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Snowmelt-Based IDF Curves

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25 YEARS OF ESTCP
SYMPOSIUM
2019 | Enhancing DoD's Mission Effectiveness

The Project Team

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(Transitioned to permanent staff)

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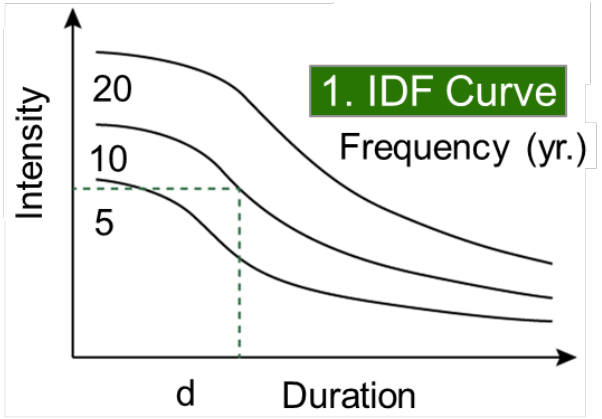
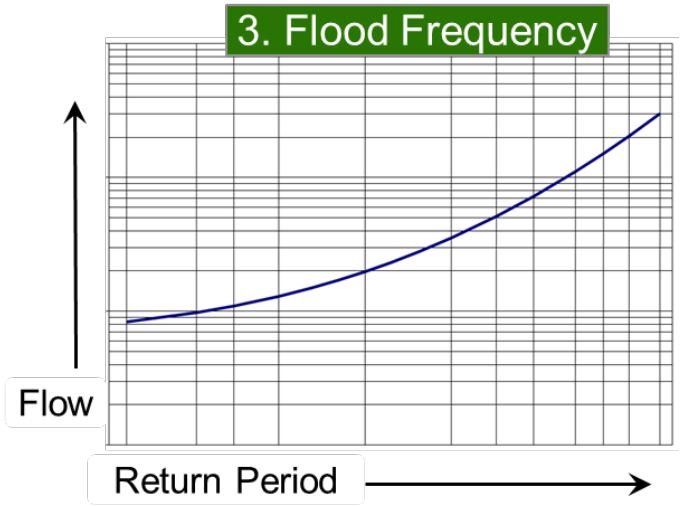
Snow processes
(Transitioned to research facility)

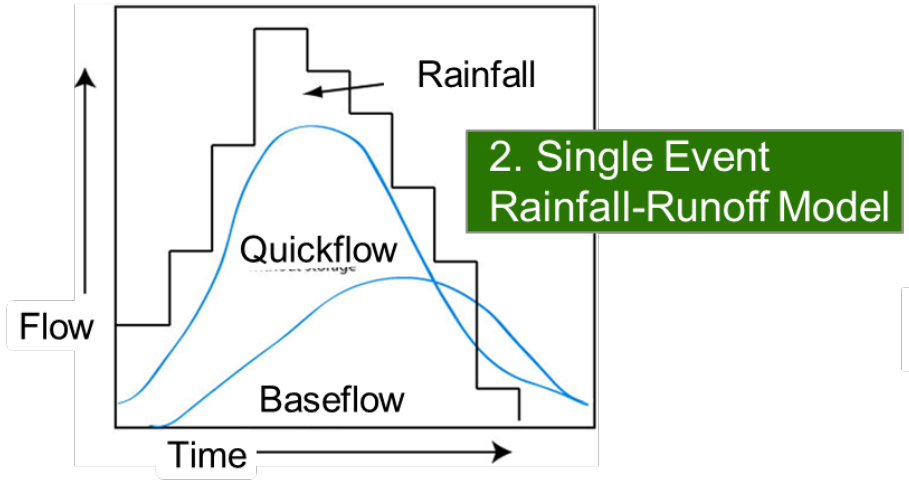
Benefits to DoD

- 1/6 of the worlds population live in snowmelt-dominated regions
- 70%+ nation's roads are in snowy regions
- Advanced physically based modeling approach for hydrologic design is costly and labor intensive
- NG-IDF curves can improve design in snow dominated locations with minimal additional cost or training

Traditional Intensity-Duration-Frequency (IDF) Based Hydrologic Design







4. Hydrologic Design

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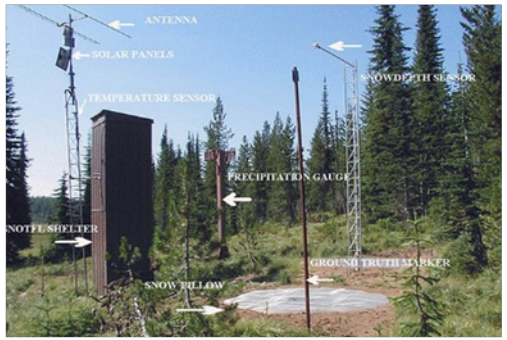
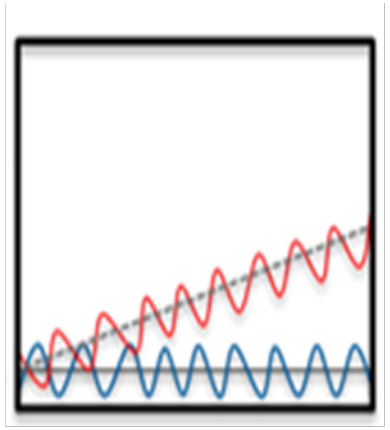
Next Generation IDF (NG-IDF) Curve Development

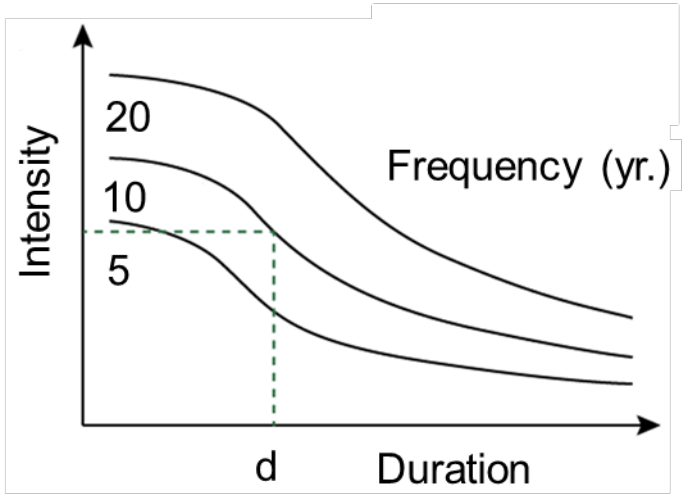
From SNOTEL Observations



SNOTEL observations of precipitation and SWE



Non-stationarity and trend analysis; Detrending



IDF's

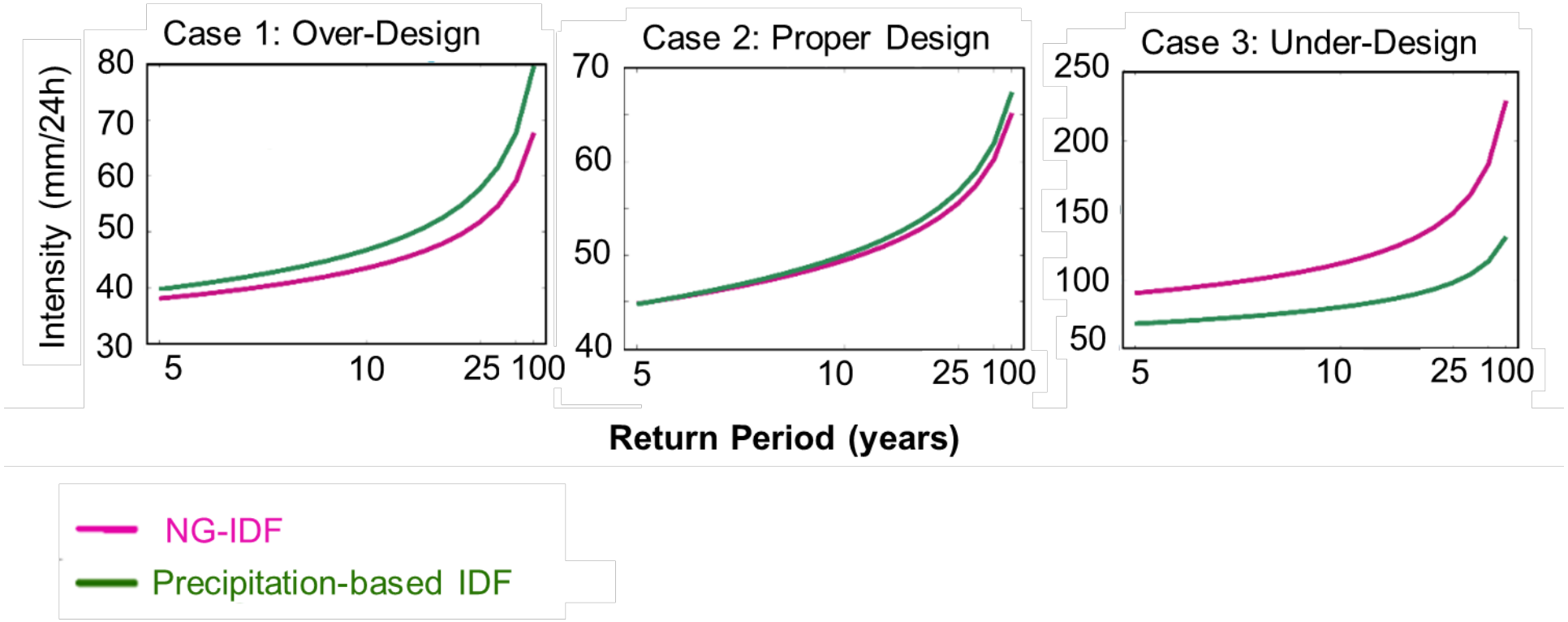
- Precipitation (P)
- Water available for runoff (NG-IDF)

