Colorado and New Mexico Regional Extreme Precipitation Study (CO-NM REPS)

Western Water Assessment
Stakeholder Community Meeting
Boulder, CO
October 9, 2018

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Bill McCormick, P.E., P.G.
Colorado Dam Safety

Presentation Outline

- Why we needed it
- What we wanted from it
- How we did it
- What we got out of it
- What remains to be done

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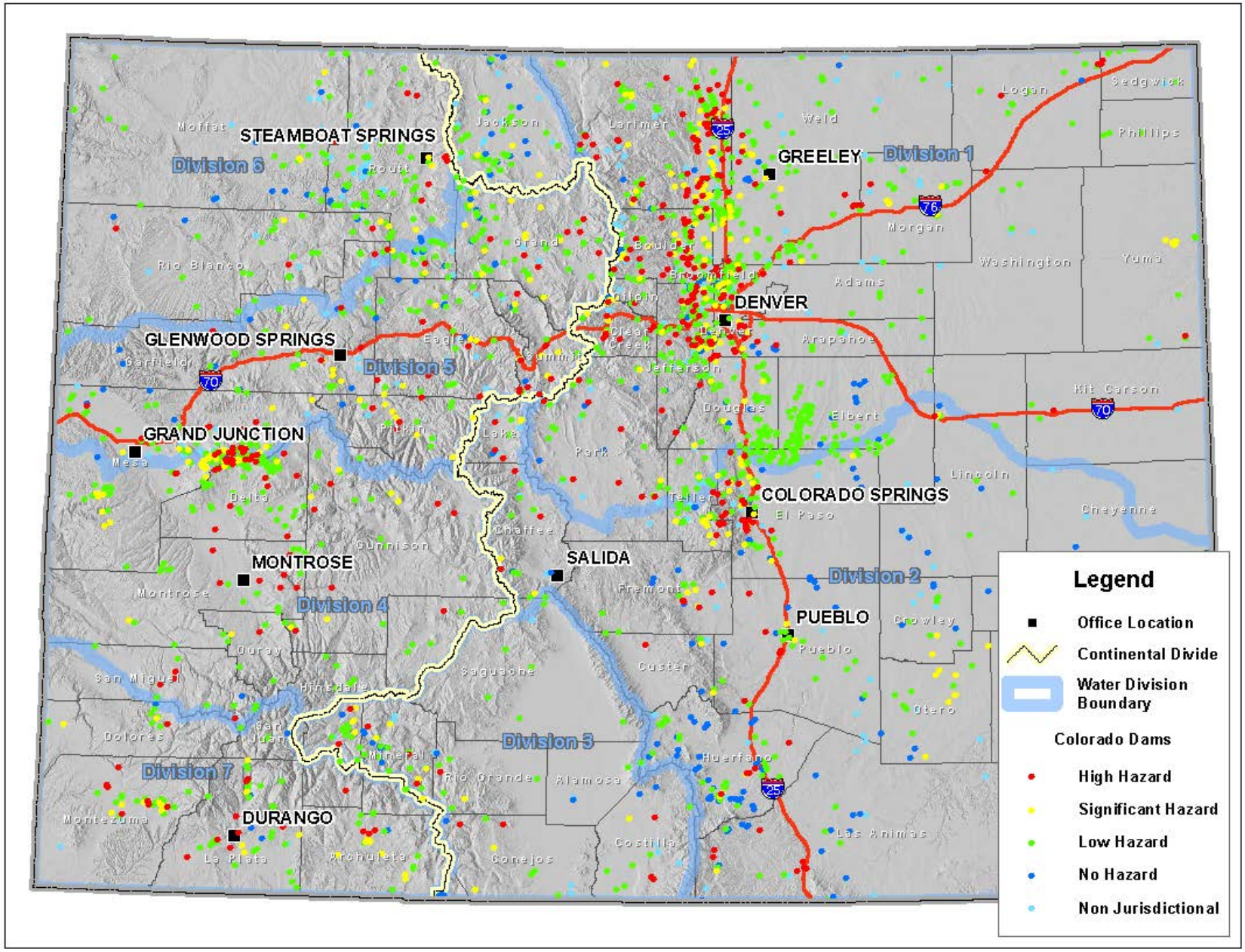
Dams in Colorado – 3000 ish



Hazard Classification

- Based on an evaluation of consequences of dam failure, NOT condition of the dam
- Establishes standards for design and prioritization of inspection, monitoring and emergency preparedness

Hazard Classification	Description
HIGH	Loss of human life is expected in the event of a failure
SIGNIFICANT	Significant damage is expected, but no loss of human life
LOW	No significant damage and no loss of human life

Hazard Classifications – How Many

Hazard Classification			
High	Significant	Low	Total
426	297	1014	1737

- Colorado Dam Safety is a Risk-Based program
- Focus efforts on higher consequence dams

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Why Do Dams Fail? – Failure Modes

Earth Dams

Overtopping (48%)

Piping/Internal Erosion (46%)

Foundation (4%)

Seismic (2%)

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Dam Overtopping

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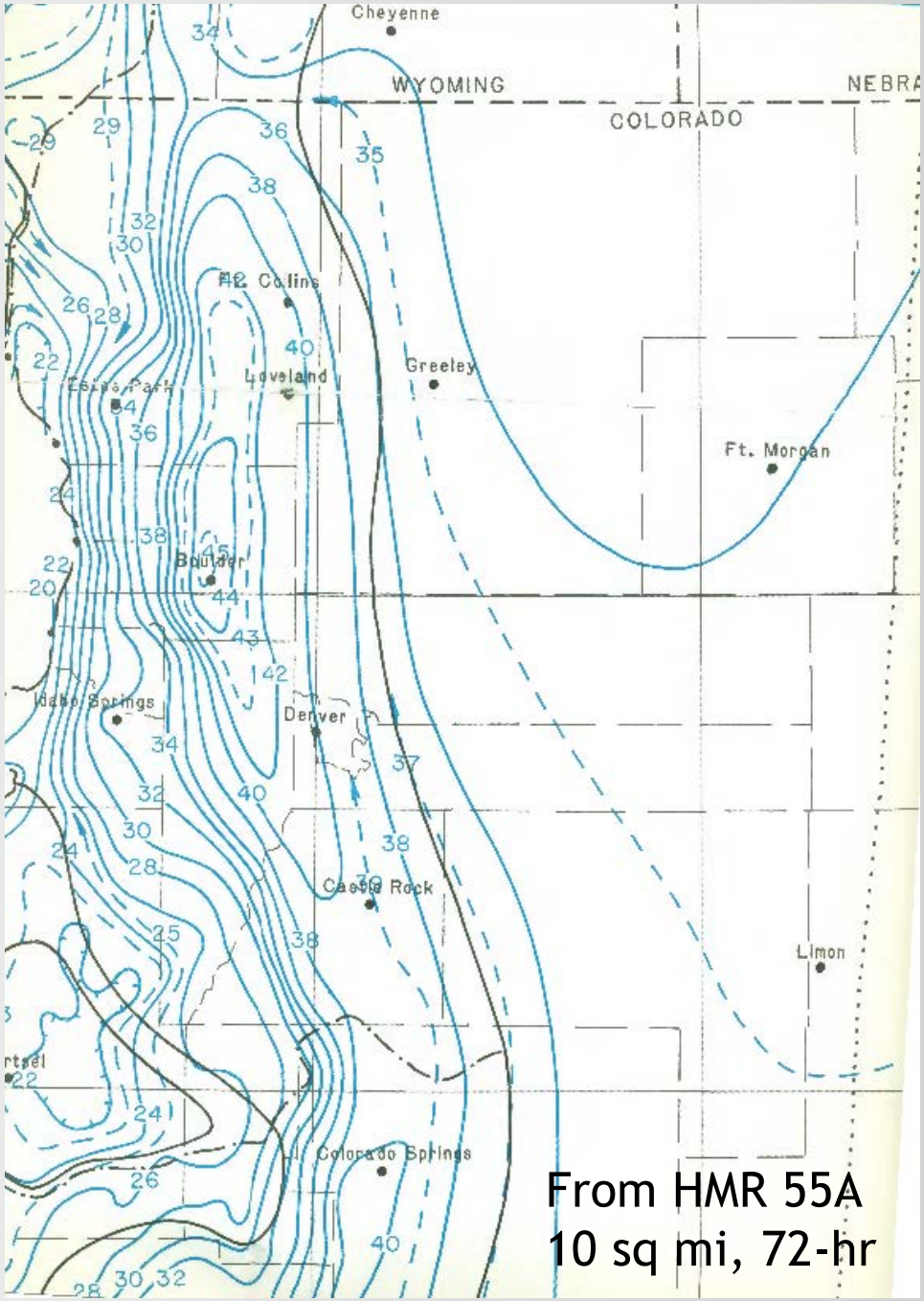
Spillways Operations

