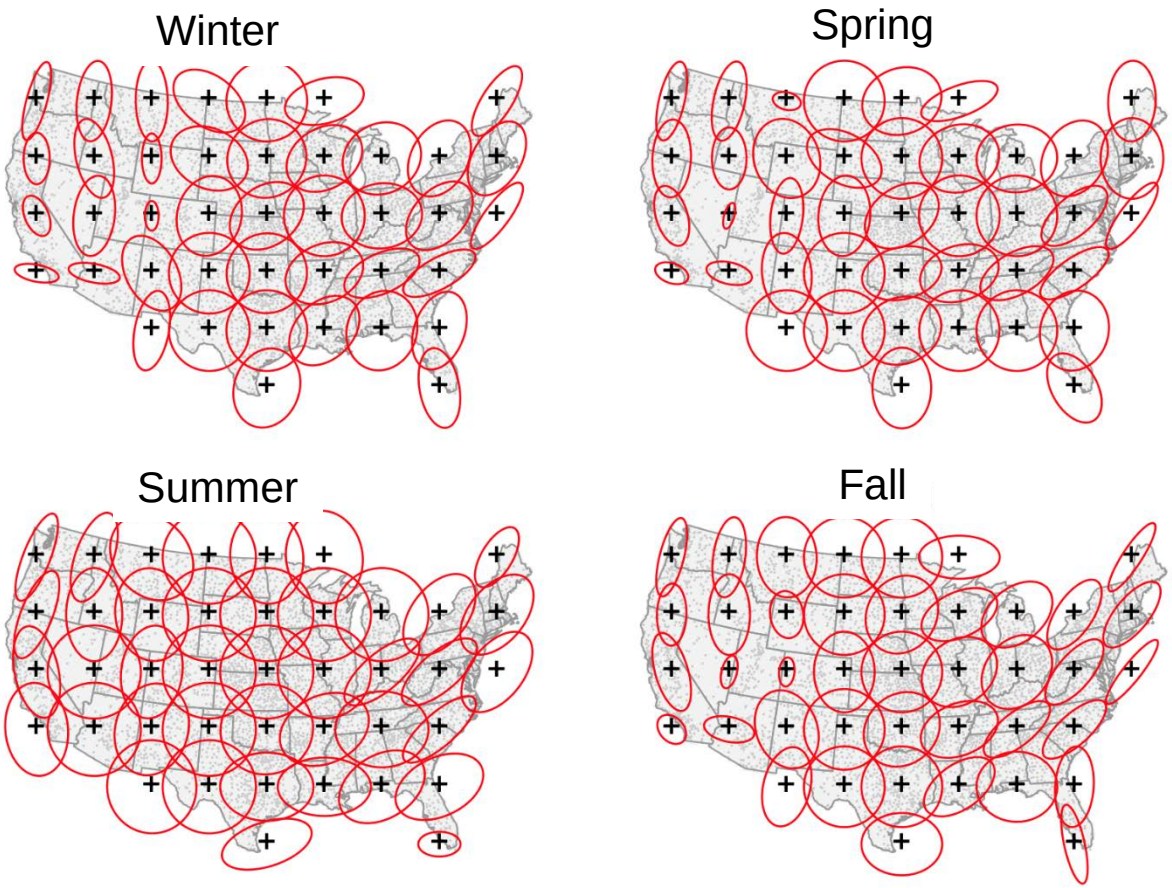
Image Source:
Oyler et al., IJC, 2015

Notes: GHCN = Global Historical Climatology Network; RAWS = Remote Automated Weather Stations; SNOTEL = Snow Telemetry

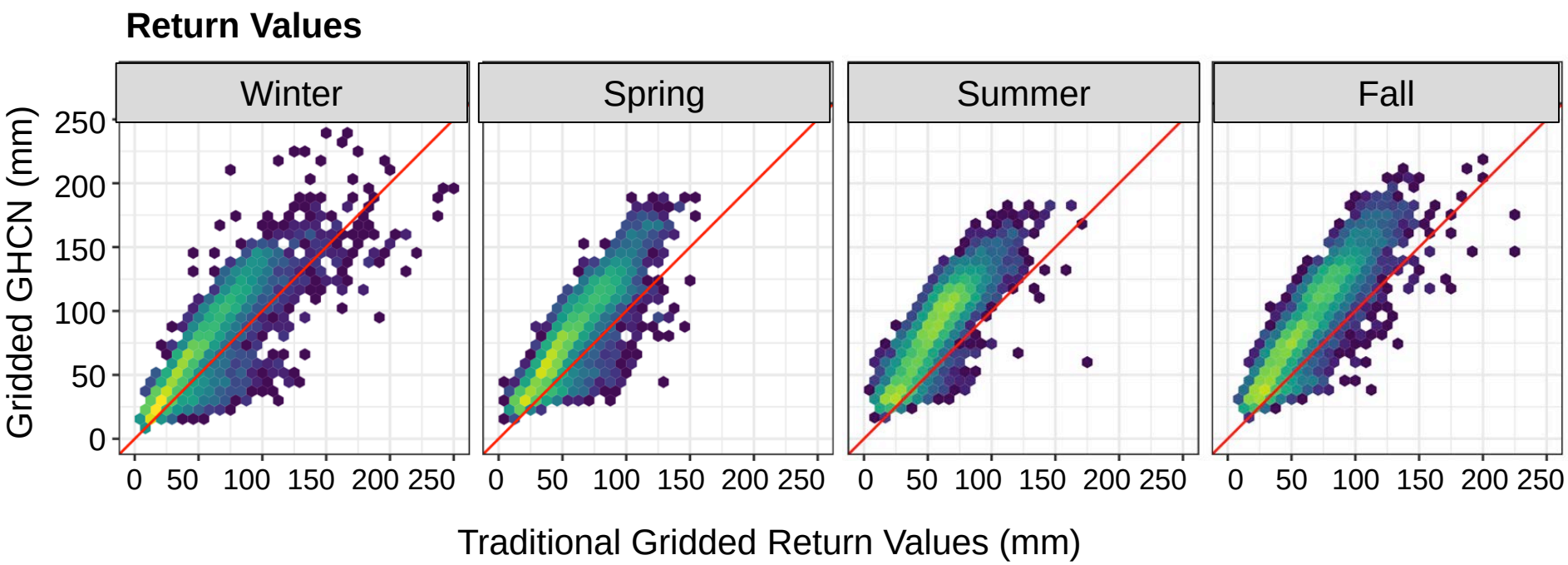
Gridding to Preserve Extreme Precipitation

Proceed with Caution!

- Extreme precipitation is spatially correlated in the CONUS
  - Anisotropic correlation
  - Seasonal variation
- Traditional gridding of discrete station data will spread out localized extremes over multiple grid cells