Water Available for Runoff (W) from mass balance:

$W = P - \Delta SWE$ (any combination of rainfall/snowmelt/ROS)

***Notes**: P = precipitation; SWE = snow water equivalent; ROS = rain-on-snow*

Precipitation vs. Next-Generation IDF Curves
Overdesign vs. Under-Design



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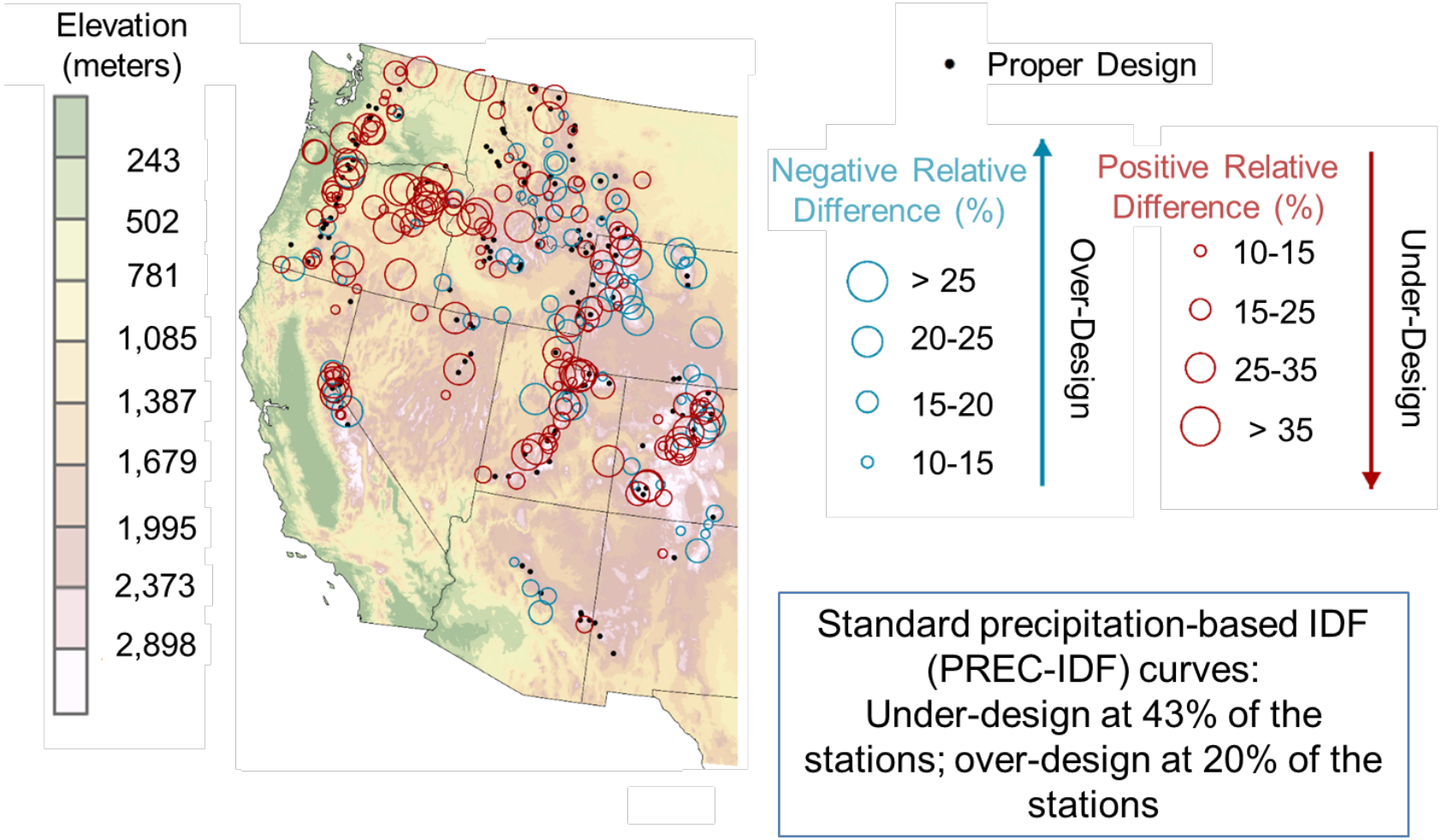
Precipitation vs. Next-Generation IDF Curves

24-Hour, 100-Year Event



Standard precipitation-based IDF (PREC-IDF) curves: Under-design at 43% of the stations; over-design at 20% of the stations

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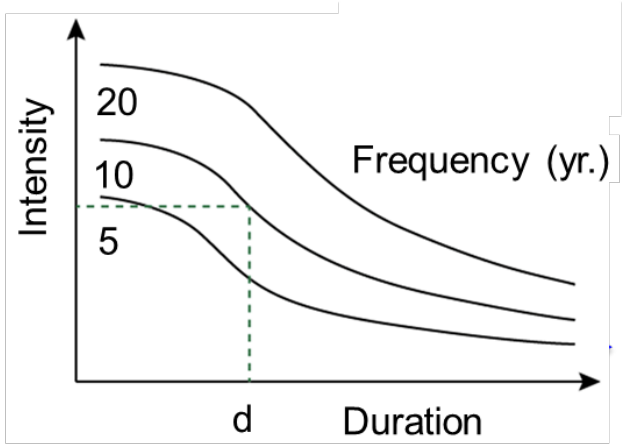
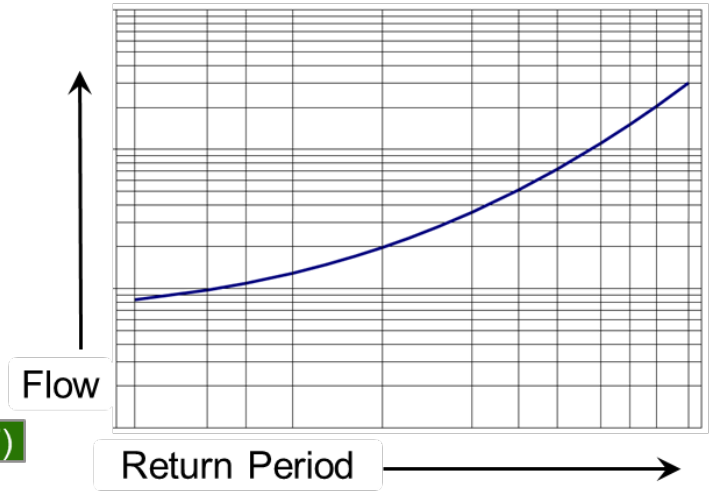
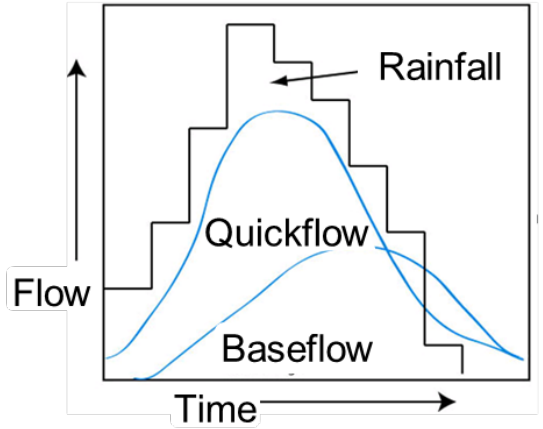
Estimation of Flood Frequency