Spillway Design

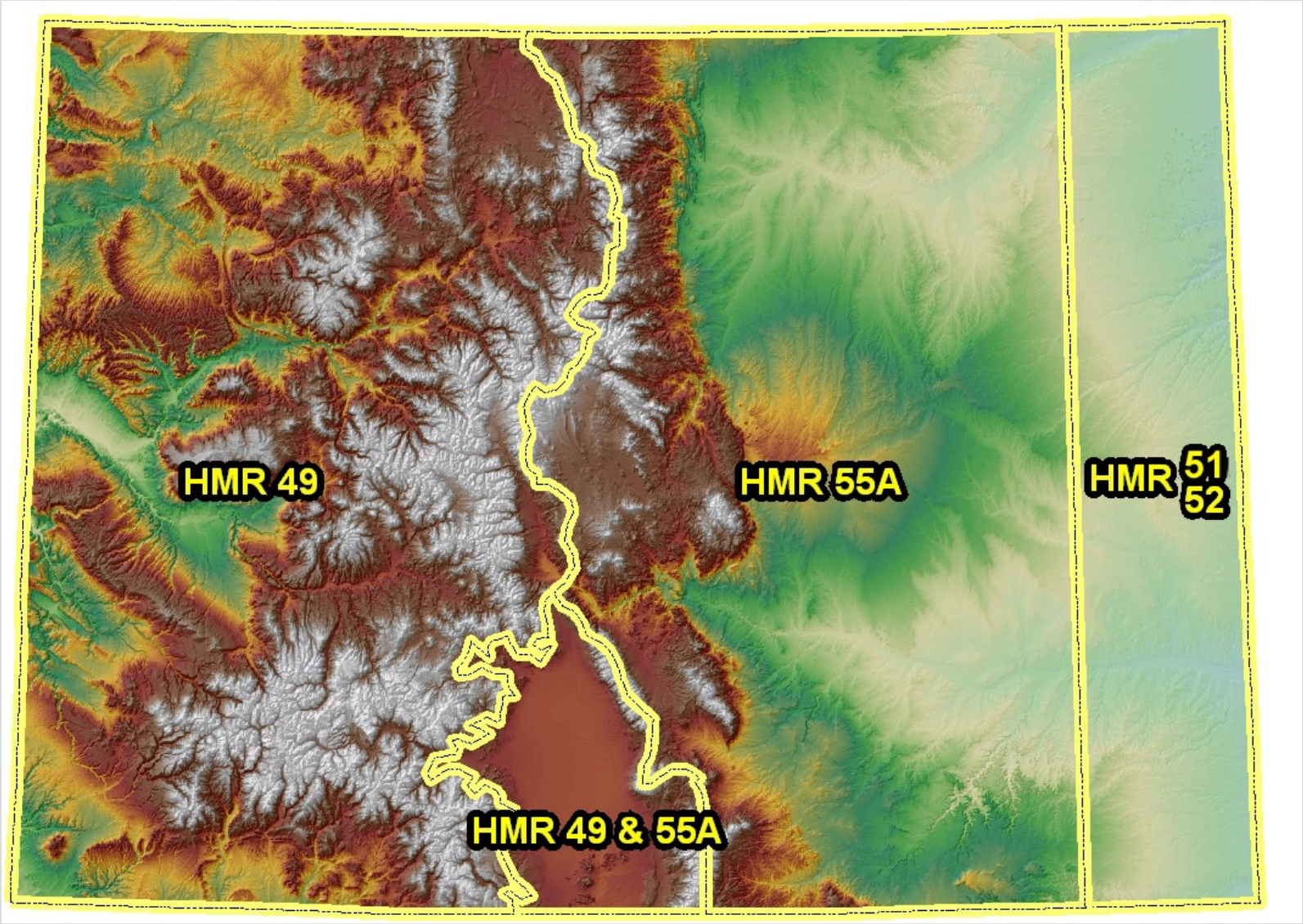
- Rainfall
  - Extreme Precipitation
  - Area size and Duration
  - Intensity
- Runoff
  - soil, slope, basin area, length
- Routing
  - Reservoir area, dam configuration



From HMR 55A
10 sq mi, 72-hr

CO PMP Efforts - Historically

- NOAA HDSC - HMR 49 – 1977, HMR 55A - 1988
- HMR program discontinued 1999



CO-NM REPS Goals and Objectives

Three Goals - Goal 1

New/Updated Tools: To create updated, broadly accepted tools and procedures for estimating extreme precipitation depth, area, and duration relationships and precipitation frequency estimates for individual basins within the regional area that includes Colorado and New Mexico.

"Essentially, PMP methods as applied in the HMRs, are static and outdated."

"There are readily-available probabilistic alternatives to PMP for assessments and designs of critical infrastructure."

(USBR, 2011 England, Sankovich, Caldwell)

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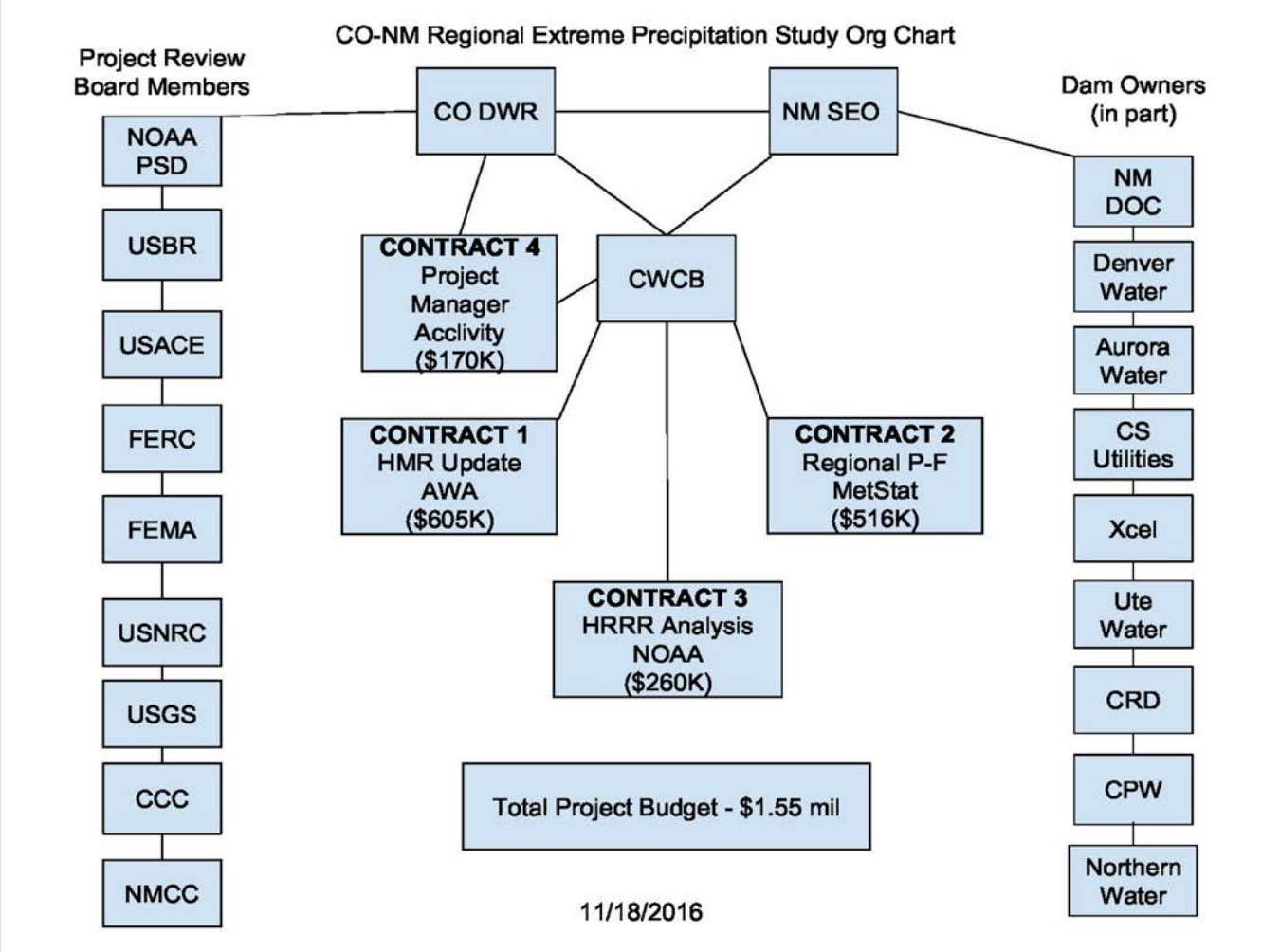
CO-NM REPS
Project Organization Chart

- Two States, 1 MOU
- Four Tasks
- PRB participation
- Dam owner support/oversight
- Project funding through CWCB, CDWR, NM OSE, NM Dam Owners Coalition, WWA