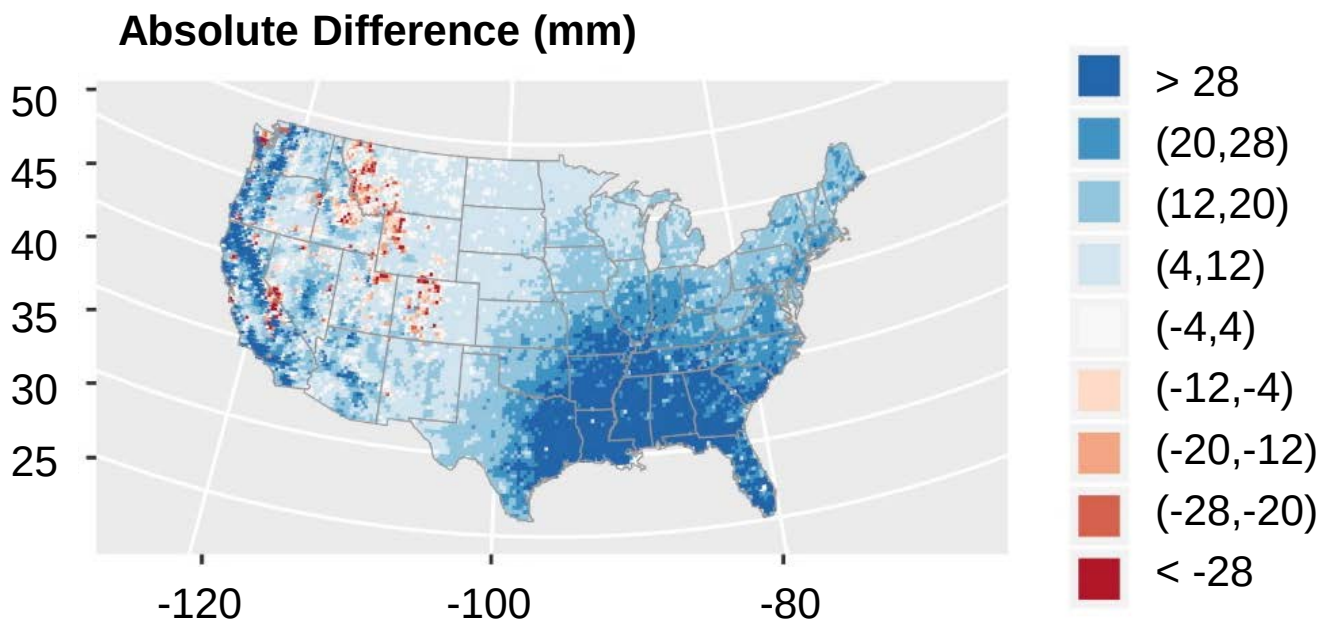
Unbiasing Precipitation Bias Correction



Methods that assume isotropy generally underestimate extreme precipitation

Unbiasing Precipitation Bias Correction

- Statistical model that admits spatial anisotropy
  - From this, we produced a probabilistic gridded product



The historical record must be interpreted carefully, since future projections critically rely on this record

Revisiting Key Assumptions

Stationarity in Downscaling

- Climate model spatial resolution is ~ 100 km^2
  - Too coarse for local decision-making
  - Need downscaling approaches
- One widely-used statistical downscaling approach is LOCA
  - Evaluates coarse model and selects analogue observational days for coarse-to-fine relationship. Implicit assumption of stationarity

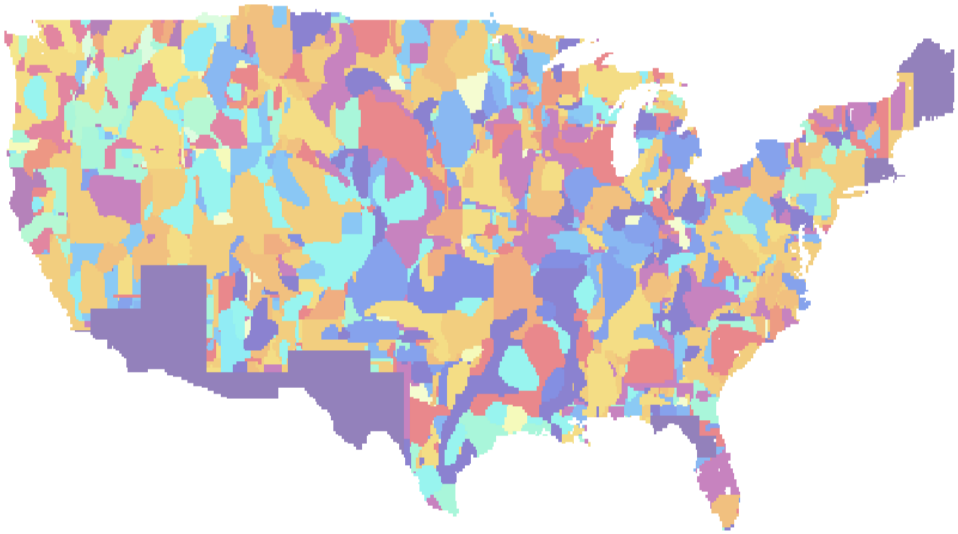
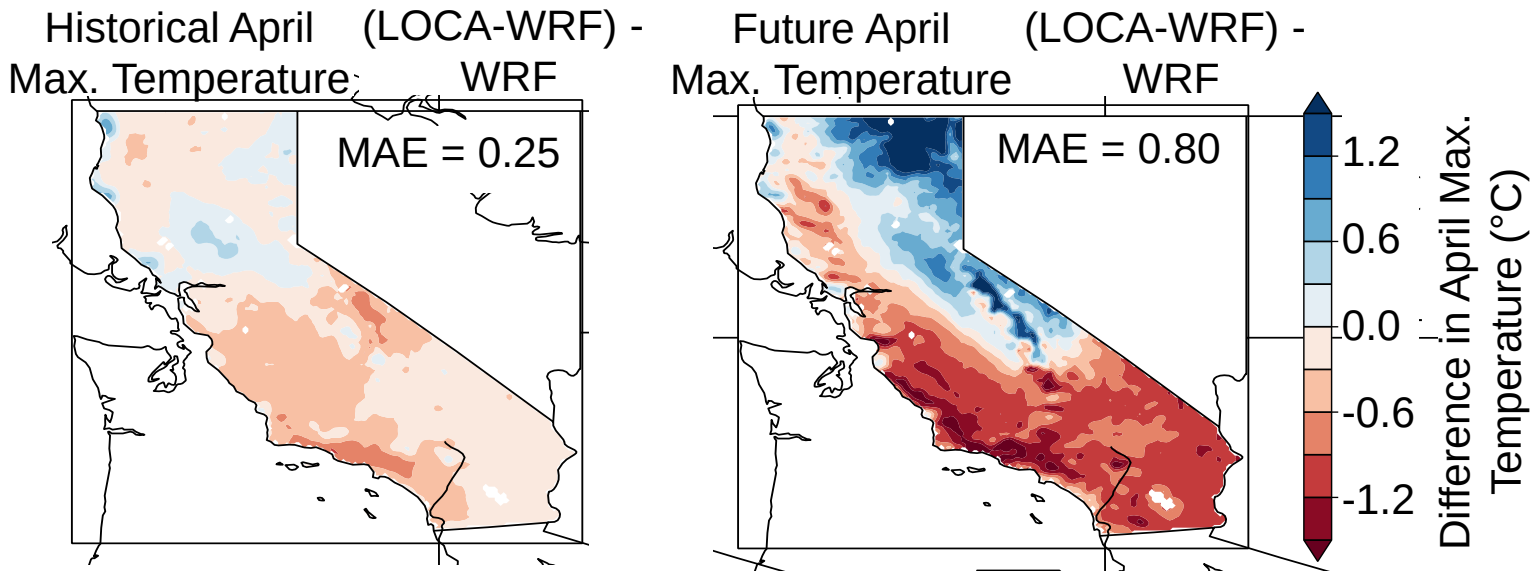