1. IDF's: Precipitation (P); Water Available for Runoff (NG-IDF)



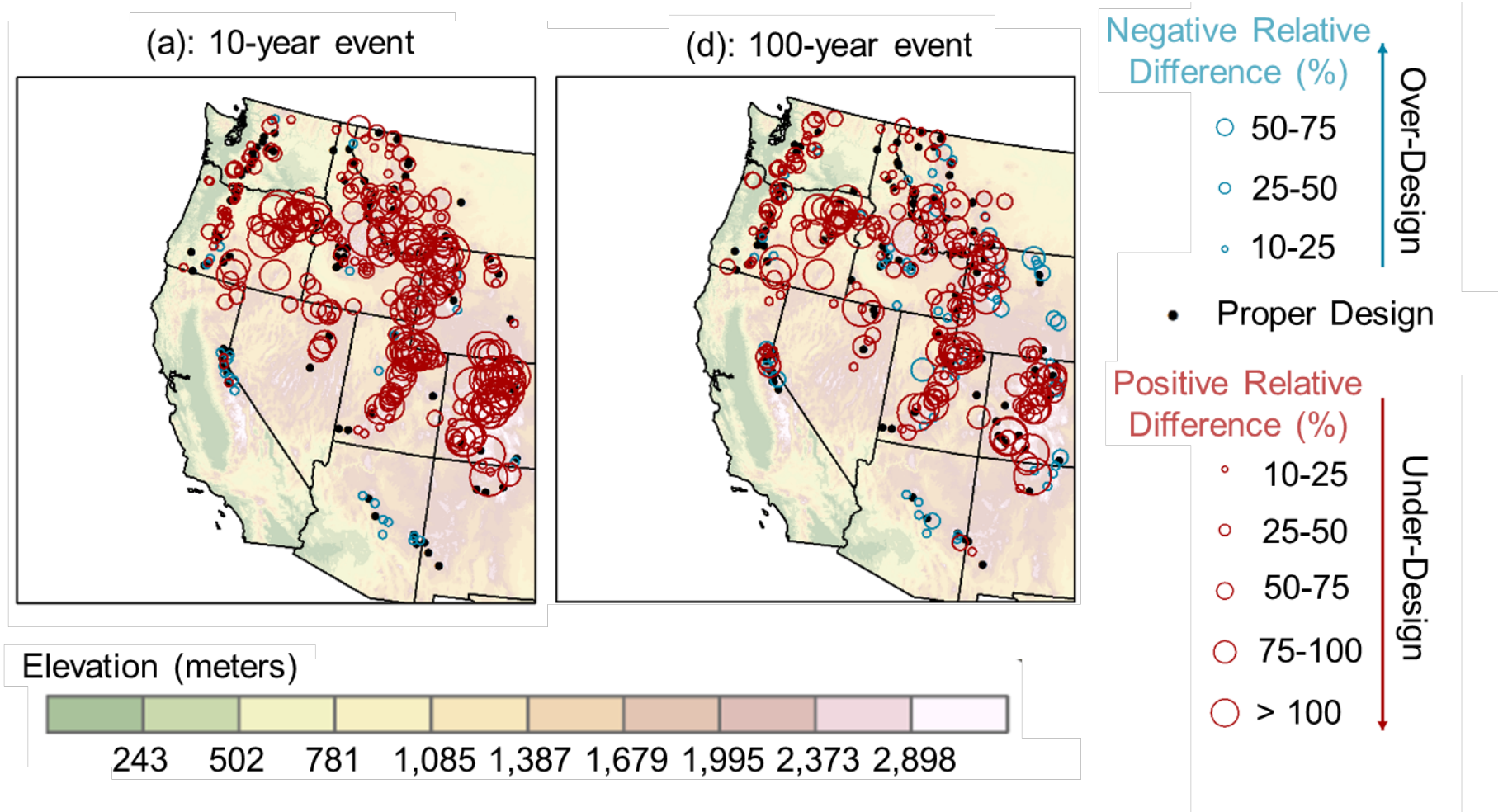
3. Flood Frequency



2. TR-55 Single Event Hydrologic Model

Note: *TR55 = single event hydrologic model described in USDA Soil Conservation Service Technical Release 55 - Urban Hydrology for Small Watersheds*

PRCP-IDF vs. NG-IDF Flood Frequency Estimates



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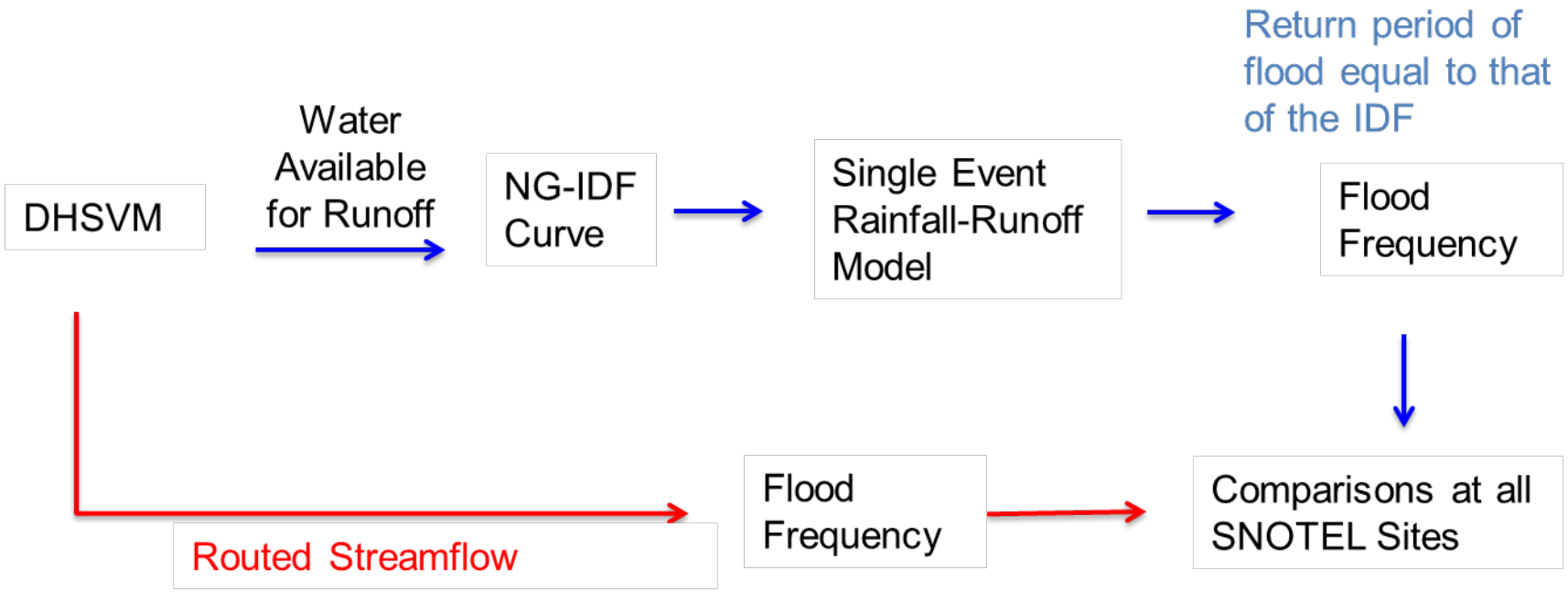
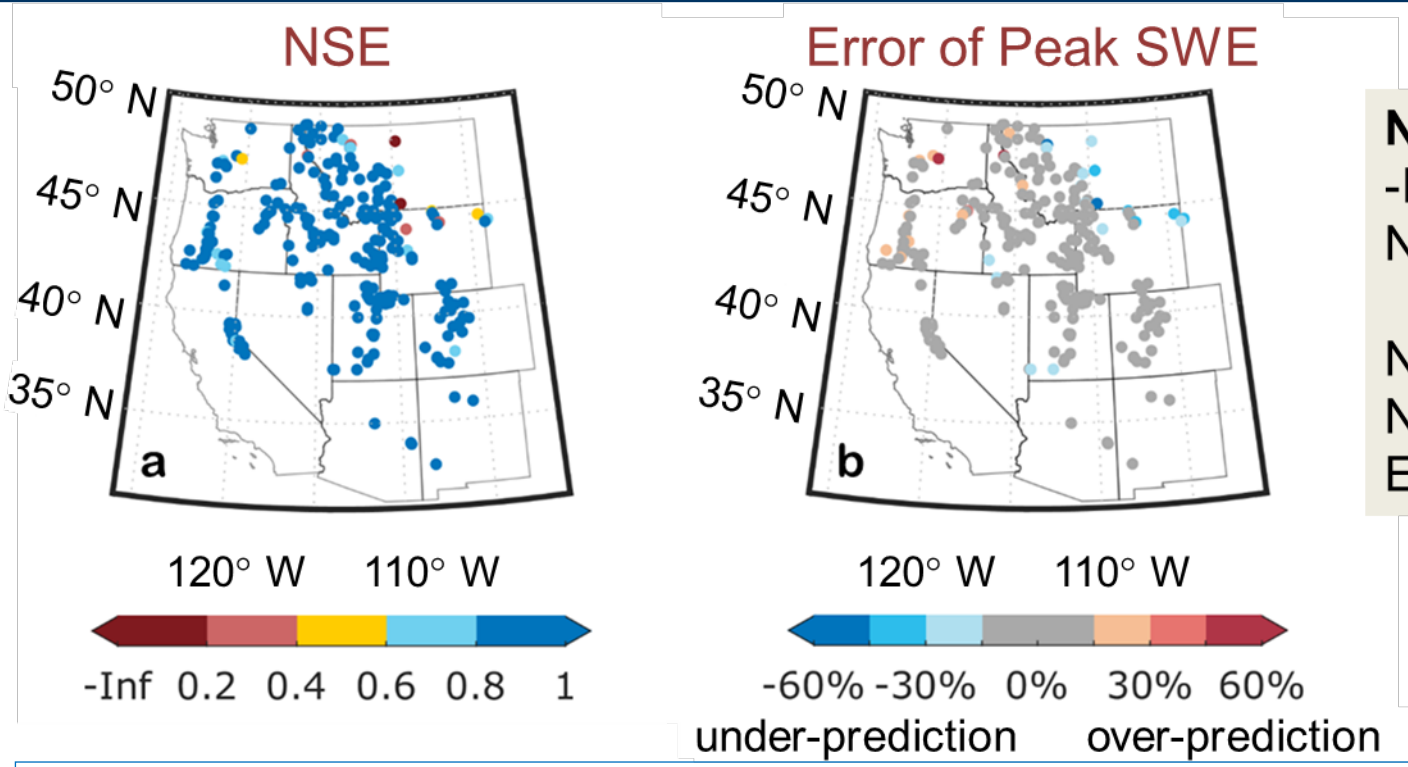
Benchmarking NG-IDF Performance
Using DHSVM Simulated Streamflow



How do flood frequencies based on NG-IDF curves compare with those from a complex continuous simulation model?