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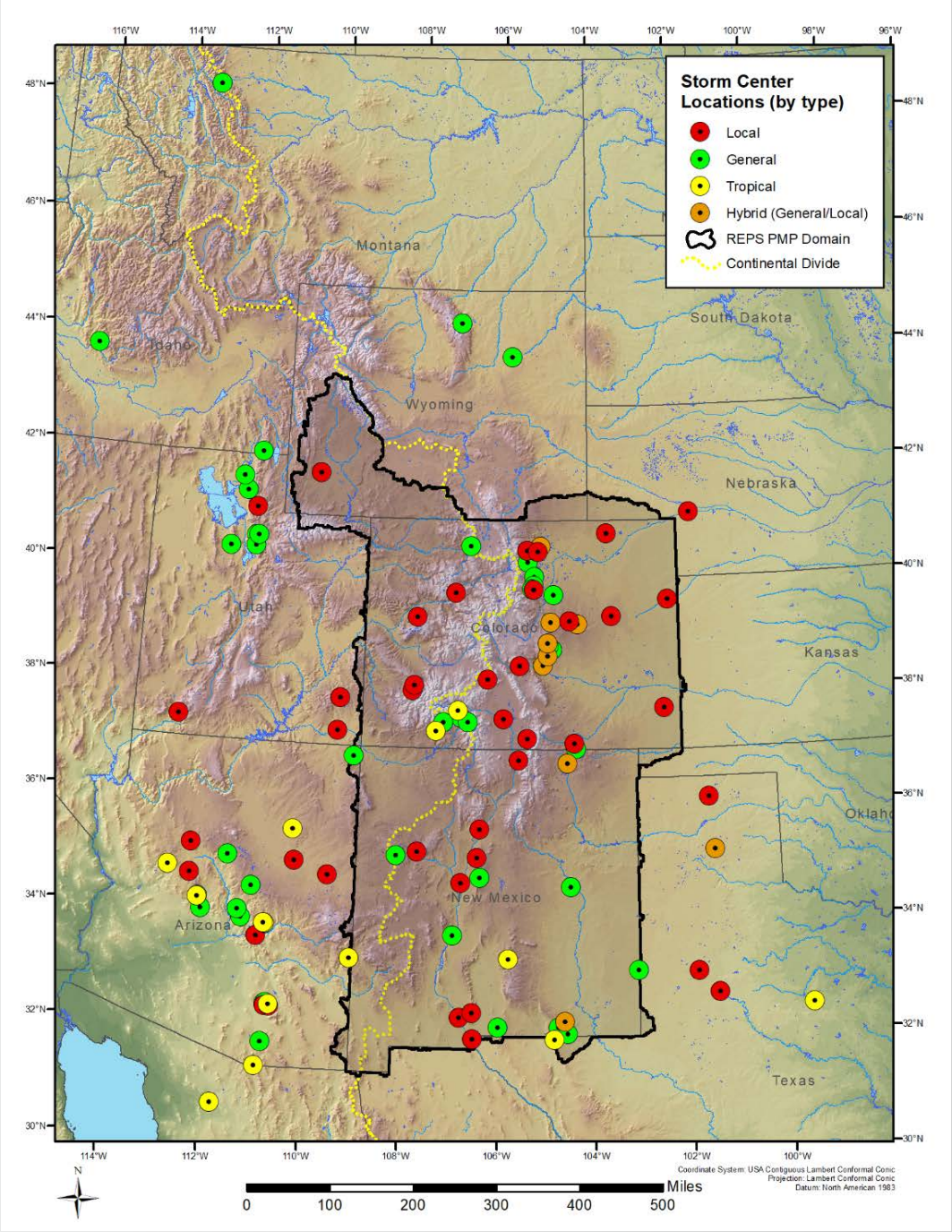
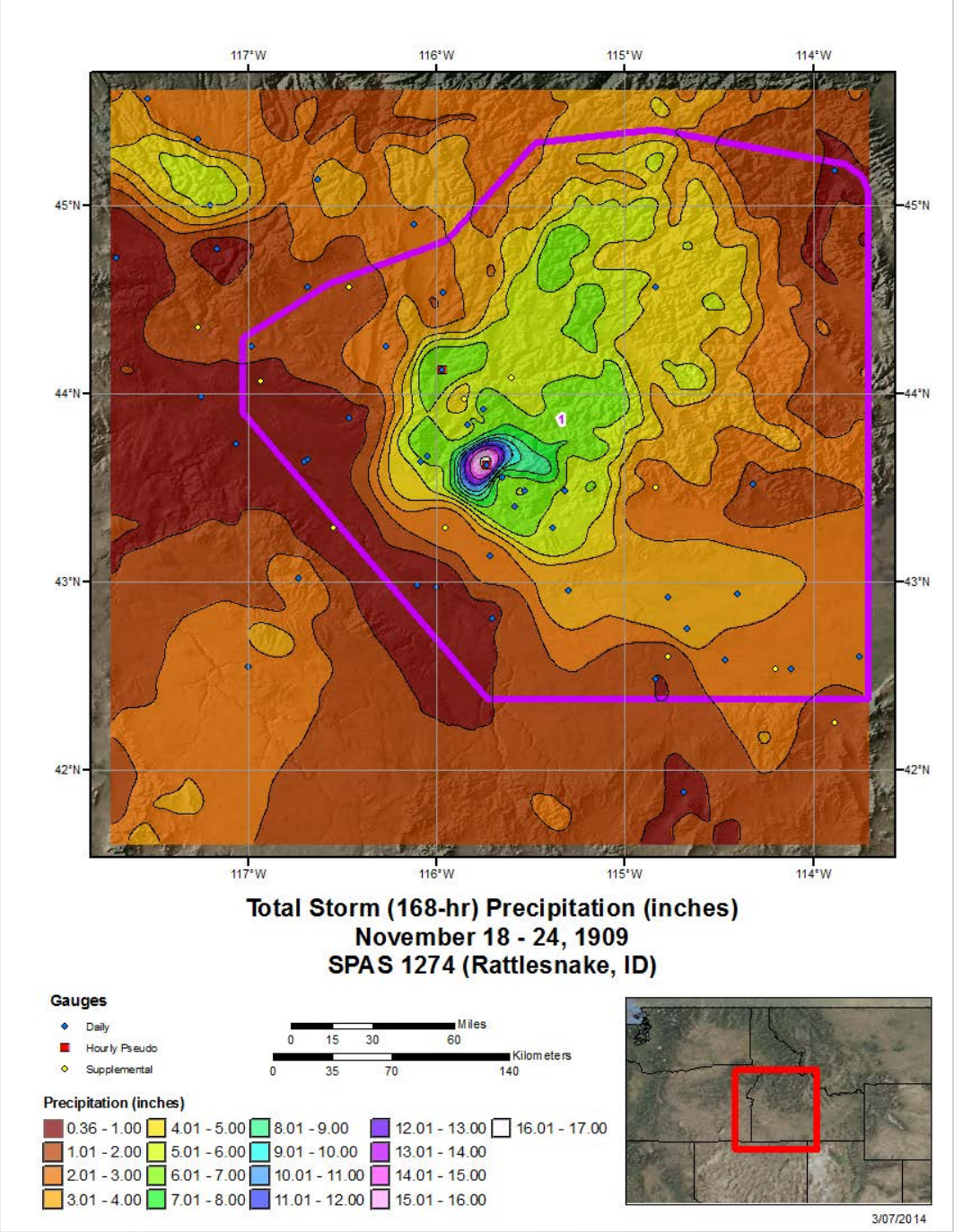
Task 1 - Deterministic PMP Analysis

- Storm- Based
- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
  - Storm Types
    - Local
    - General
    - Tropical



Storm Analysis

- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
- Analyze Storms
  - SPAS
    - Modern take on historic storms
    - Sometimes data limited



Generate DAD Tables

- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
- Analyze Storms
  - SPAS vs older methods

Storm 1231 Zone 1
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

areasqmi	1	2	3	4	Total
0.2	7.16	8.58	9.41	9.82	9.82
1	7.08	8.45	9.26	9.67	9.67
10	6.46	7.83	8.85	9.35	9.35
25	5.78	7.08	8.26	8.84	8.84
50	4.89	6.14	7.44	8.02	8.02

USBR
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

areasqmi	1-hr	2-hr	3-hr	4-hr	Total
0.2	6.7	9.5	11.3	12.5	12.5
1	6.2	8.9	10.5	11.7	11.7
10	4.8	7.2	8.6	10.0	10.0
25	3.9	5.8	7.0	8.2	8.2
50	2.7	4.1	5.0	5.9	5.9

Difference (SPAS 1231 - USBR)
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

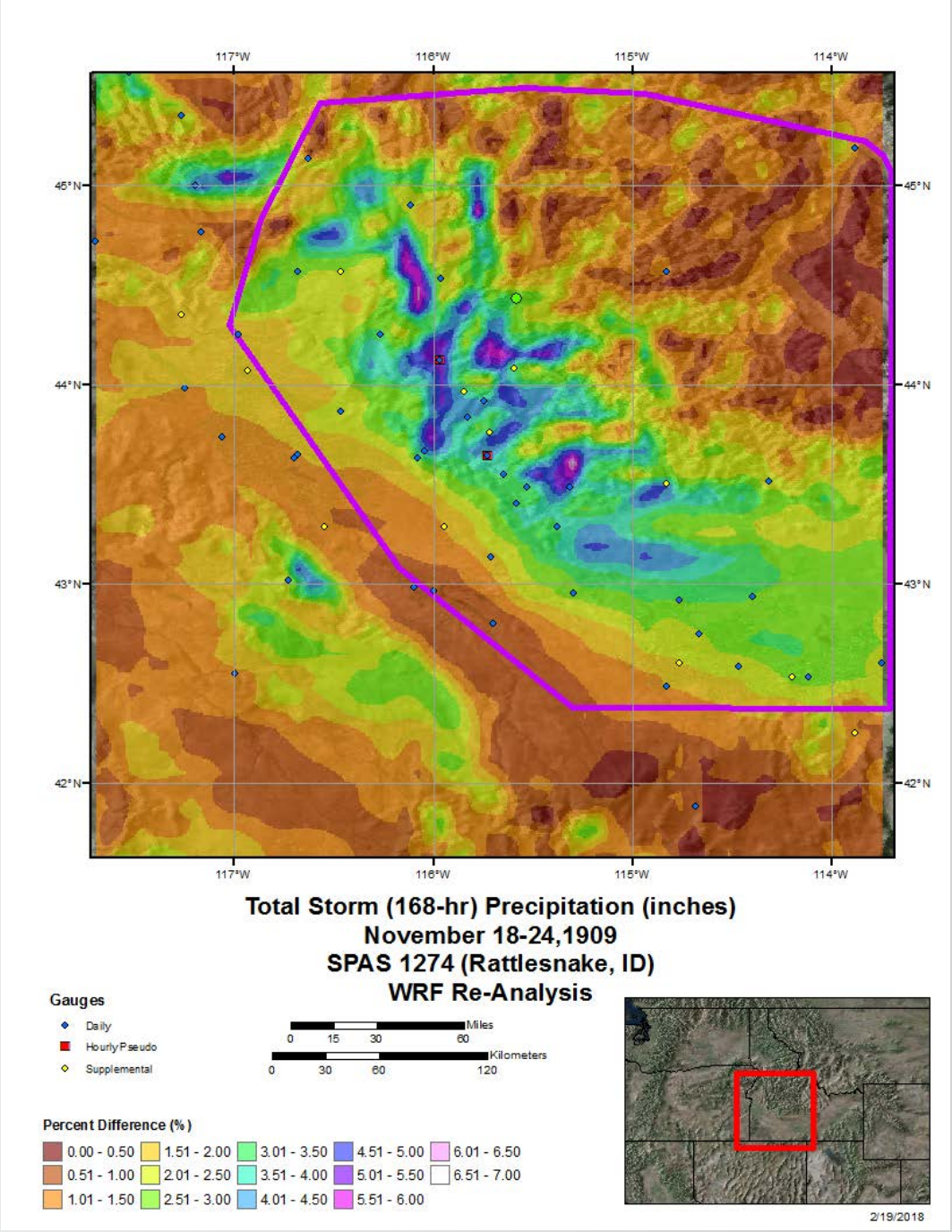
areasqmi	1-hr	2-hr	3-hr	4-hr	Total
0.2	0.5	-0.9	-1.9	-2.7	-2.7
1	0.9	-0.5	-1.2	-2.0	-2.0
10	1.7	0.6	0.3	-0.7	-0.7
25	1.9	1.3	1.3	0.6	0.6
50	2.2	2.0	2.4	2.1	2.1

Percent Difference ((SPAS 1231 - USBR)/USBR)
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

areasqmi	1-hr	2-hr	3-hr	4-hr	Total
0.2	7%	-10%	-17%	-21%	-21%
1	14%	-5%	-12%	-17%	-17%
10	35%	9%	3%	-7%	-7%
25	48%	22%	18%	8%	8%
50	81%	50%	49%	36%	36%