Image Source: Pierce et al., J. Hydromet., 2014

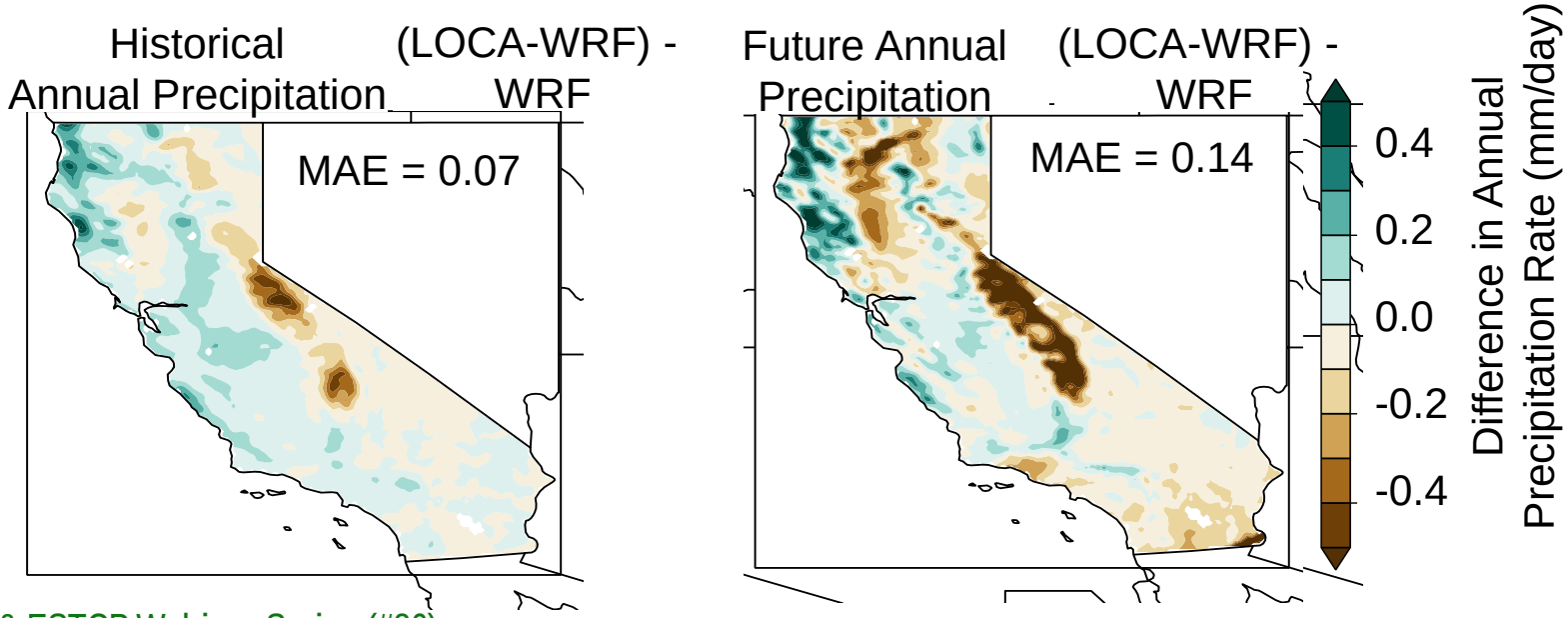
Divergence Between Downscaling Methods

- LOCA trained on historical record
- Dynamical downscaling is computationally-expensive
- WRF dynamical downscaling agrees with LOCA for present-day conditions, but disagrees in late 21st century
  - Over California, mean absolute error (MAE) triples for temperature

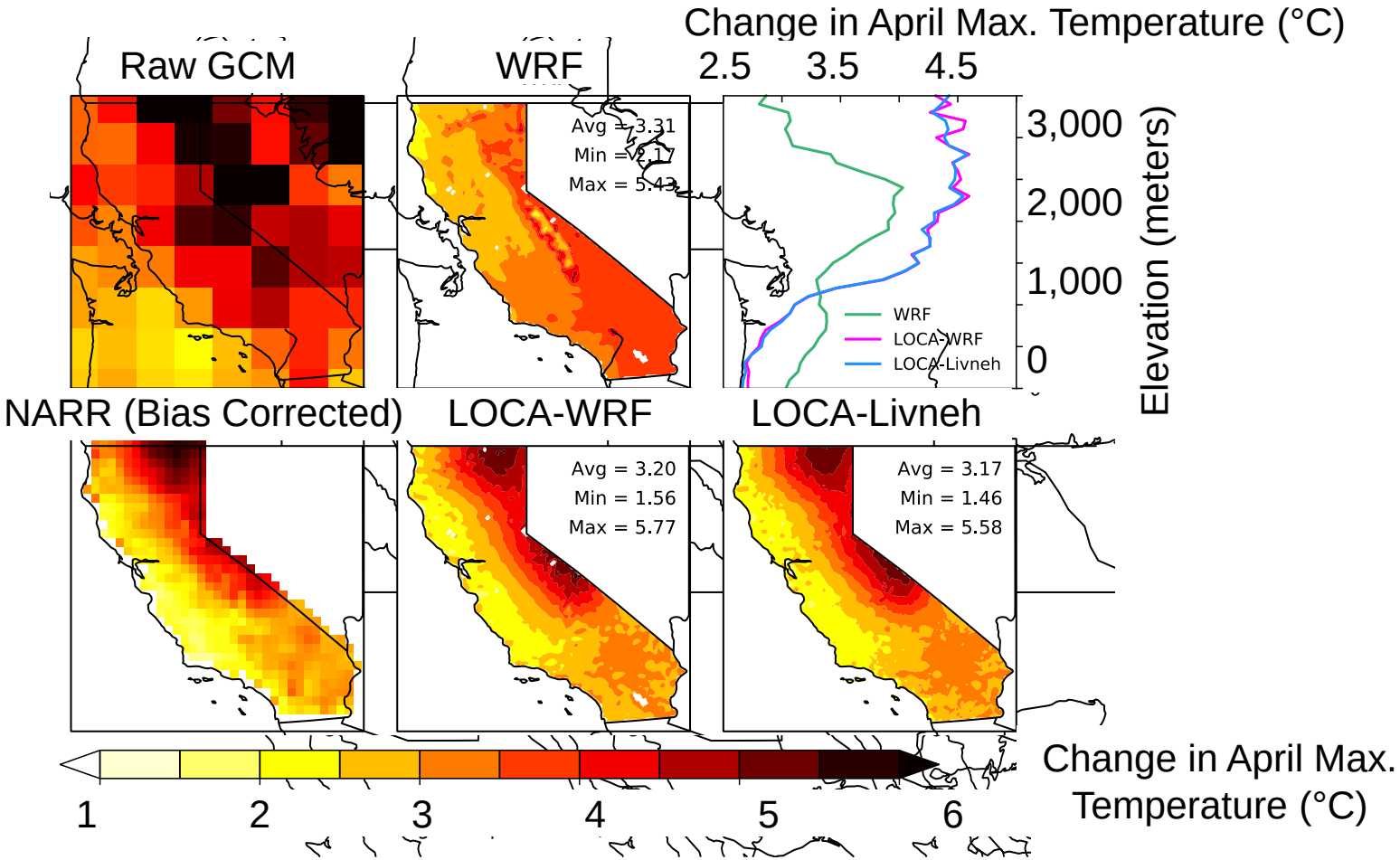


Divergence Between Downscaling Methods

- MAE doubles for precipitation by late 21st Century
- Why is historical performance a poor predictor for future projections?
  - A deeper dive is needed to understand why downscaling errors apparently grow
  - Is it downscaling or problems with the parent model or a combo?



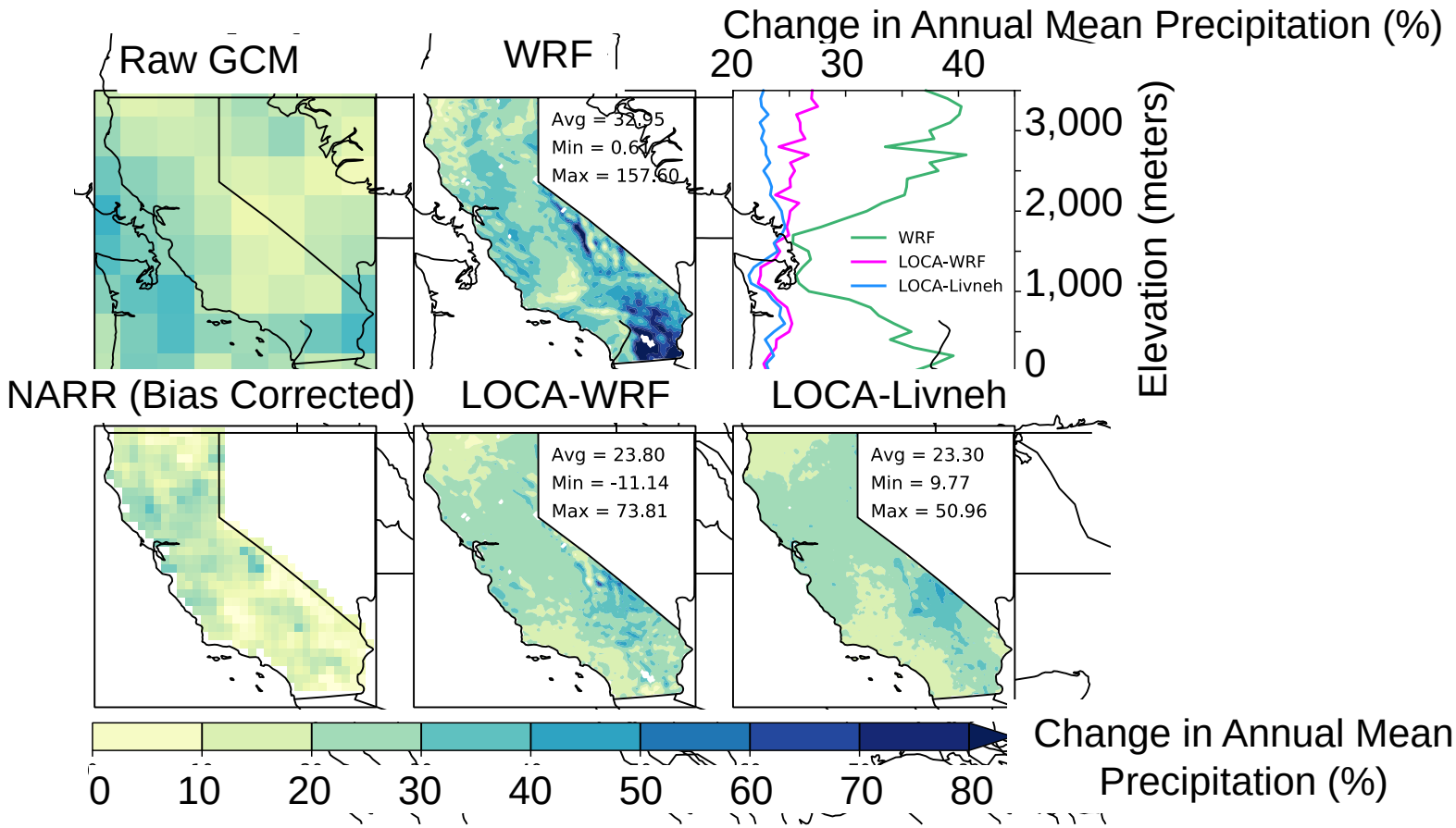
Process Biases Exist in the Parent Model