Assessment of DHSVM Snow Modeling Skill

246 SNOTEL Stations, WY 2007-2013



Notes:
-Inf = Negative Infinity

NSE = Nash-Sutcliffe Efficiency

DHSVM simulated SWE

- NSE > 0.8 at 91% of stations (mean NSE = 0.9)
- Error of peak SWE is within ±15% at 88% of stations
- NSE < 0.6 at only eight sites (Rocky Mountains)

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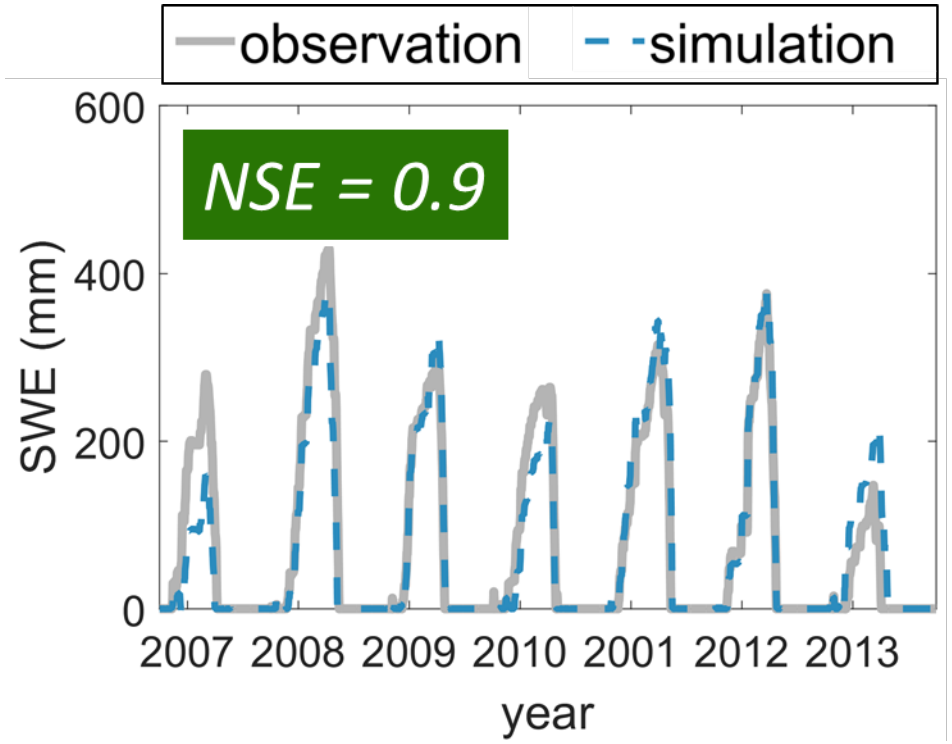
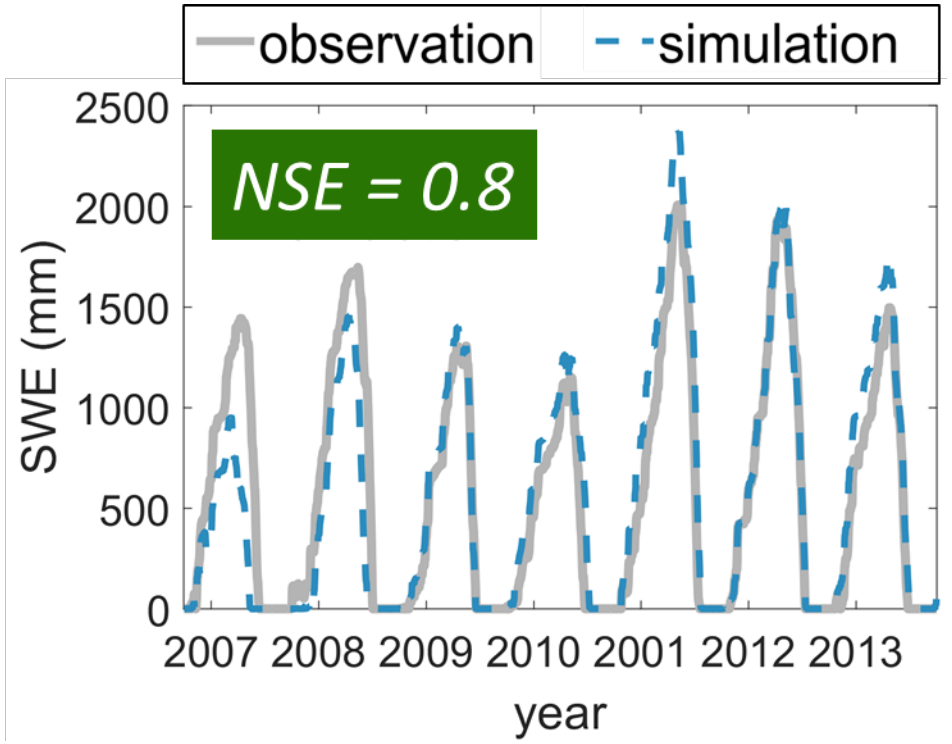
DHSVM Simulated and Observed SWE
For Selected Stations





NSE ranges from -∞ to 1. The closer to 1, the more accurate the model is. **NSE>0.65** indicate satisfactory to very good hydrologic simulations (Dechmi et al., 2012; Moriasi et al., 2007; Saleh et al., 2000).

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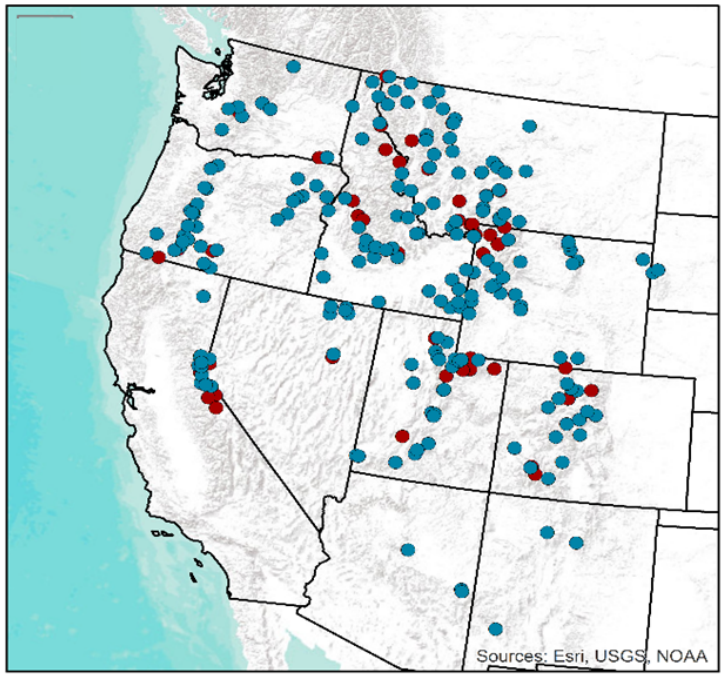
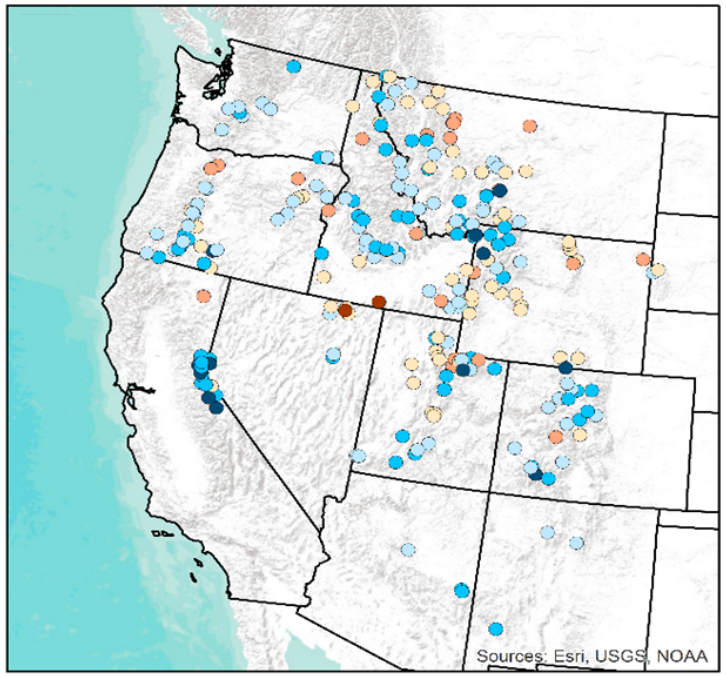
Daily Annual Maximum W from DHSVM *Compared to SNOTEL Observations*





- P-value>5%: 82% stations
- P-value≤5%: 82% stations

-30% -20% -10% 0% 10% 20% 30%

Under-prediction Over-prediction

82% stations accepted null hypothesis that the two annual maximum W were drawn from the same distribution; 94% stations errors < 20%