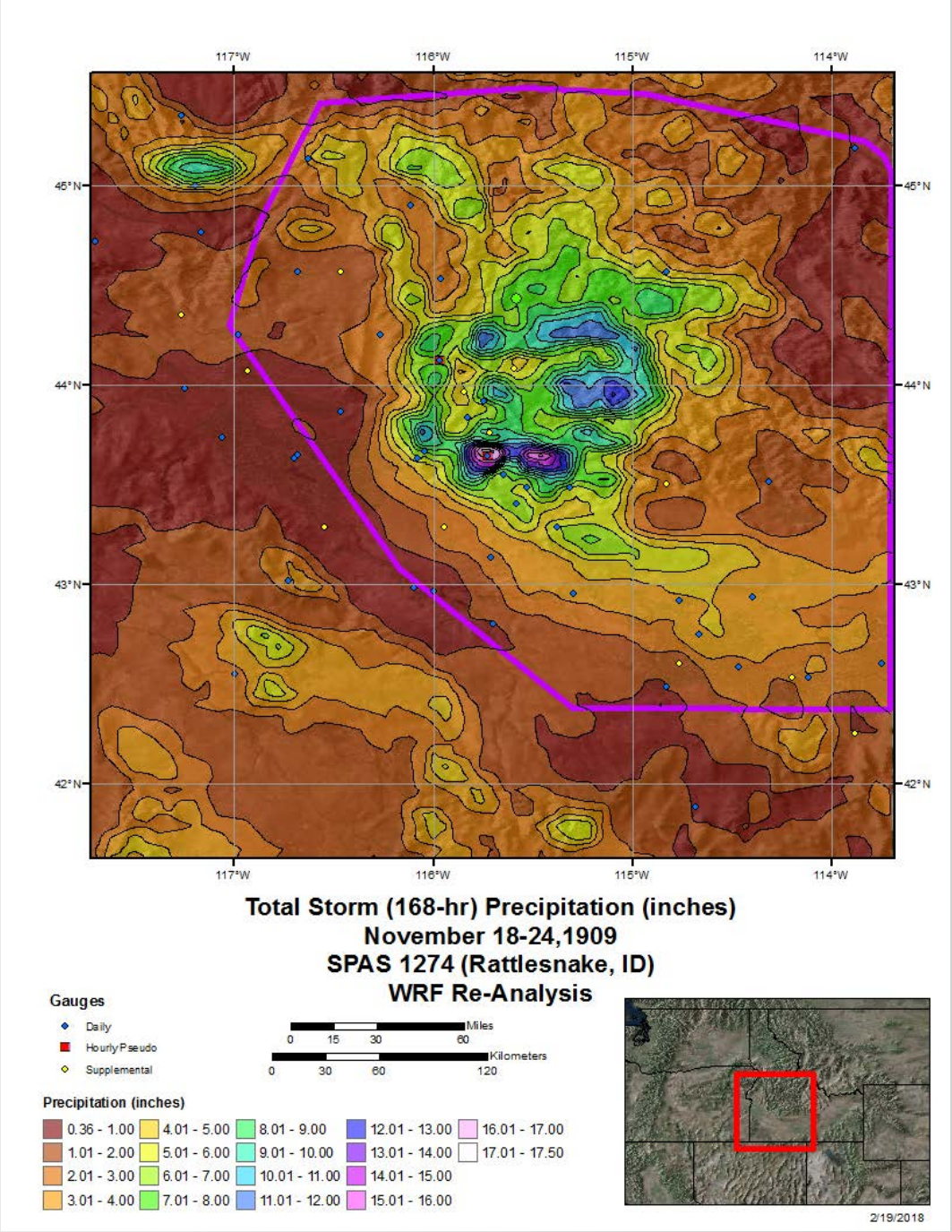
Storm Analysis Improvements

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Analyze Storms
  - SPAS
  - WRF – Re-analysis



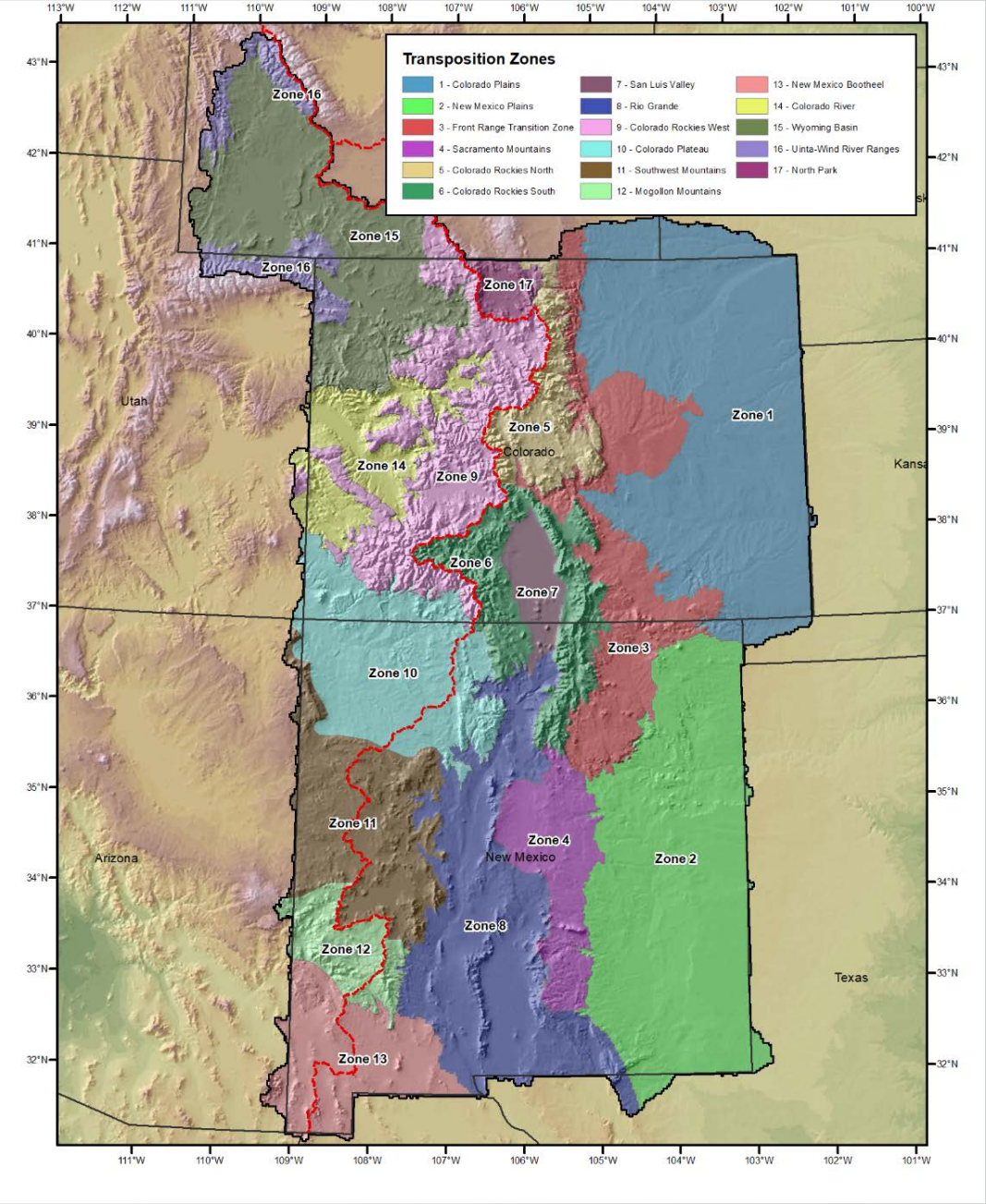
Storm Analysis Improvements

- Generally follows NOAA HMR/WMO procedures (with updates)
- Gridded, GIS-based
- Select a Storm List
- Analyze Storms
  - SPAS
  - WRF adjusted



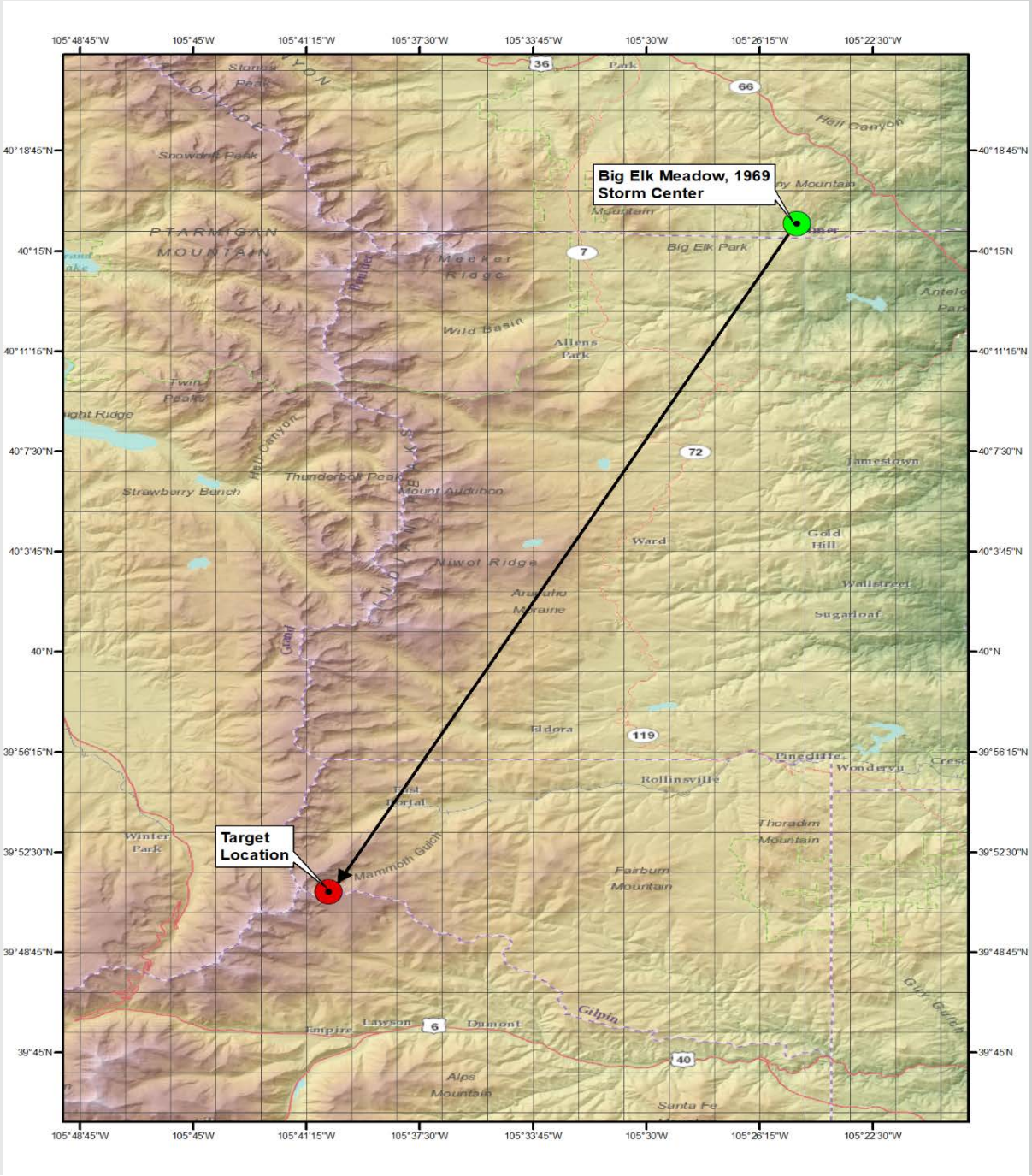
Storm Transposition

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Analyze Storms
- Define Transposition Limits