All statistical downscaling solutions differ from the dynamical solution because the model has a crude representation of the Sierra and gets the snow-albedo feedback wrong

Notes: GCM = General Circulation Model; NARR = North American Regional Reanalysis

Process Biases Exist in the Parent Model



Statistical downscaling or hybrid methods may underestimate local changes

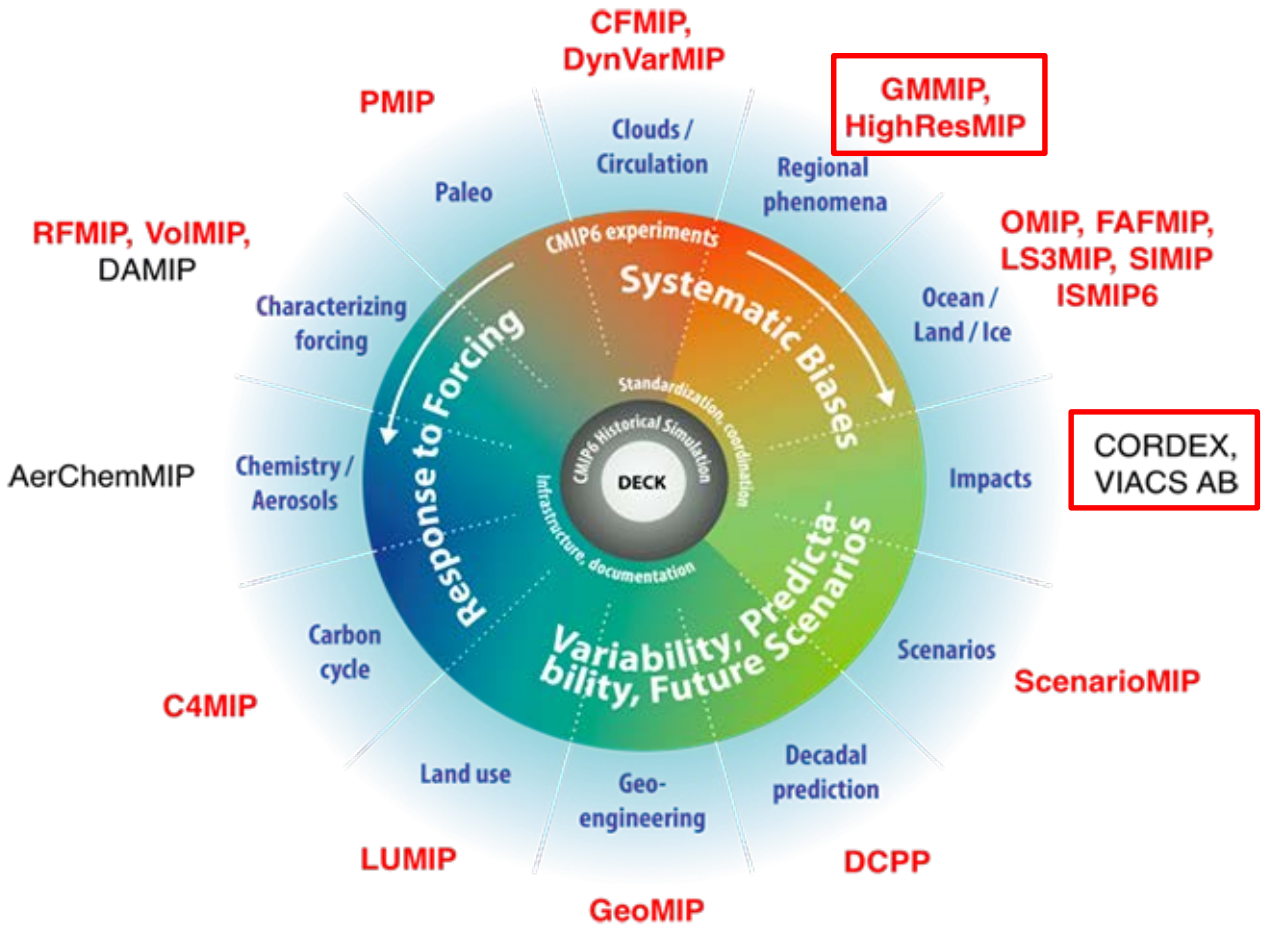
Dynamical downscaling will reveal error growth with space and time

Addressing Model Process Biases

- A deeper dive is needed to understand why apparent errors in downscaling grow
- Coastal and mountainous gradients not resolved by the parent model
- These inter-comparisons show the need dynamical downscaling for those facilities and north-south gradients
  - Bias-correction sweeps parent model errors under the rug. Those errors re-emerge in future projections if statistical methods are used

Preparing for CMIP6

20 - 40 petabyte estimated data volume



Results may reveal potential underestimation of risk to DoD facilities from stationarity assumptions

Image Source: Eyring et al., GMD, 2016

Conclusions

- Many process steps from ensembles of climate model runs to facility-level risk
  - Must carefully examine each step
  - First step – weight models by historical performance and independence
- Exercise caution when
  - Using gridded observational products for bias correction
  - How downscaling approaches are utilized to avoid re-emergence of parent model errors.
- CMIP6 experiments may reveal potential underestimation of facility-level risk under climate change

Acknowledgments

- Dr. Jovan Tadic, Lawrence Berkeley National Laboratory
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- Dr. Alex Hall, University of California, Los Angeles
- Dr. Dan Cayan, University of California, San Diego
- Dr. Dave Pierce, University of California, San Diego

For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Resiliency/Infrastructure-Resiliency/Vulnerability-and-Impact-Assessment/RC18-1577

Speaker Contact Information

drfeldman@lbl.gov; 510-495-2171

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Q&A Session 1

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Next-Generation Rainfall IDF Curves for the Virginian Drainage Area of Chesapeake Bay