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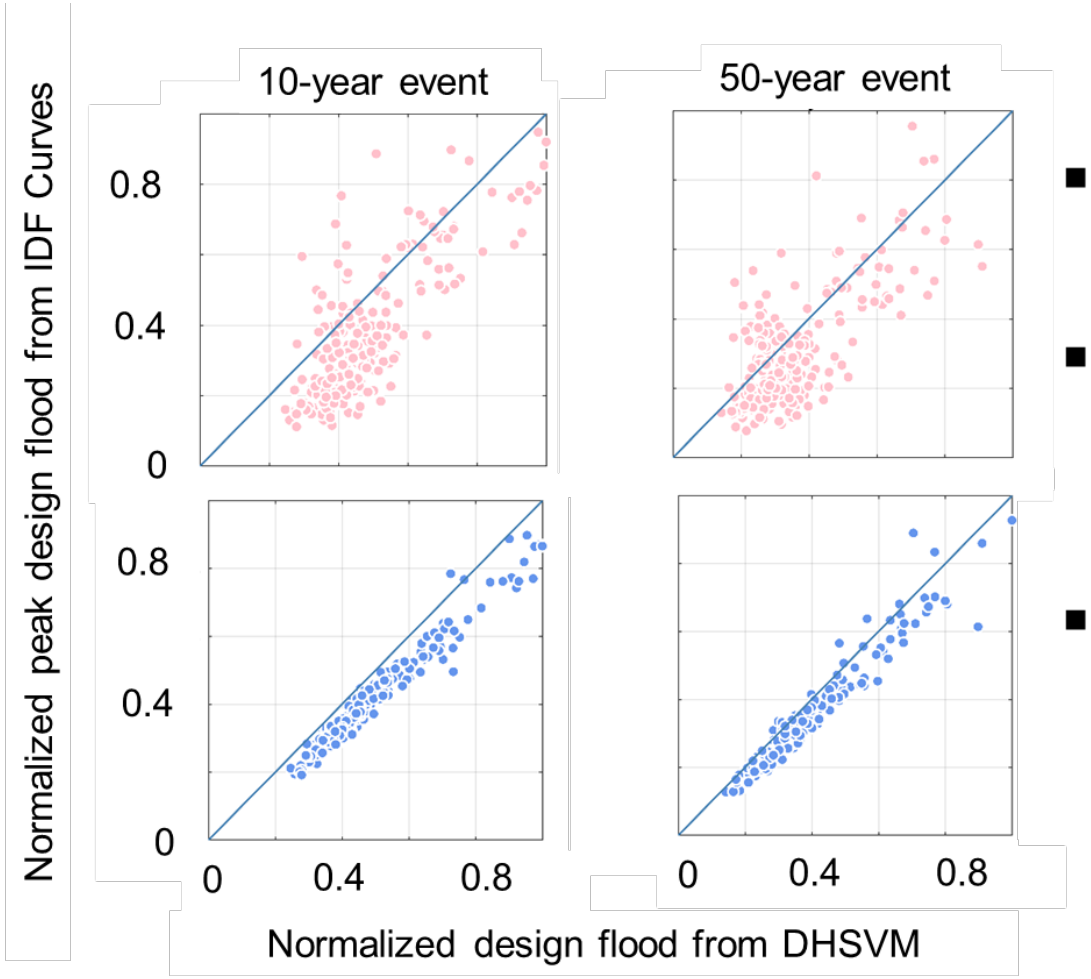
IDF vs. DHSVM

Continuous Streamflow-based Flood Estimates



- 399 SNOTEL Stations
- Precipitation IDF
  - 31-33% error
- NG-IDF
  - 12-14% error

Precipitation IDF

NG-IDF

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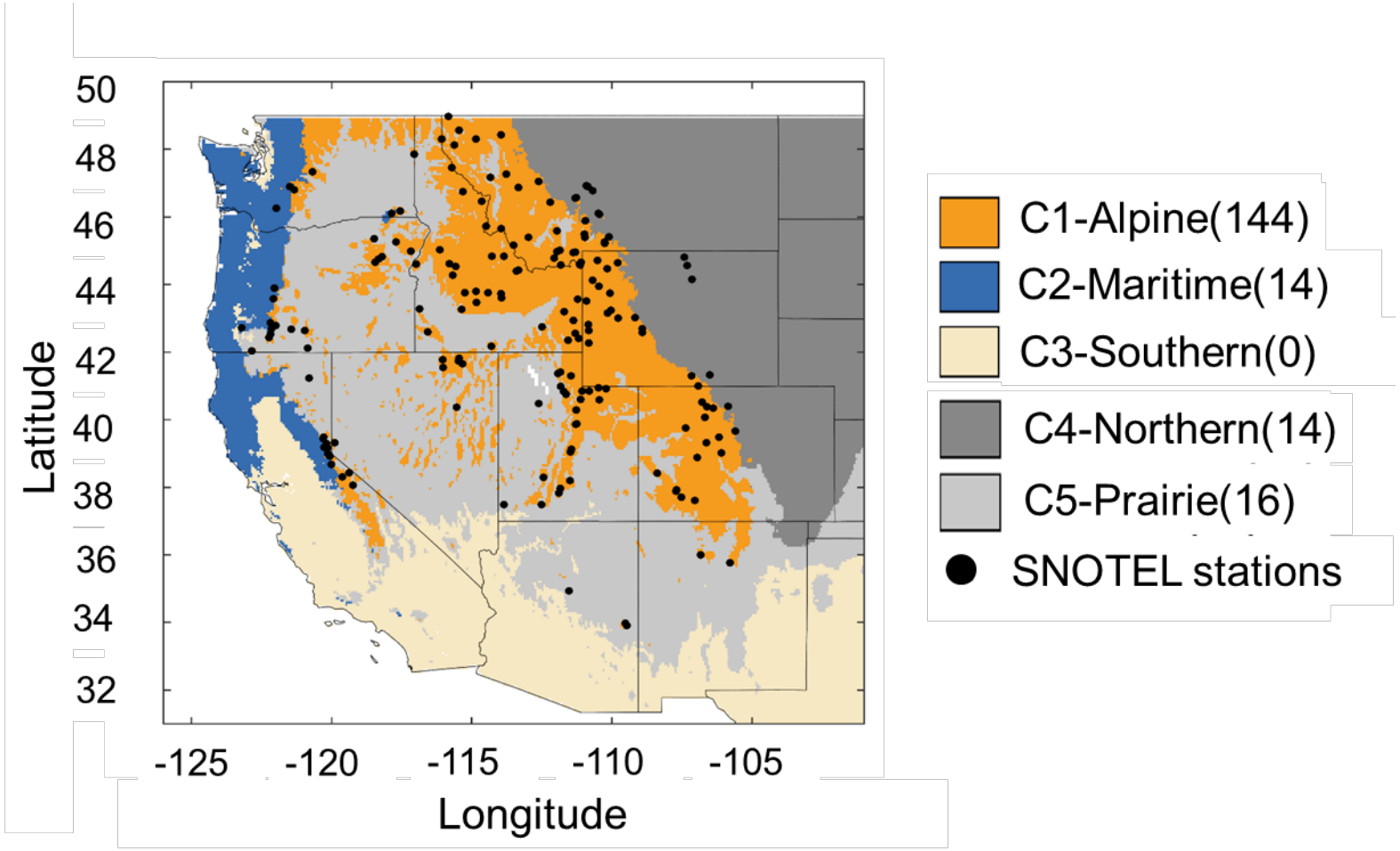
Successful Snow Modeling
Using Regional Snow Parameters



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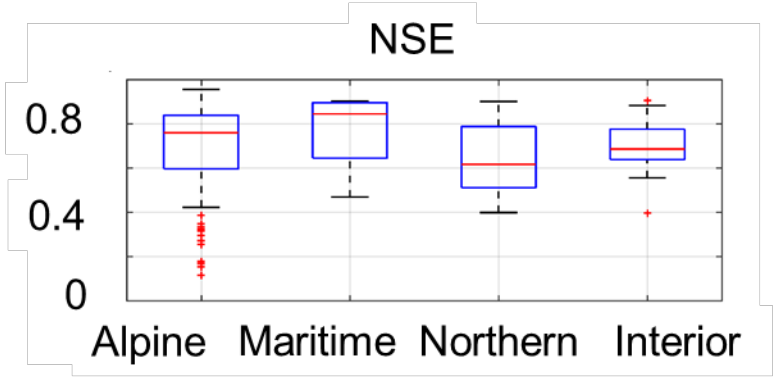
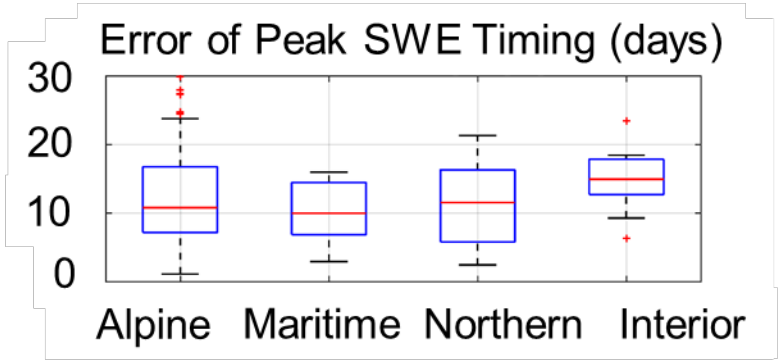
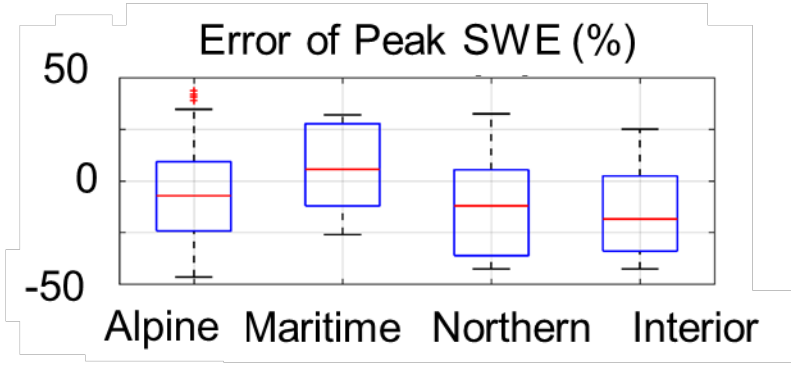
Successful Snow Modeling
Using Regional Snow Parameters