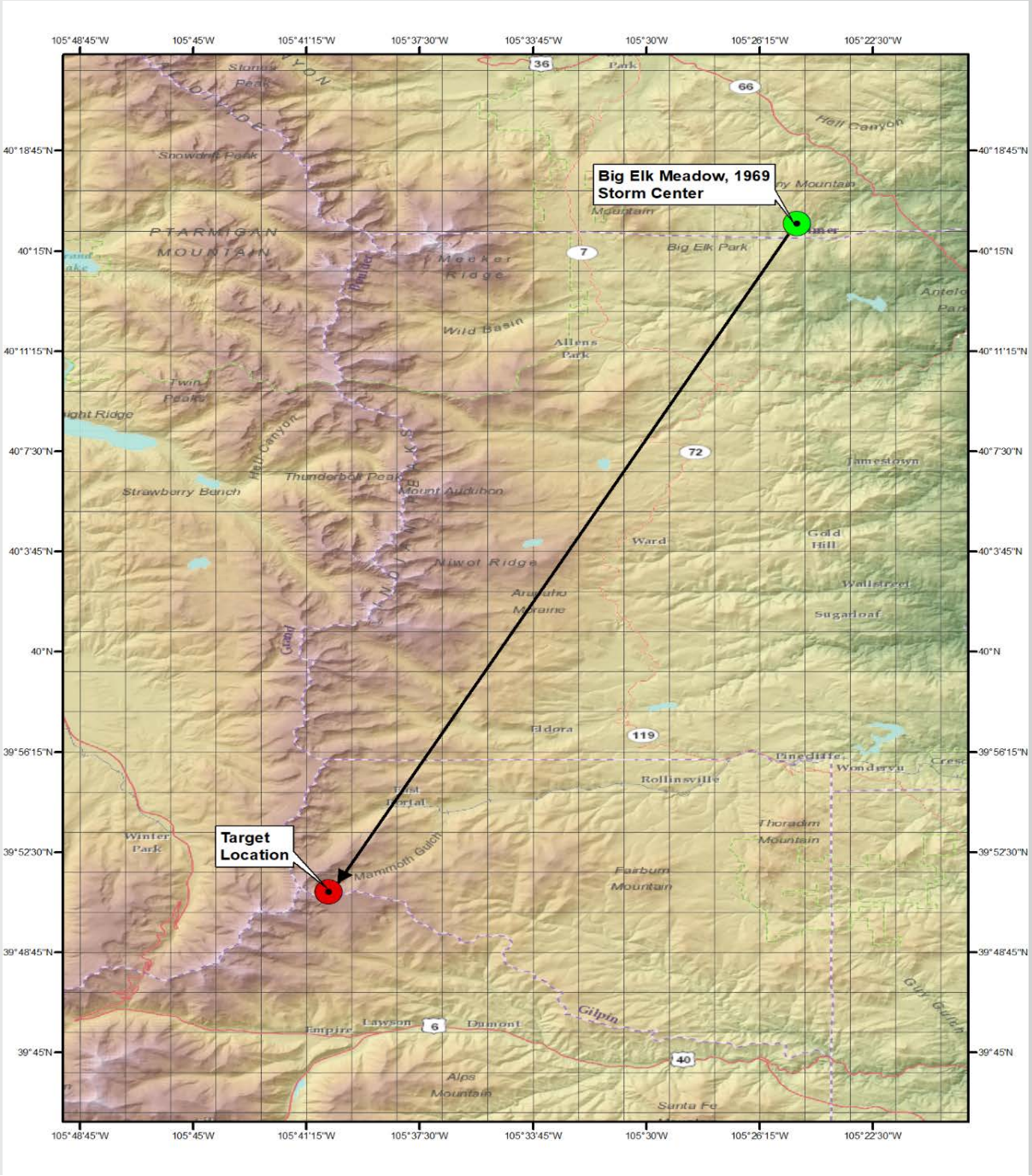
Storm Transposition

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Analyze storms
- Define Transposition Limits
  - Transpose from original to target location

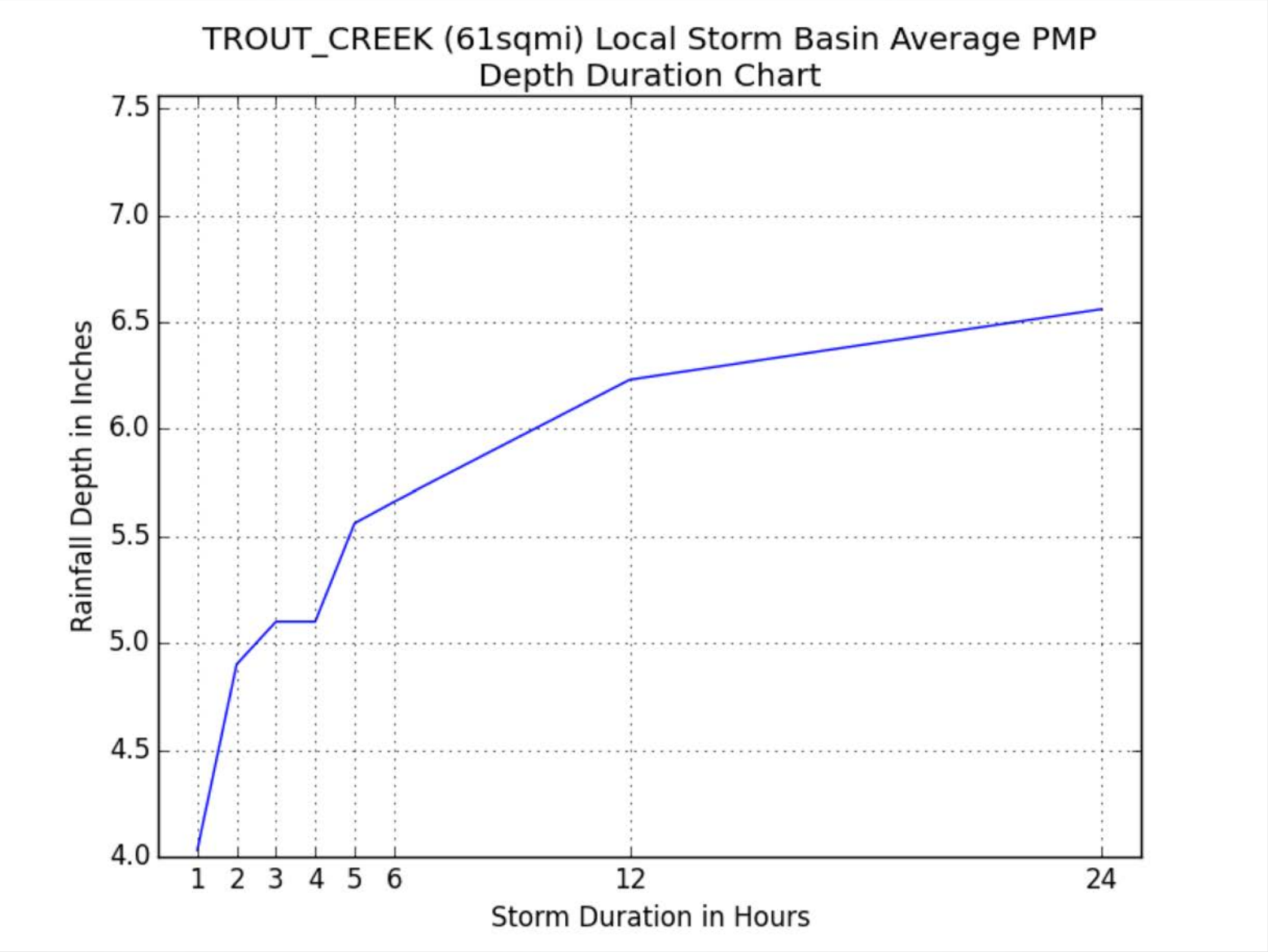


Adjustment Factors

- Generally follows NOAA HMR/WMO procedures (with updates)
- Select a Storm List
- Define Transposition Limits
  - Transpose from original to target location
  - Apply adjustment factors
    - IPMF, MTF, GTF
    - Product = TAF