Xixi Wang, Ph.D.
Old Dominion University

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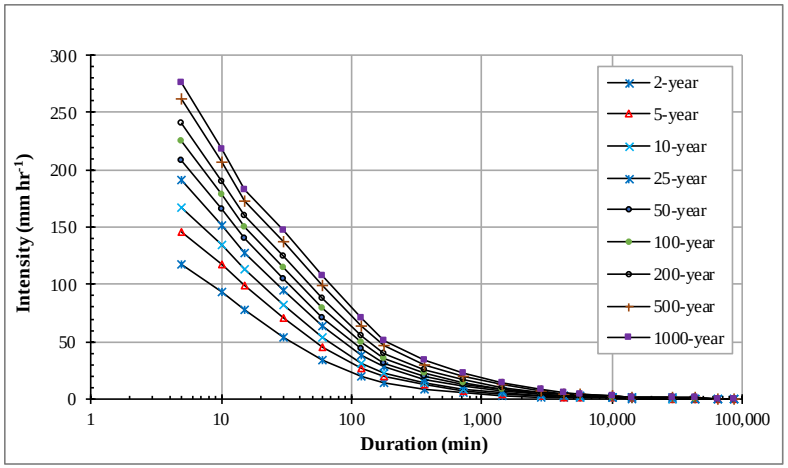
Agenda

- Introduction
- Benefits to DoD
- Goals and objectives
- Historical vs. next-generation IDF curves
- Approach, study site, data
- Methods
- Results
- Conclusions

Introduction

What Are IDF Curves

- IDF: Intensity-Duration-Frequency relationship
  - Intensity: rainfall per unit time
  - Duration: lasting time of a rainfall event
  - Frequency: percent chance to occur
- Return period: reciprocal of frequency
- Flood forecasting and management: 100-year
- Engineering plan and design: 50-year storm



Introduction

Why Next-Generation IDF Curves?

- Significant changes in rainfall characteristics
- Historical IDF curves assumed stationarity
- Infrastructure over- or under-designed
- Next-generation IDF curves needed but lacking

Image Source: The Associated Press, September 9, 2018

Benefits to DoD

- Acknowledge uncertainties resulting from climate non-stationarity
- Consider uncertainties
  - Planning of future DoD infrastructure
  - Design of ongoing DoD infrastructure
  - Management of existing DoD infrastructure
- Guard against over- or under-committing resources

Image Source: Harmon et al., 2014

Goals and Objectives

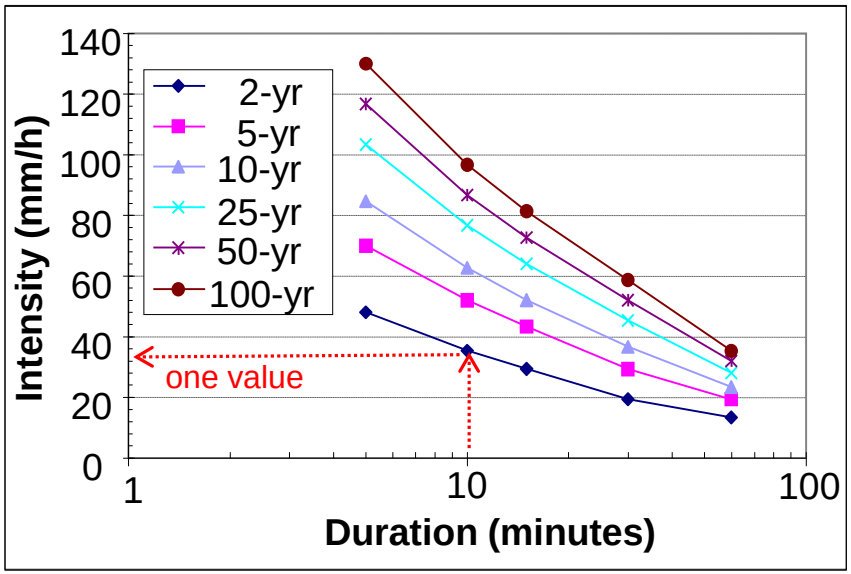
- Advance understanding of climate non-stationarity
- Improve infrastructure planning, design and management
- Develop approach for probability-based IDF curves
- Create next-generation IDF curves for Virginia

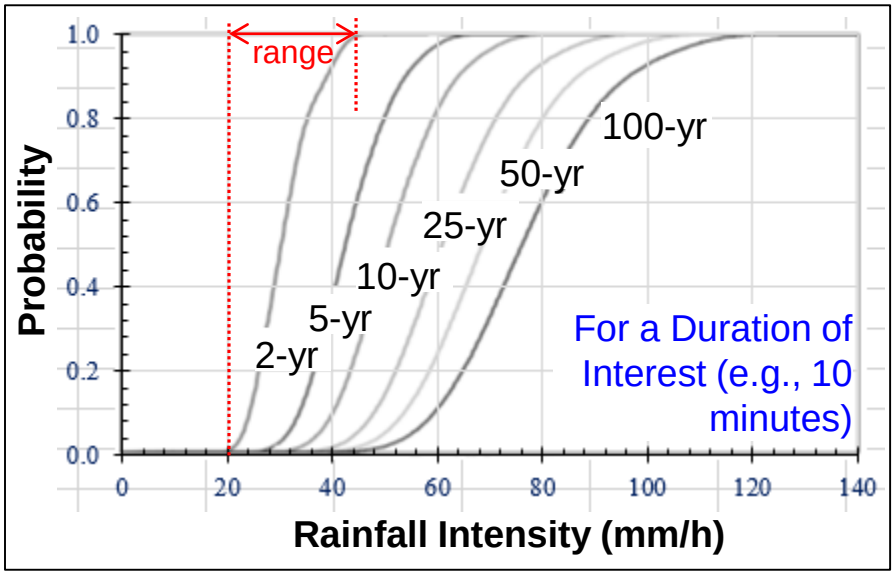
Image Sources: militarybases.com and en.Wikipedia.org

Historical IDF vs. Next-Generation IDF

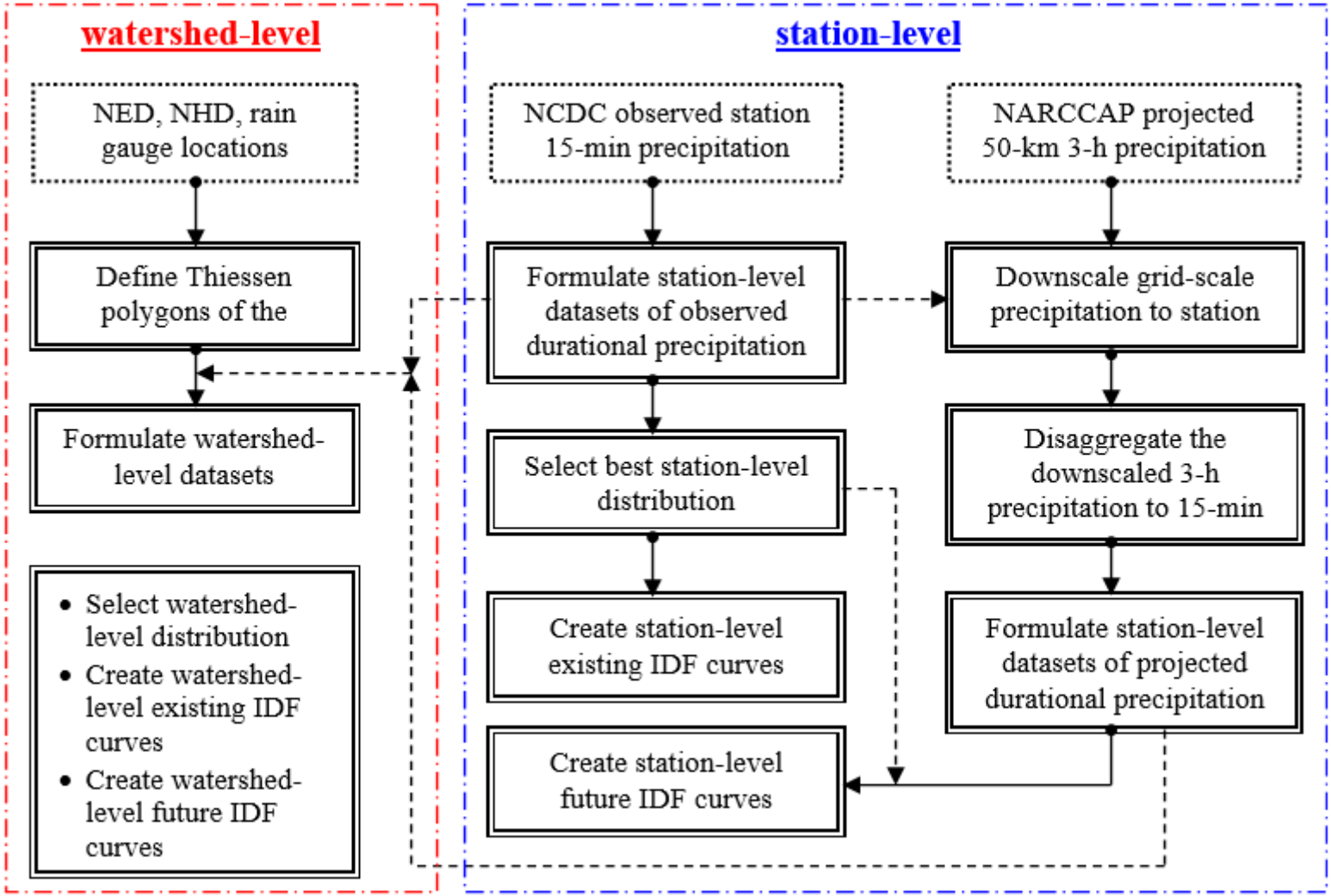
- Developed with observed rainfall
- Deterministic
- Stationary climate