The use of climate-based regional snow parameters allows NG-IDF curves to be generated across the CONUS

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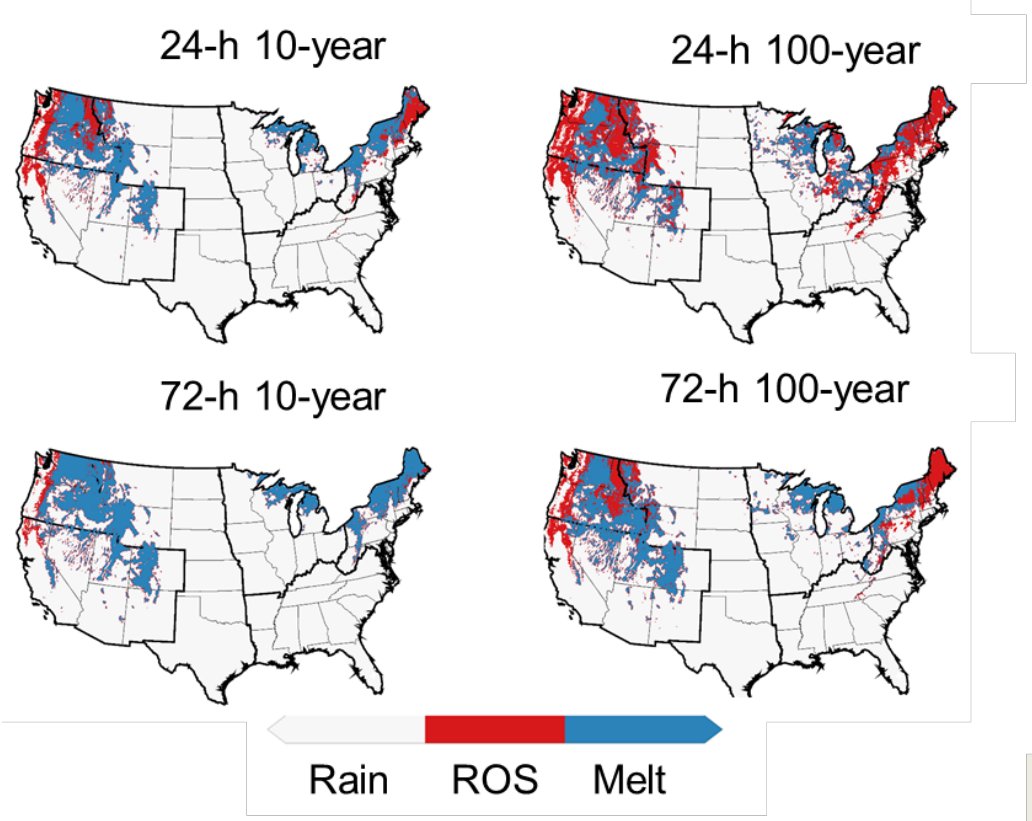
Historical Extreme W Events
Dominant Drivers

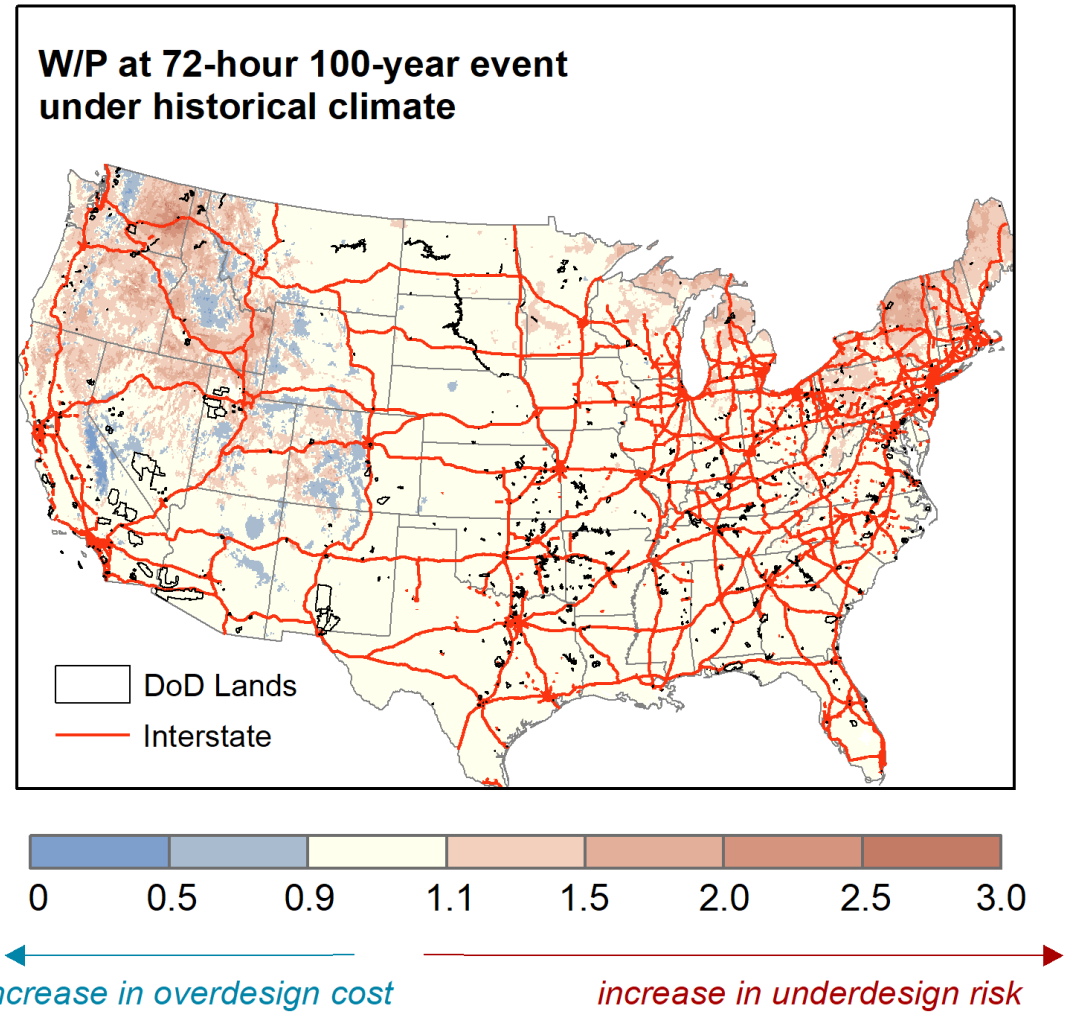


- Northwest:
  - 10-yr events: rain, snowmelt
  - 100-yr events: snowmelt, ROS
- Northeast:
  - 10-yr events: rain, snowmelt
  - 100-yr events: rain, ROS