Example Results – Basin of Interest



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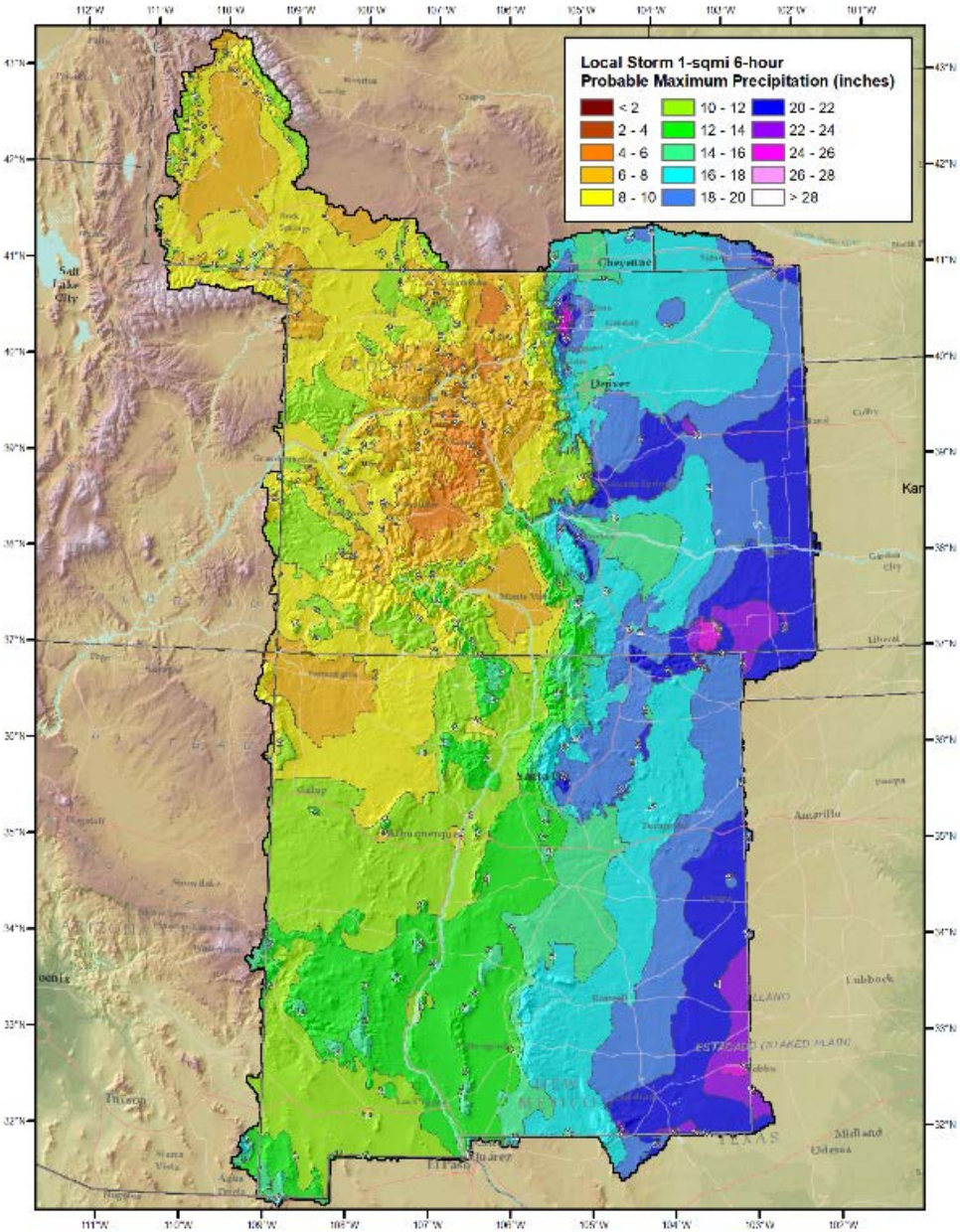
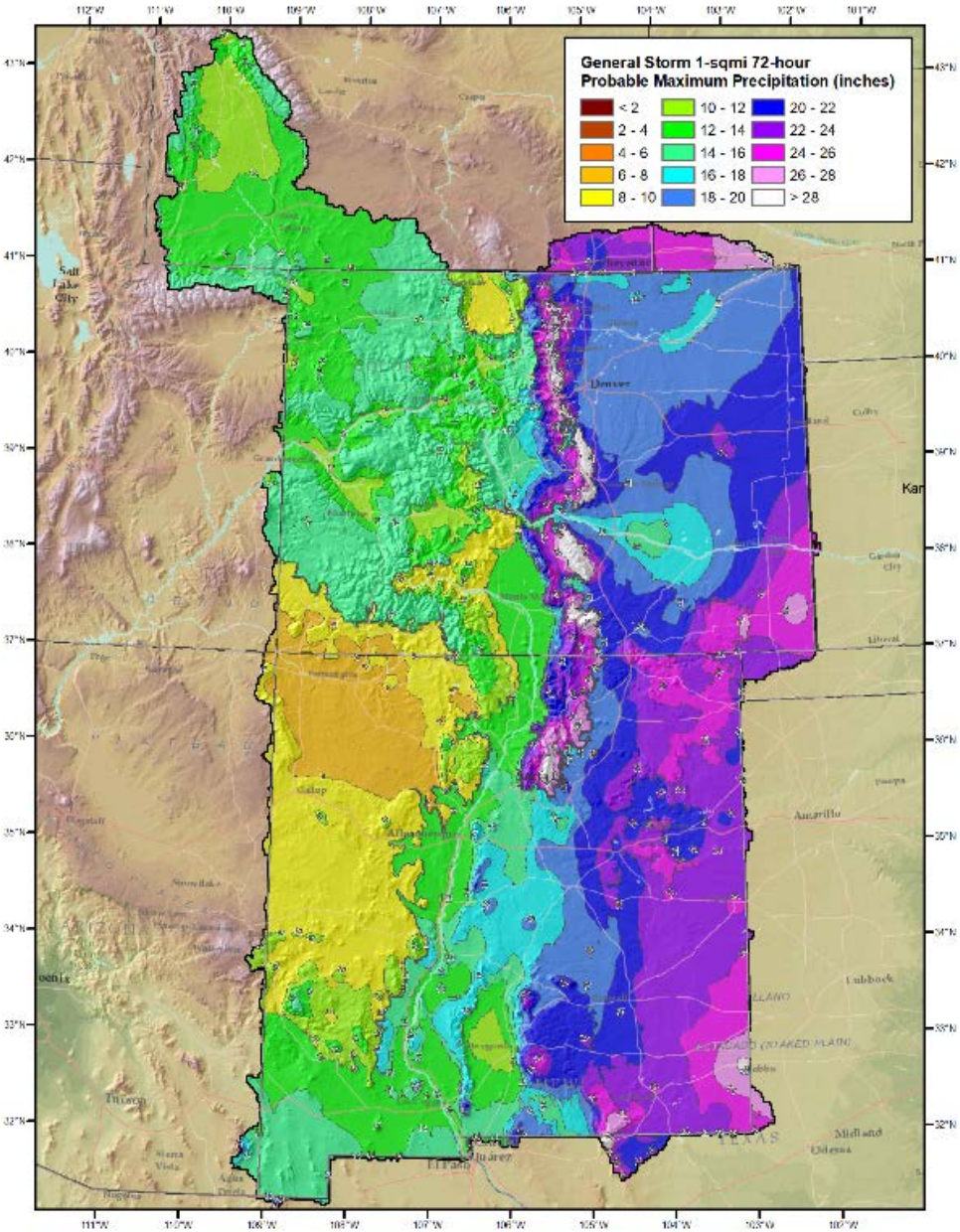
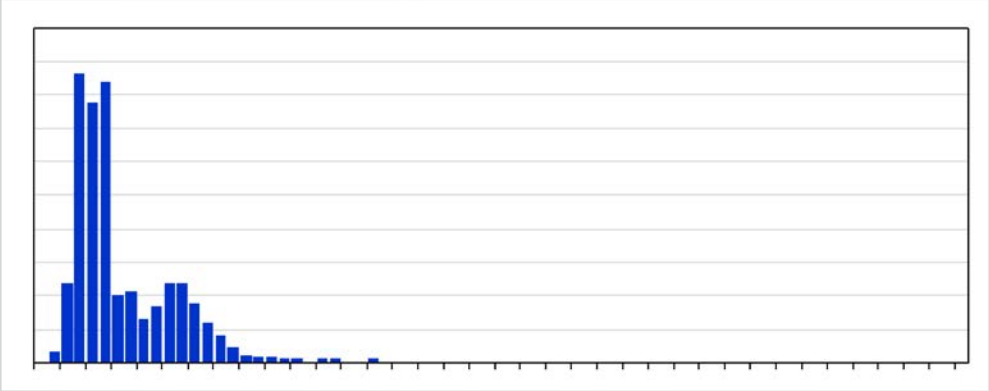
Example Results – Regional GS

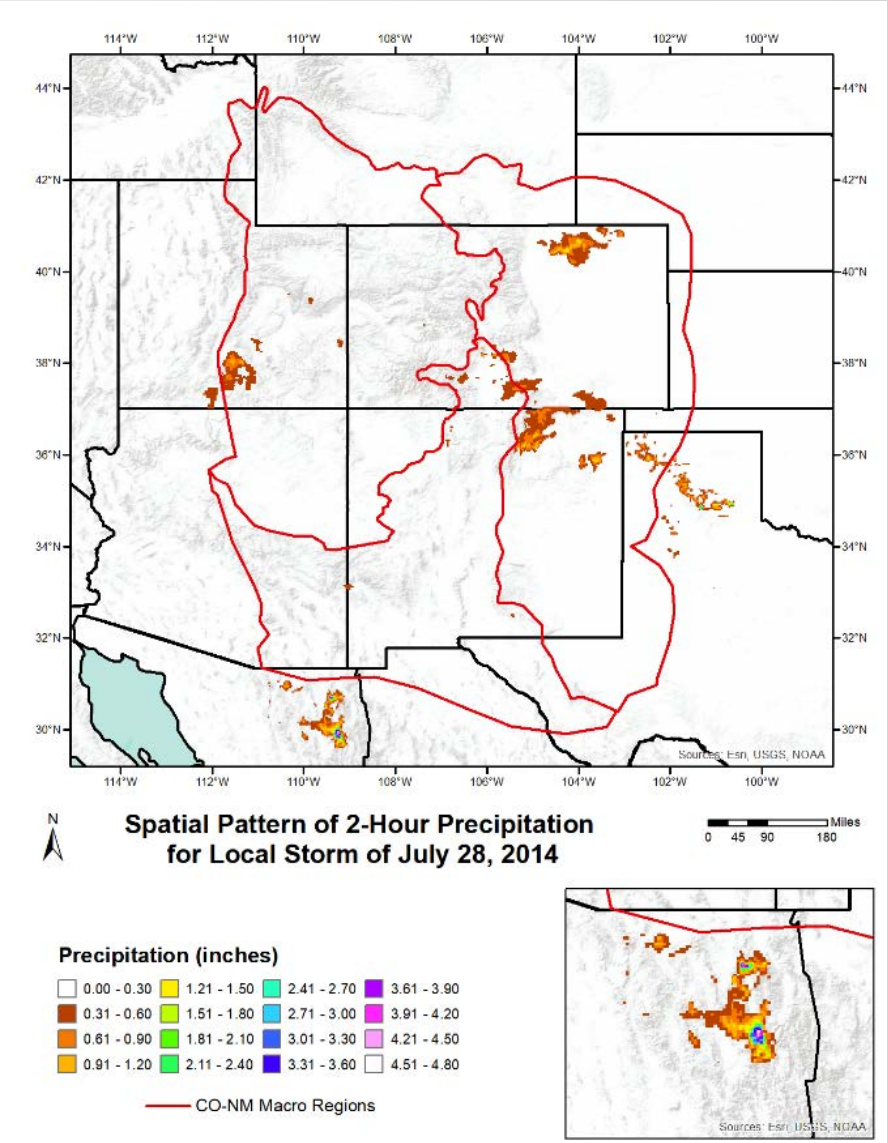




Task 2 – Regional Precipitation-Frequency Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - Local – 2 hr