- Developed with observed and predicted rainfall
- Probability-based
- Non-stationary climate





Overall Approach



Study Site

Chesapeake Bay

Climatic Division:

- Central Mountain
- Eastern Piedmont
- Northern
- Southwestern Mountain
- Tidewater
- Western Piedmont

Physiographic Division:

- Appalachian Plateaus
- Blue Ridge
- Coastal Plain
- Piedmont
- Valley and Ridge

Notes: Map symbols show rain gauges

Data

- NHD from USGS
- 57 gauges from NCDC
  - 15-minute precipitation
- Twelve RCM-GCMs
  - 3-hour 50-kilometer predicted precipitation
  - NARCCAP operated the models

Notes:

NHD = National Hydrograph Dataset; USGS = United States Geological Survey;
NCDC = National Climatic Data Center;
RCM = Regional Climate Model; GCM = general circulation model;
NARCCAP = North American Regional Climate Change Assessment Program

Methods

- Filling missing values
- Detection of trend and non-stationarity
  - Modified Mann-Kendall
- Selection of best statistical distribution by gauge
  - Gumbel
  - Fréchet
  - Weibull
- Downscaling/disaggregating RCM-GCM predictions
- Creation of IDF curves
  - Gauge-level historical
  - Watershed-level historical
  - Gauge-level probability-based
  - Watershed-level probability-based

Methods

- Non-stationarity tested on cumulative deviations from overall mean
- Kolmogorov-Smirnov (K-S) test for distribution selection
- Four grids around a gauge for downscaling
- Regressions over 3-hour predictions for disaggregating
- Thiessen polygons for calculating areal precipitation

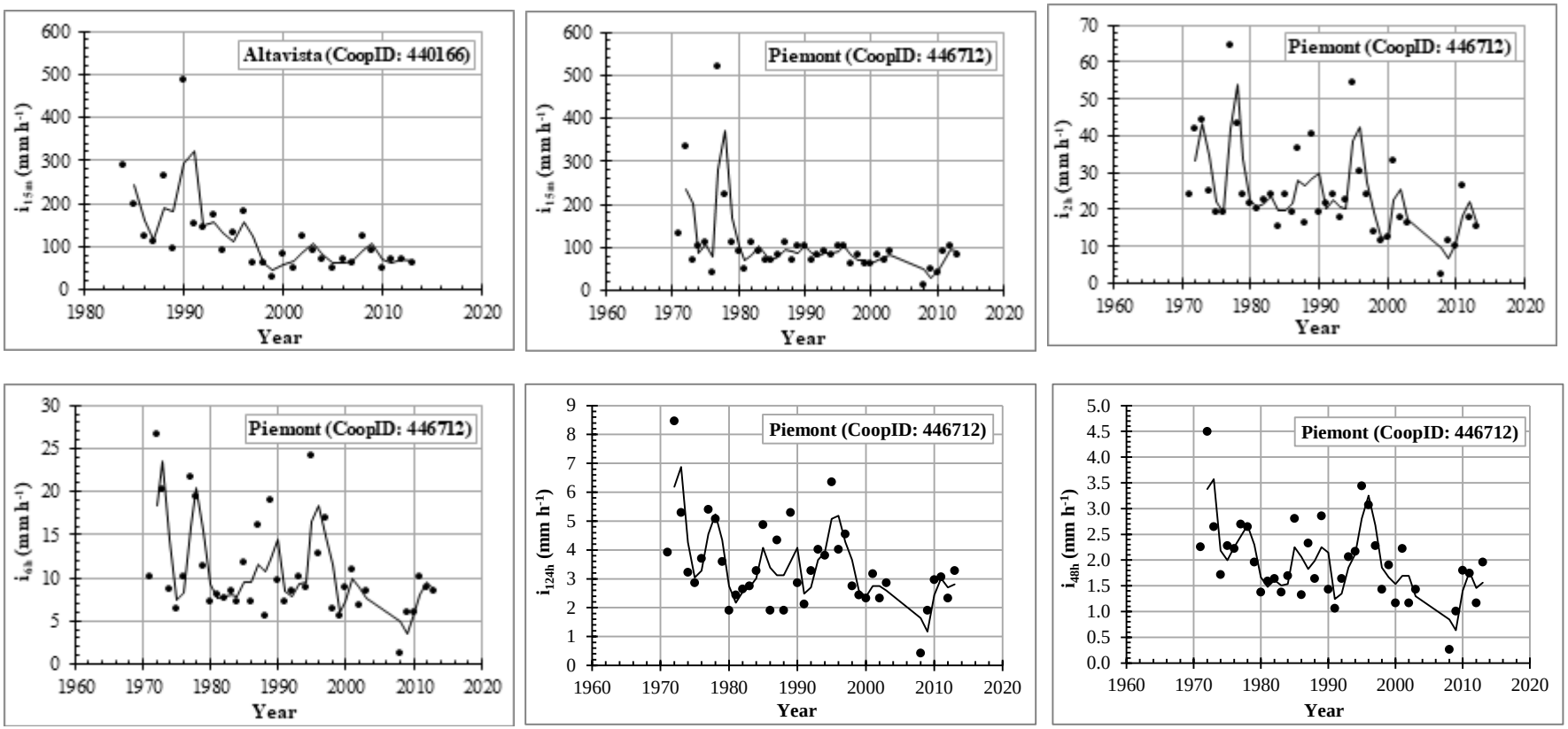
Results

Trend and Non-Stationarity

- 11 gauges: significant decreasing trend of intensity
- One gauge: significant increasing trend
- All gauges: no step changes
- Four gauges: significant non-stationarity
- Annual decreasing rate
  - 0.01 to 2.54 mm/hr
- Interannual variation decreasing → larger runoff volume
- Historical IDF → oversize peak-controlled but undersize volume-controlled structures