Notes: ROS = rain-on-snow

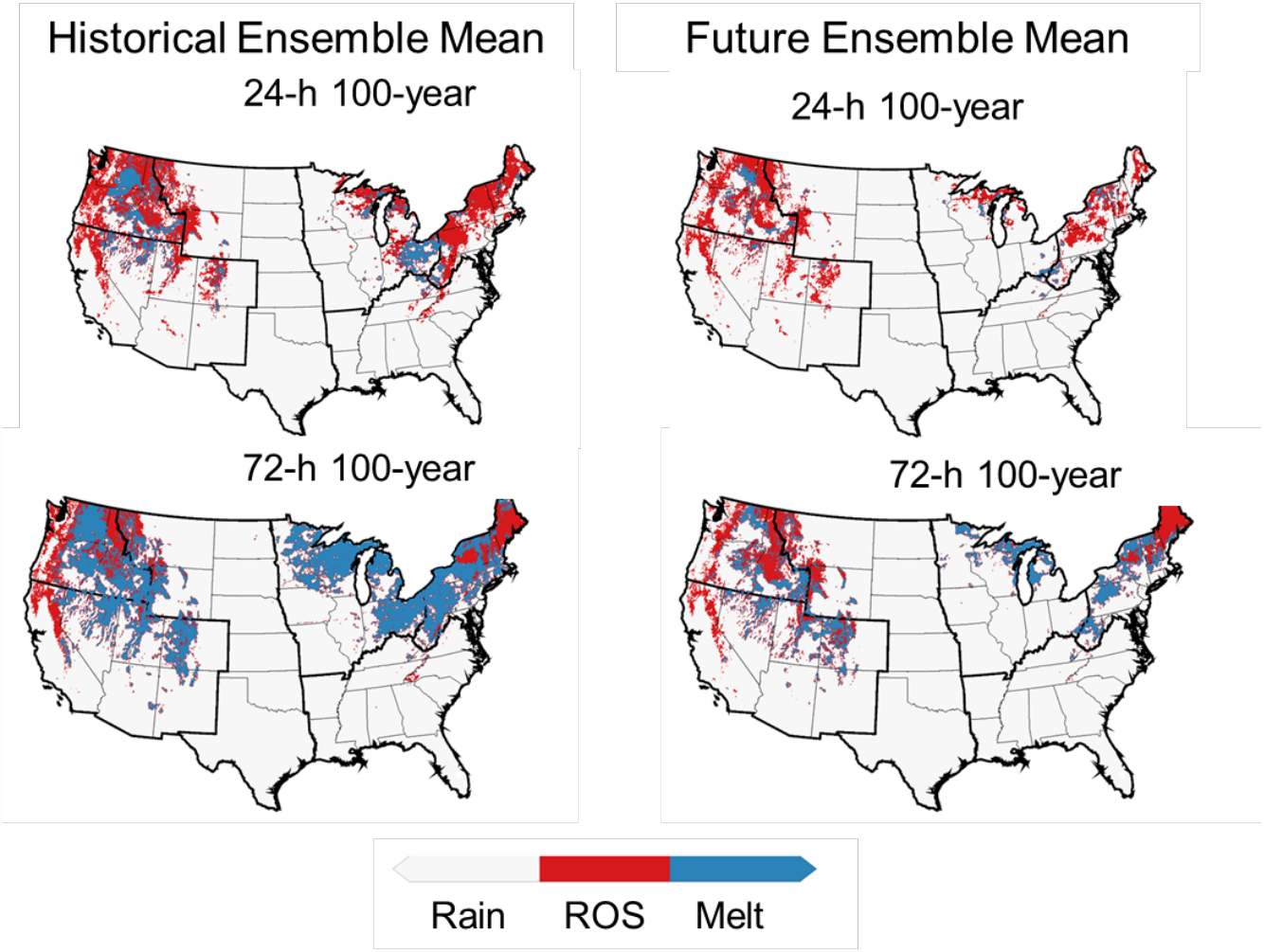
With longer duration:
ROS-driven event magnitude decreases; melt-driven event magnitude increases

Historic Design Risk



About 6% of DoD lands in CONUS are in regions with the potential for under-design in the 72-hr 100-year event

Future Extreme Events
Shift from Snow- to Rain-Dominated



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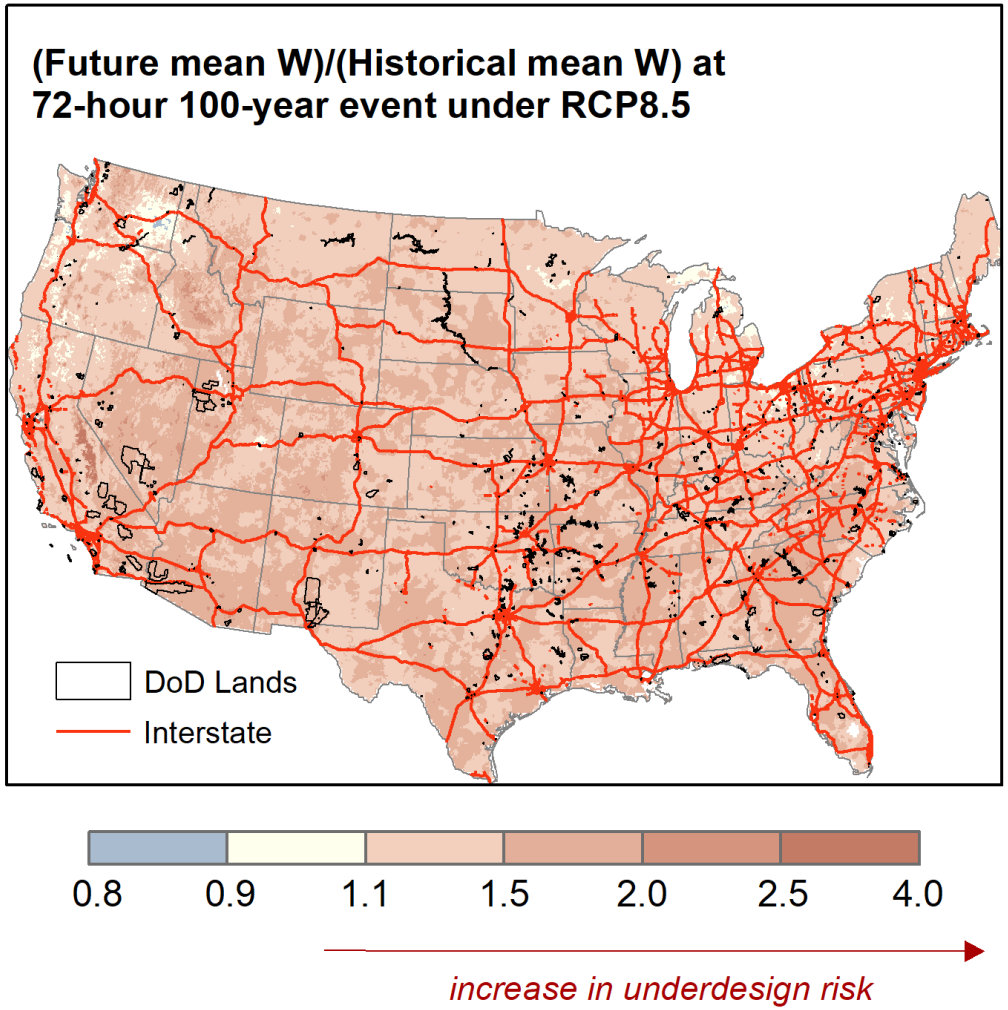
Future Design Risk



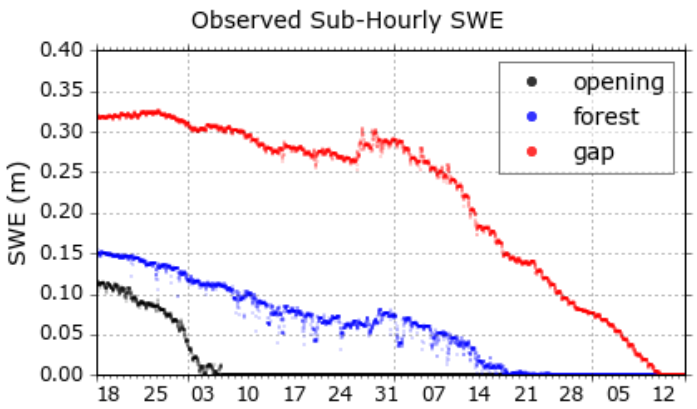
Conclusions

- Standard precipitation-based IDF curves under-estimate design flood peaks at most SNOTEL locations
- DHSVM accurately reproduces annual maximum daily water available for runoff
  - Allows construction of NG-IDF curves across CONUS
  - About 6% of DoD lands in CONUS show potential for under-design
- Design flood peaks from NG-IDF curves coupled with TR-55
  - Compared favorably with continuous streamflow simulation
- NG-IDF curves in standard engineering design may replace complex simulation models
  - Lower-risk hydrologic design in snow dominated regions

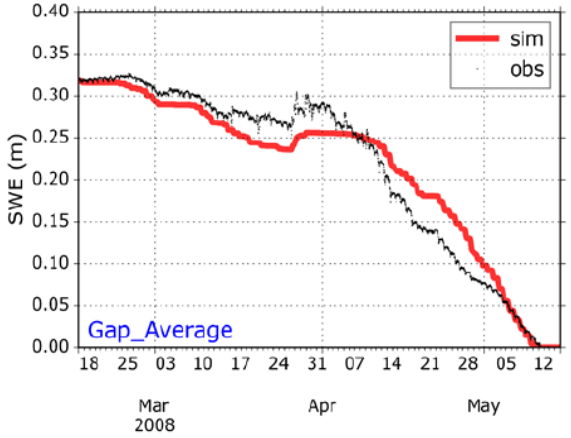
Future Research

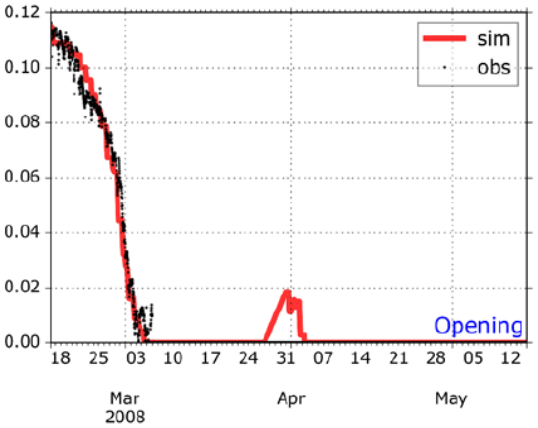
- Provide NG-IDF for different land cover (e.g., grassland, forest)
- Develop regional hyetograph of W
- Examine areal reduction factor for W
- Develop probabilistic NG-IDF curves with transparent uncertainty quantification