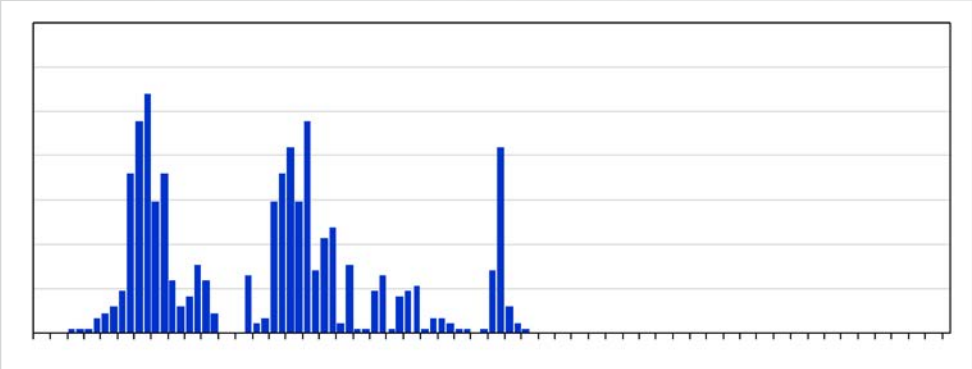


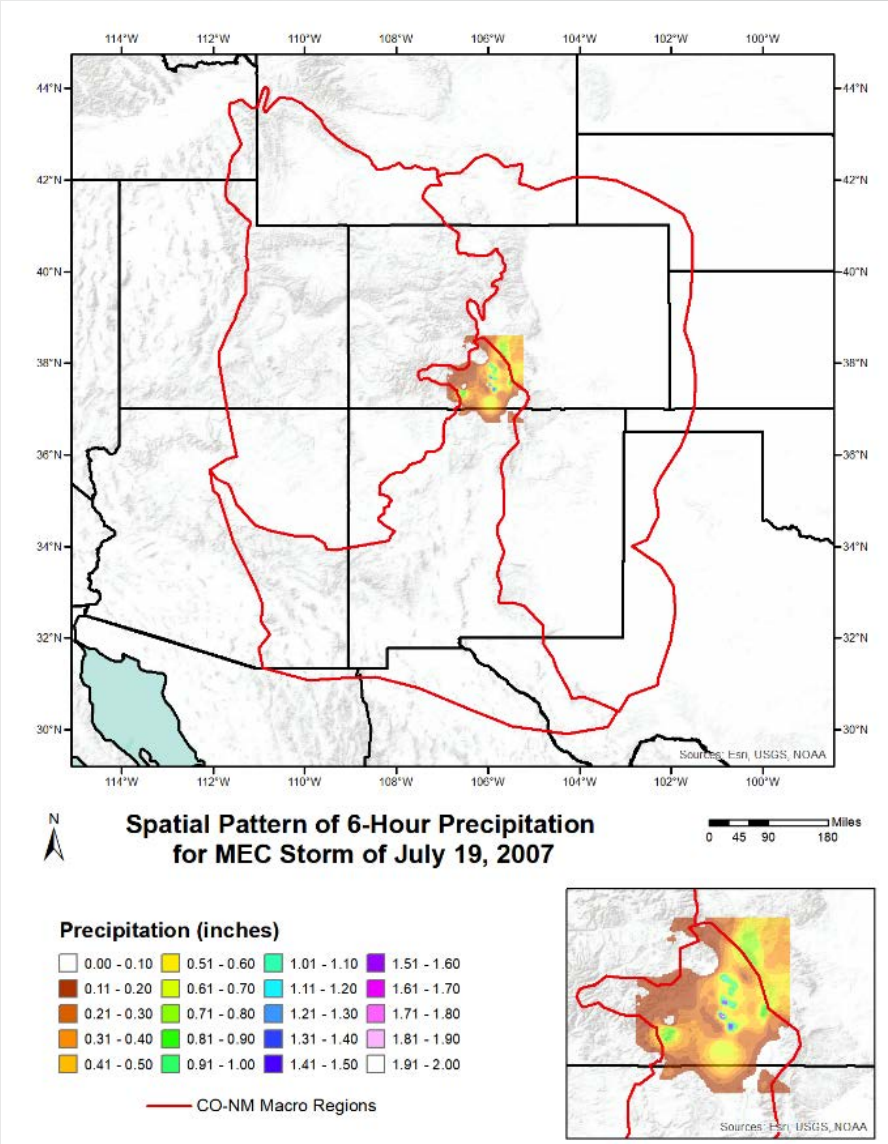


Local storm temporal and spatial signatures

Task 2 – Regional Precipitation-Frequency Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - MEC – 6 hr