Results

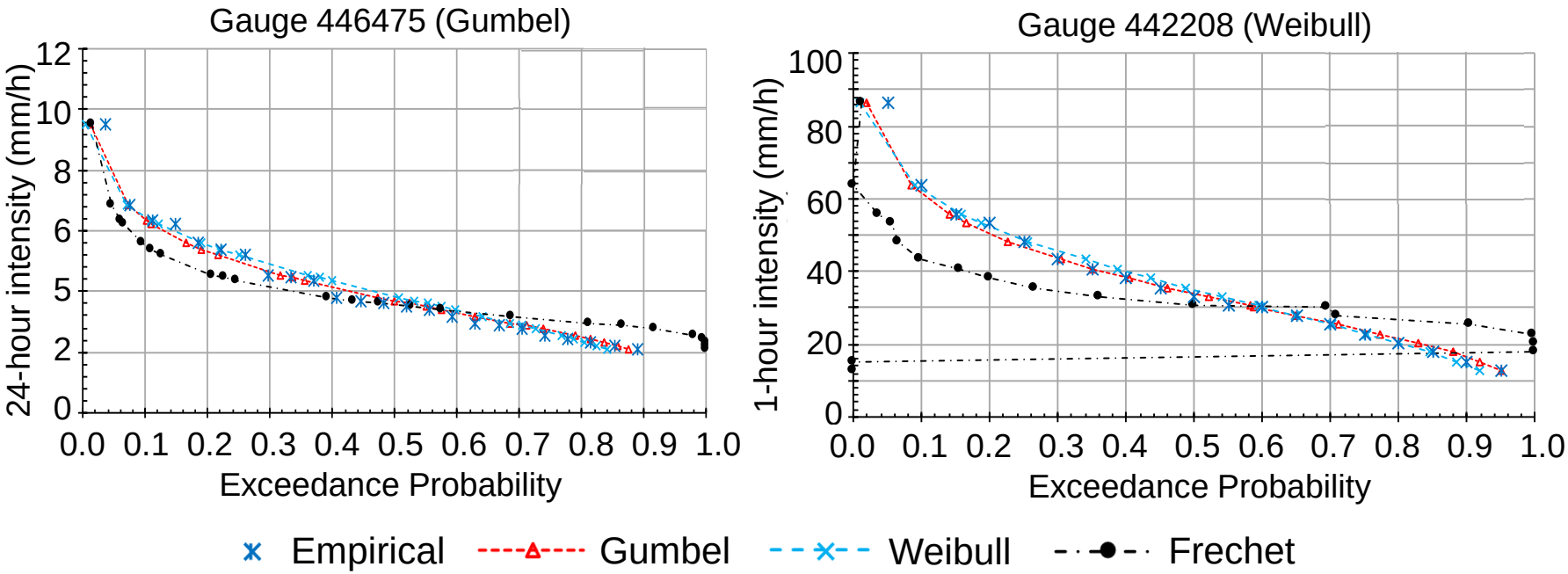
Trend and Non-Stationarity



- For a gauge, decreasing rate larger for shorter duration
- More decreasing trends for durations <1 hour

Results

Best Distribution

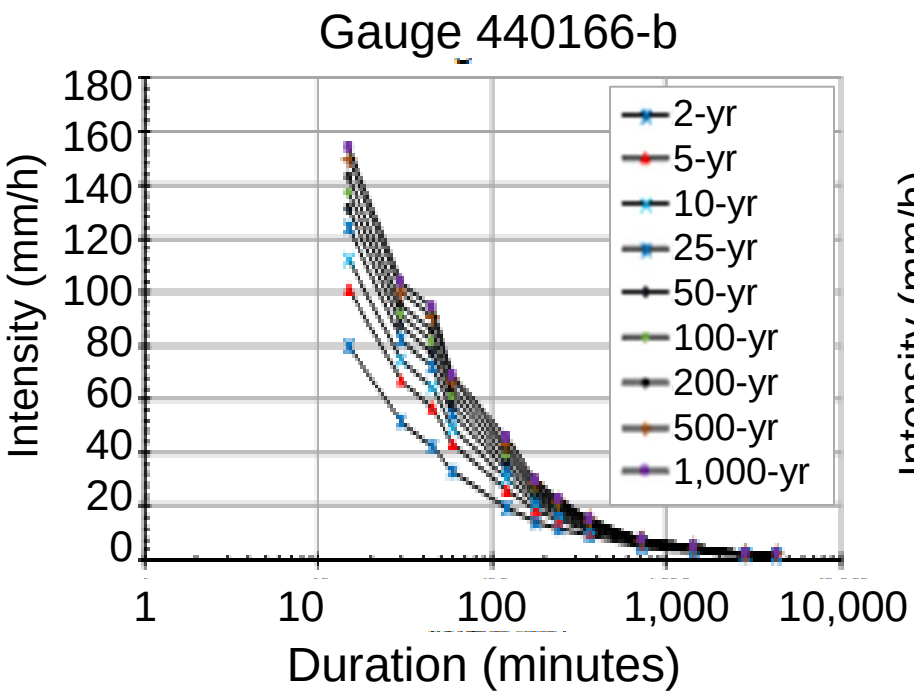


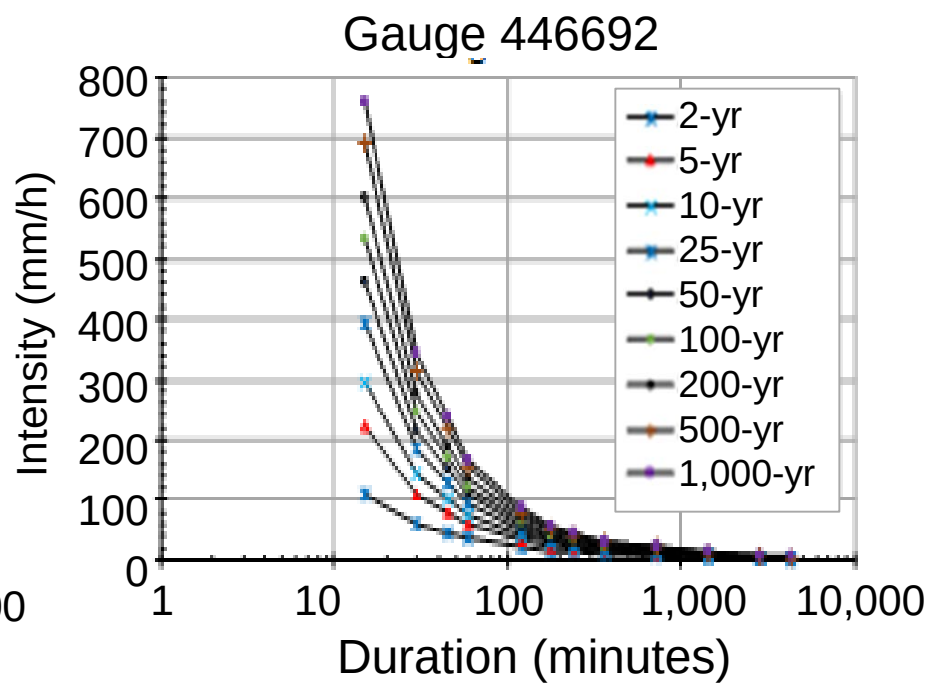
Number of Gauges – Best Distribution

- 30 Gumbel
- 23 Weibull
- 4 Both

Results

Gauge-Level Historical IDF





- Comparable with NOAA PPFEs for durations ≥ 1 hour
- Larger than PPFEs for durations < 1 hour
- Greater discrepancy for return period ≥ 100-year

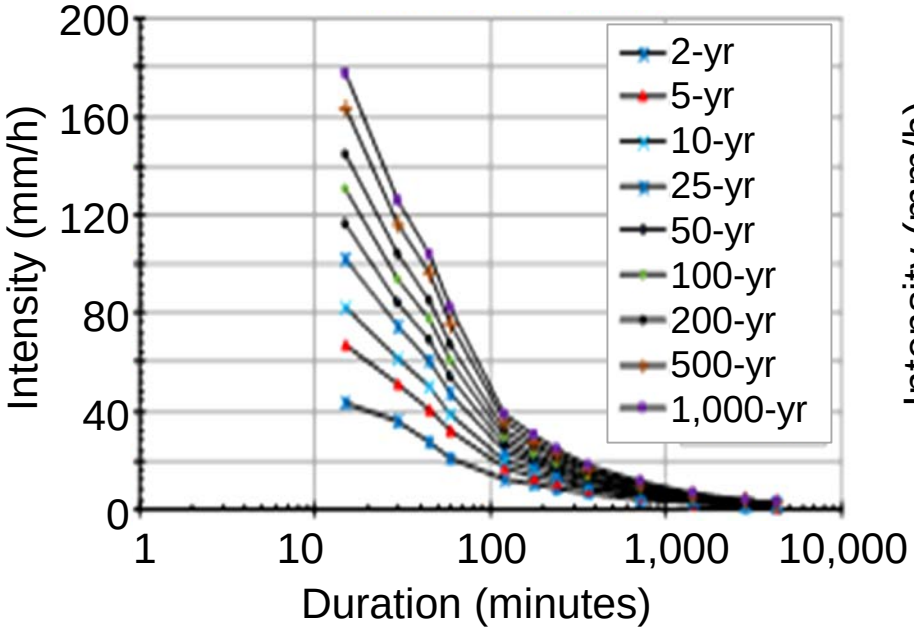
Note: PPFE = Point Precipitation Frequency Estimates