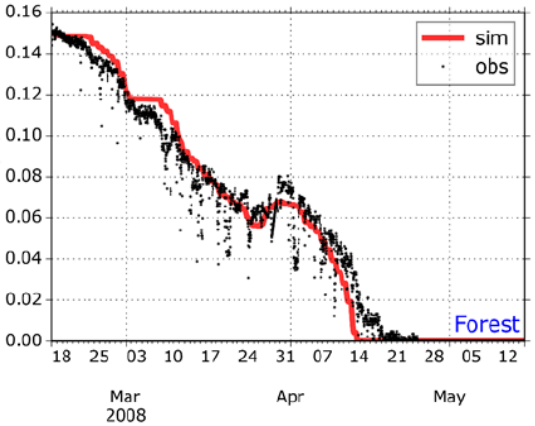
The Need for Improved Representation of Canopy-Snow Interactions



Proper representation of canopy-snow interactions is critical to estimating the impacts of land use change on snowmelt and runoff



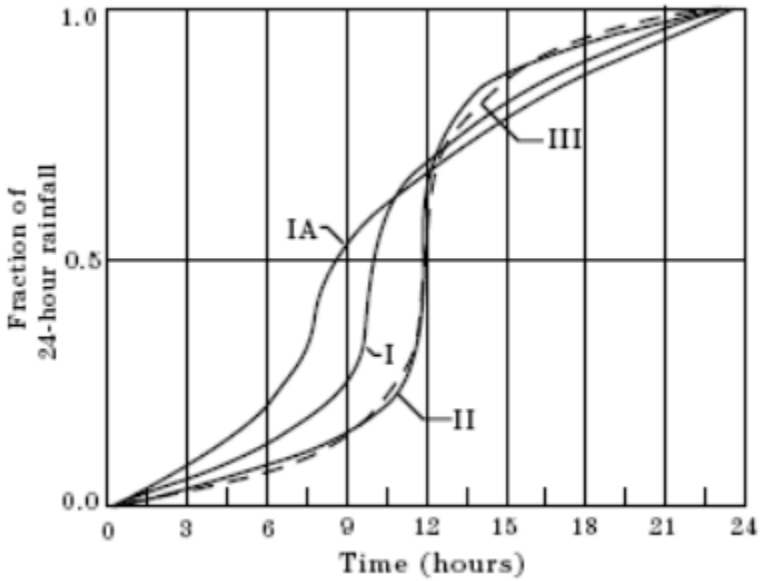




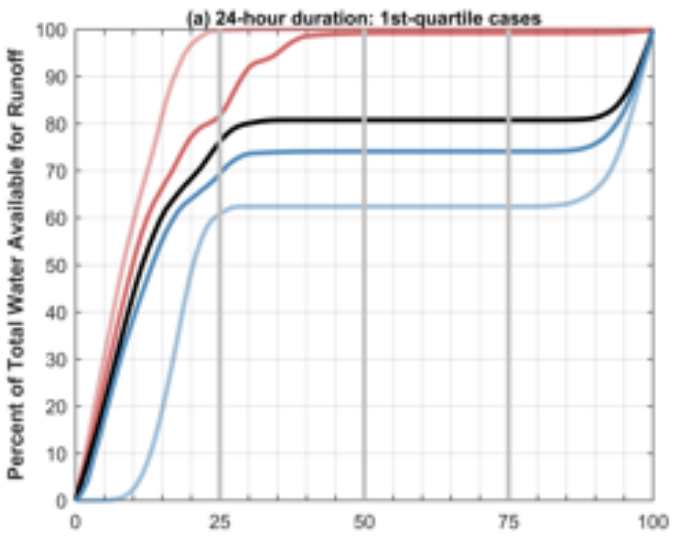
DHSVM was enhanced under this project to better represent snow-canopy interaction

Path Forward: W Hyetograph

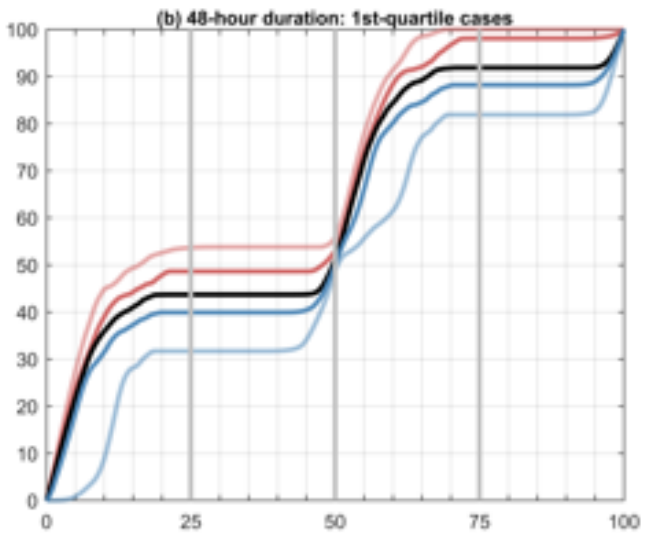
Rainfall 24-hr



W 24-hr



W 48-hr



The time distribution (hyetograph) of water available from runoff (W) exhibits a diurnal

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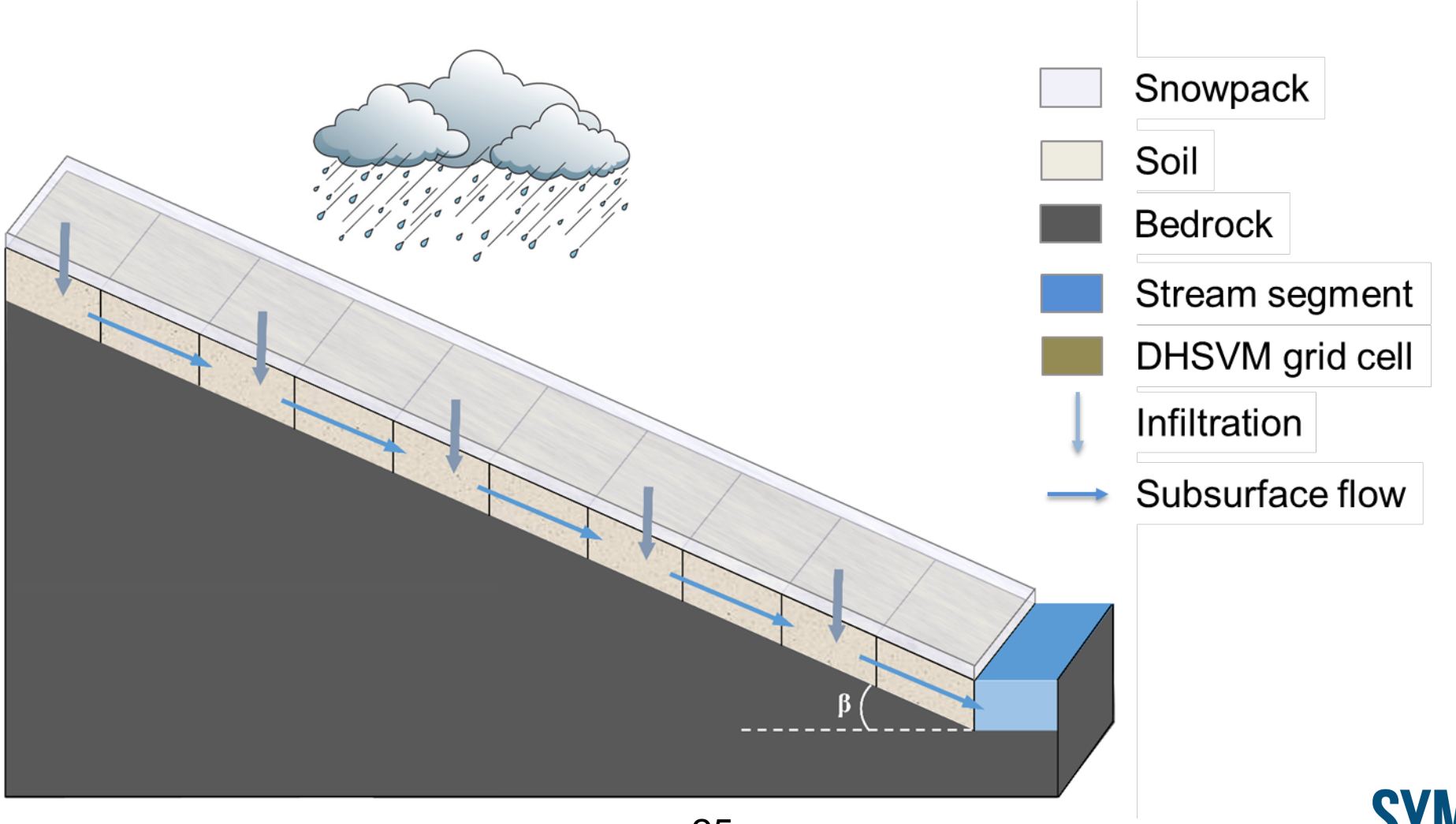
Experimental Hillslope
Flood Frequency Estimates



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