Results

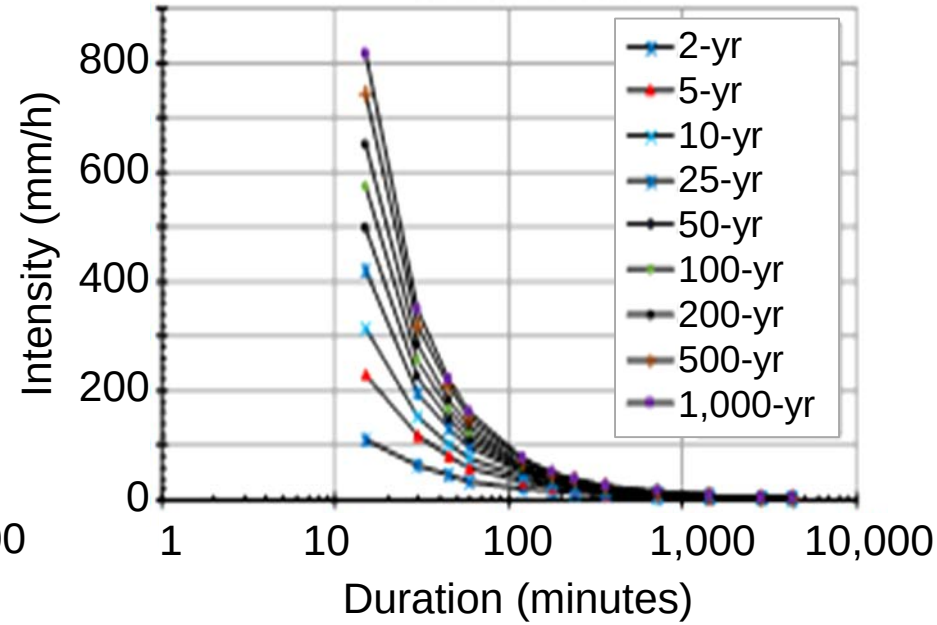
Watershed-Level Historical IDF

HUC Gauge	Area (km^2)	Best Distribution for the Gauge	Best Distribution for the HUC	HUC Gauge	Area (km^2)	Best Distribution for the Gauge	Best Distribution for the HUC	HUC Gauge	Area (km^2)	Best Distribution for the Gauge	Best Distribution for the HUC
2040303	**2716.3**		**Gumbel**	**2080108**	**592.9**		**Gumbel**	**3010201**	**4463.5**		**Weibull**
446475	2716.3	Gumbel		446475	0.0	Gumbel		440778	501.0	Gumbel	
2040304	**1961.3**		**Gumbel**	449151	592.9	Gumbel		441322	933.0	Weibull/Gumbel	
446475	1941.8	Gumbel		**2080110**	**2514.1**		**Gumbel**	442941	23.5	Weibull	
449151	19.6	Gumbel		446475	2514.1	Gumbel		448129	2126.0	Weibull	

Watershed 2070003-b



Watershed 2070005



Results

Spatial Downscaling

RCM-GCM predicted 3-h gauge precipitation → observed 3-h gauge precipitation

RCM	Zone	Regression Equation	Coefficient of Determination (R^2)
CRCM-CCSM	CPZ01	$P_{3h,obs} = 10.65e^{0.12P_{3h,rcm}}$	0.96
	CPZ02	$P_{3h,obs} = 0.13(P_{3h,rcm})^{2.31}$	0.69
	CPZ04	$P_{3h,obs} = 0.53(P_{3h,rcm})^{1.78}$	0.99
	CPZ05	$P_{3h,obs} = 7.38e^{0.16P_{3h,rcm}}$	0.96
	CPZ06	$P_{3h,obs} = 7.93e^{0.17P_{3h,rcm}}$	0.92
	CPZ07	$P_{3h,obs} = 0.034(P_{3h,rcm})^{2.83}$	0.93
	CPZ08	$P_{3h,obs} = 0.00097(P_{3h,rcm})^{4.33}$	0.74
	CPZ09	$P_{3h,obs} = 1.93(P_{3h,rcm})^{1.19}$ $P_{3h,rcm} \leq 15.0$ mm	0.96
		$P_{3h,obs} = 0.00064e^{0.74P_{3h,rcm}}$ $P_{3h,rcm} > 15.0$ mm	0.91
	CPZ10	$P_{3h,obs} = 4.18e^{0.19P_{3h,rcm}}$	0.73
	CPZ11	$P_{3h,obs} = 9.08e^{0.14P_{3h,rcm}}$	0.93
	CPZ12	$P_{3h,obs} = 6.40e^{0.15P_{3h,rcm}}$	0.87
	CPZ13	$P_{3h,obs} = 5.93e^{0.15P_{3h,rcm}}$	0.97

Note: CPZ = Climatic-Physiographic Zone

Results

Temporal Downscaling

Observed 15 min…2-h, 4-h gauge precipitation → observed 3-h gauge precipitation

Zone	Duration	Regression Equation [1]	Coefficient of Determination (R^2)
CPZ01	15 min	$P_{15m,obs} = 1.76(P_{3h,obs})^{0.62}$	0.67
	30 min	$P_{30m,obs} = 1.54(P_{3h,obs})^{0.73}$	0.83
	45 min	$P_{45m,obs} = 1.45(P_{3h,obs})^{0.78}$	0.89
	1 h	$P_{1h,obs} = 1.22(P_{3h,obs})^{0.86}$	0.95
	2 h	$P_{2h,obs} = 1.04(P_{3h,obs})^{0.96}$	0.99
	4 h	$P_{4h,obs} = 1.07(P_{3h,obs})^{1.01}$	0.99
CPZ02	15 min	$P_{15m,obs} = 0.25(P_{3h,obs})^{1.14}$	0.89
	30 min	$P_{30m,obs} = 0.21(P_{3h,obs})^{1.25}$	0.70
	45 min	$P_{45m,obs} = 0.55(P_{3h,obs})^{1.04}$	0.71
	1 h	$P_{1h,obs} = 0.36(P_{3h,obs})^{1.18}$	0.84
	2 h	$P_{2h,obs} = 0.46(P_{3h,obs})^{1.17}$	0.96
	4 h	$P_{4h,obs} = 1.01(P_{3h,obs})^{1.01}$	0.99
CPZ04	15 min	$P_{15m,obs} = 1.08(P_{3h,obs})^{0.76}$	0.90
	30 min	$P_{30m,obs} = 1.03(P_{3h,obs})^{0.86}$	0.97
	45 min	$P_{45m,obs} = 1.05(P_{3h,obs})^{0.89}$	0.98
	1 h	$P_{1h,obs} = 1.01(P_{3h,obs})^{0.92}$	0.99
	2 h	$P_{2h,obs} = 1.00(P_{3h,obs})^{0.98}$	1.00
	4 h	$P_{4h,obs} = 1.16(P_{3h,obs})^{0.99}$	0.99

Note: CPZ = Climatic-Physiographic Zone

Results

Next-Generation IDF Curves

- Underway for each of:
  - 57 gauges
  - 53 watersheds
- Durations
  - 15, 30, and 45 min
  - 1, 2, 3, 6, 12, 24, 48, and 72 h
- Return periods
  - 2-, 5-, 10-, 25-, 50-, and 100-year
  - 200-, 500-, and 1,000-year
- Total sets of curves
  - 11 durations (57 gauges + 53 watersheds) = 1,210

Conclusions

- Developed approach for next-generation IDF curves
- Detected non-stationarity and decreasing trends in Virginia
- Created gauge- and watershed-level historical IDF curves
- Creating probability-based IDF curves
- Audiences learn practical approach for non-stationarity
- Deliver a tool for resilient design of DoD's installations

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Resiliency/Infrastructure-Resiliency/Vulnerability-and-Impact-Assessment/RC18-1569

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Q&A Session 2

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The next webinar is on April 11, 2019

Managing Contaminated Sediments: Passive Sampling Methods and In-Situ Treatment

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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