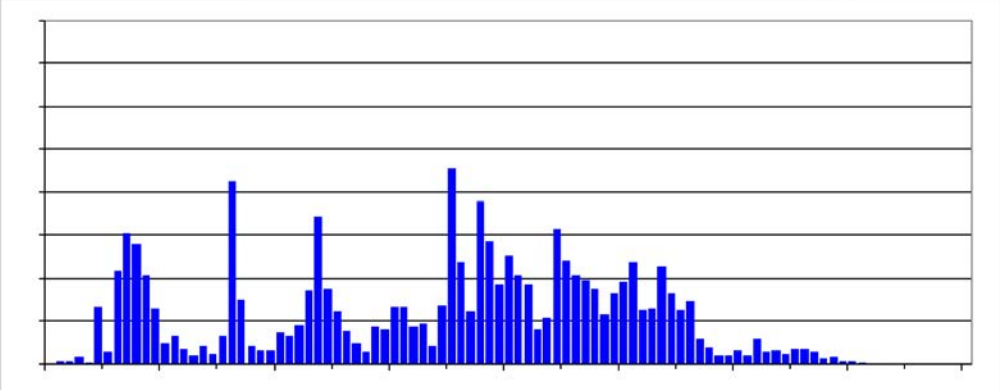


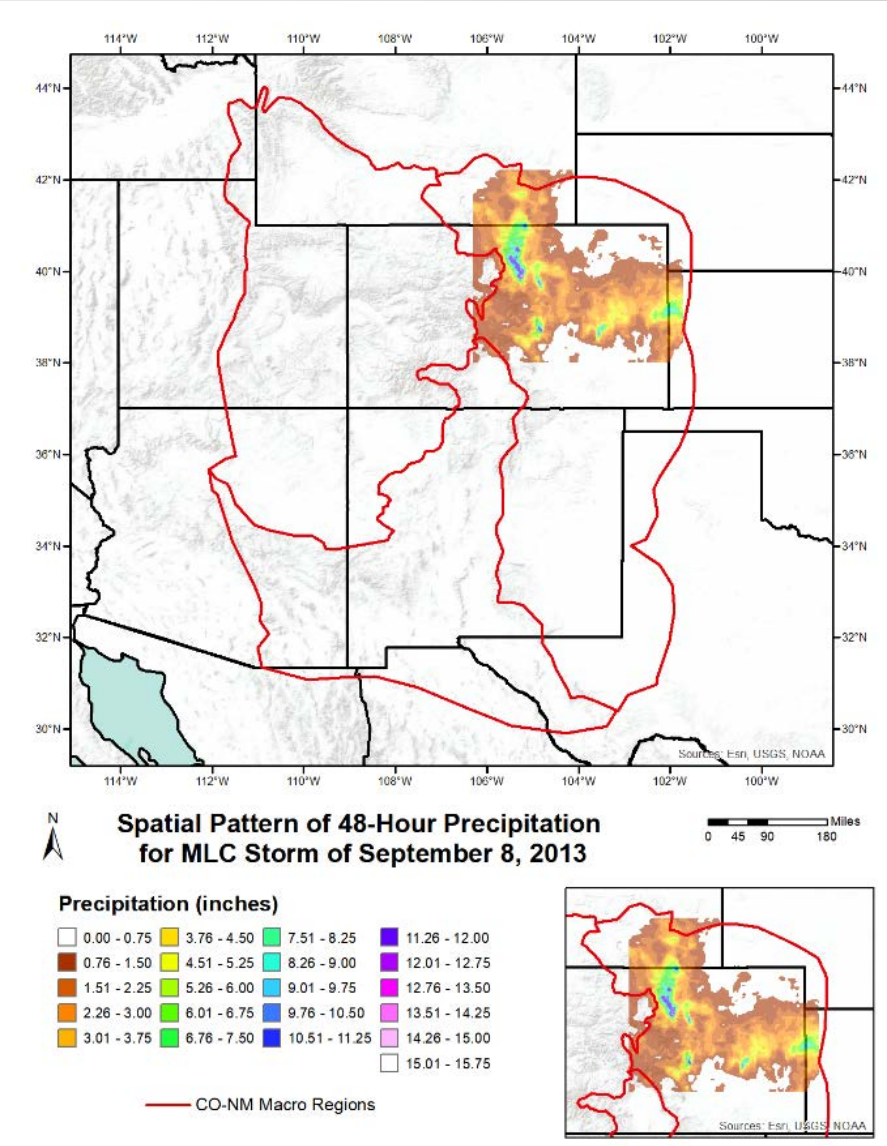


MEC storm temporal and spatial signatures

Task 2 – Regional Precipitation-Frequency Analysis

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - MLC – 48hr



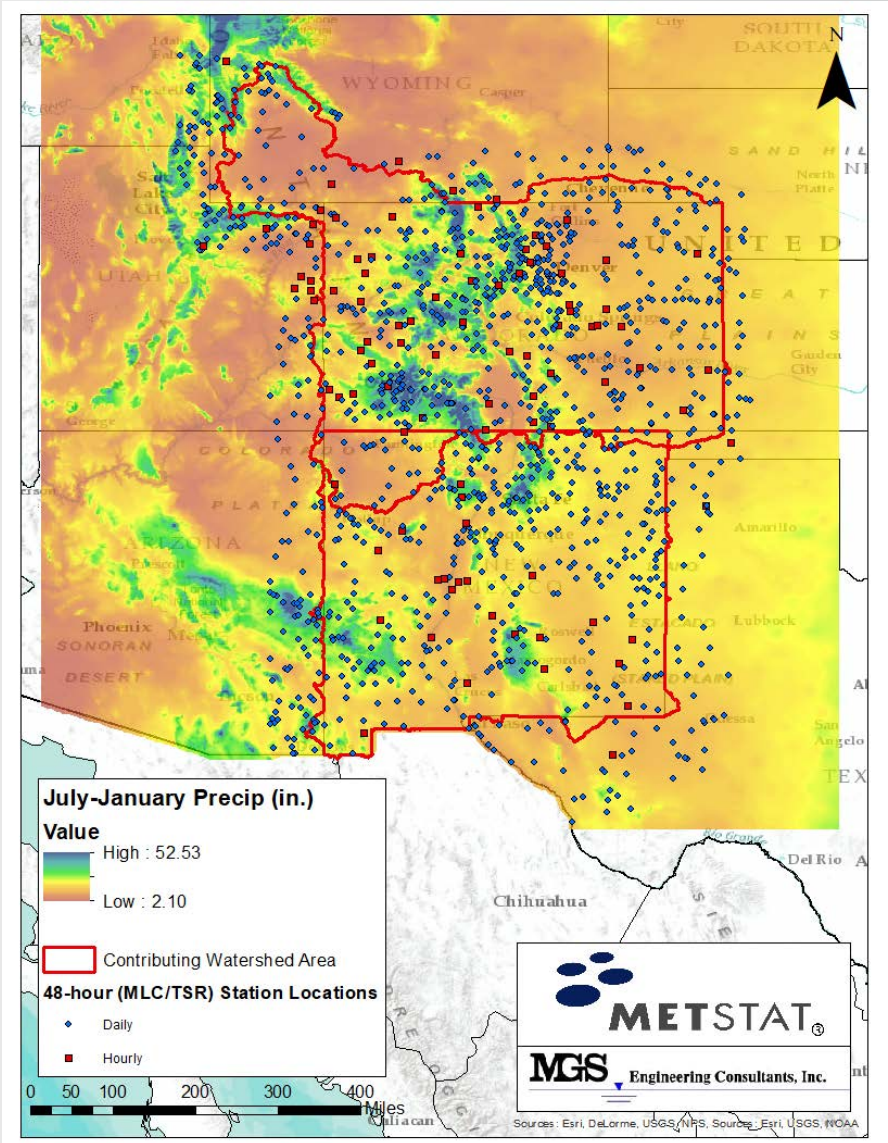


MLC storm temporal and spatial signatures

Gauge/Station Data

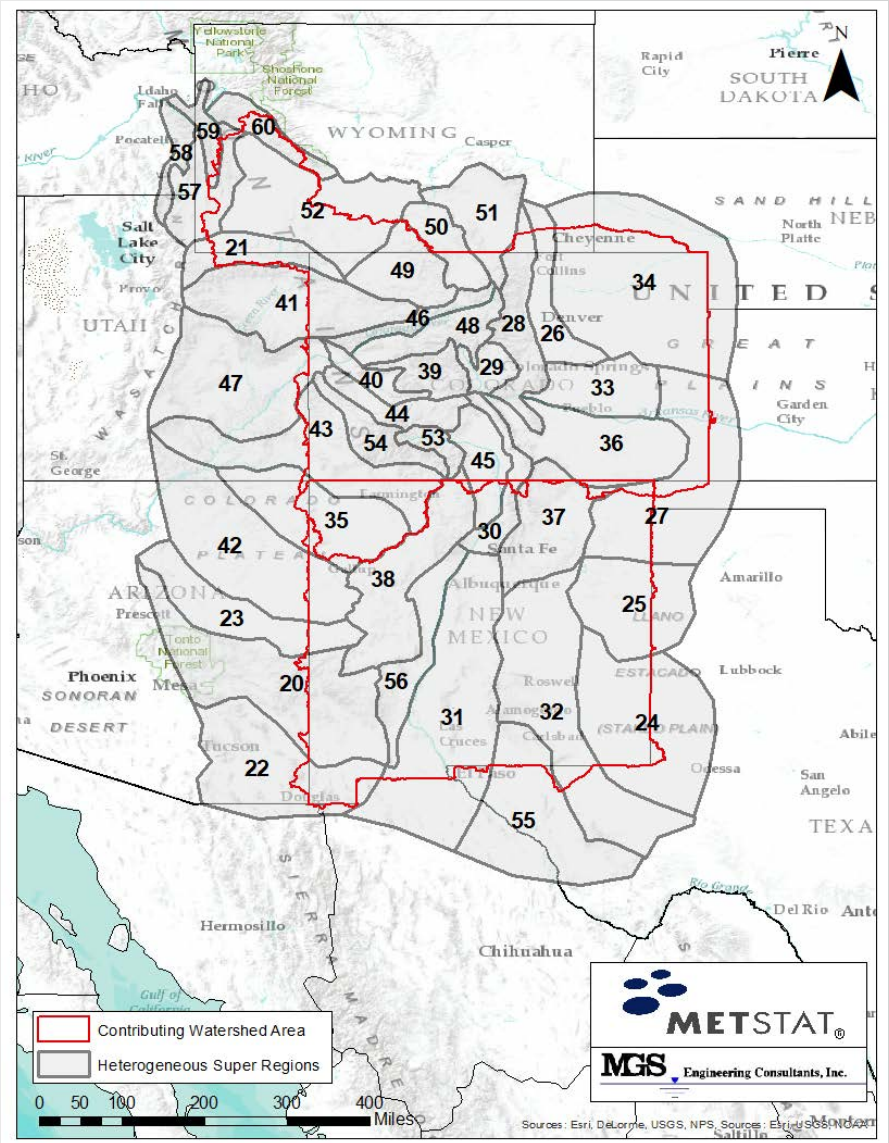
- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
  - From gauge data – MLC
  - From gauge data – MEC
  - From gauge data - Local

PRECIPITATION GAUGE TYPE	NUMBER OF STATIONS/GAUGES	TOTAL STATION DATA YEARS	AVERAGE STATION YEARS
Daily Stations	1,052	60,019	57
Hourly Stations	91	3,373	37
TOTAL	1,143	63,392	55



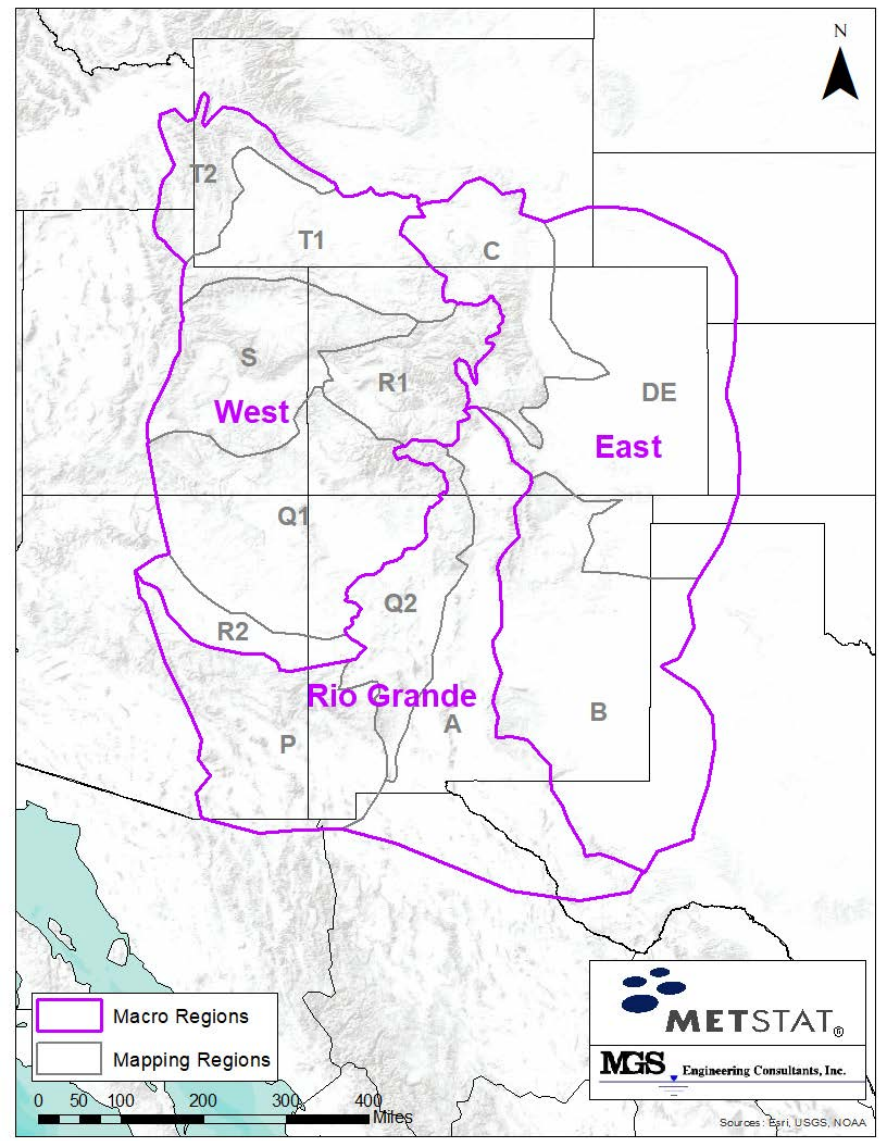
Statistical Mapping

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
  - Heterogeneous Regions (41)



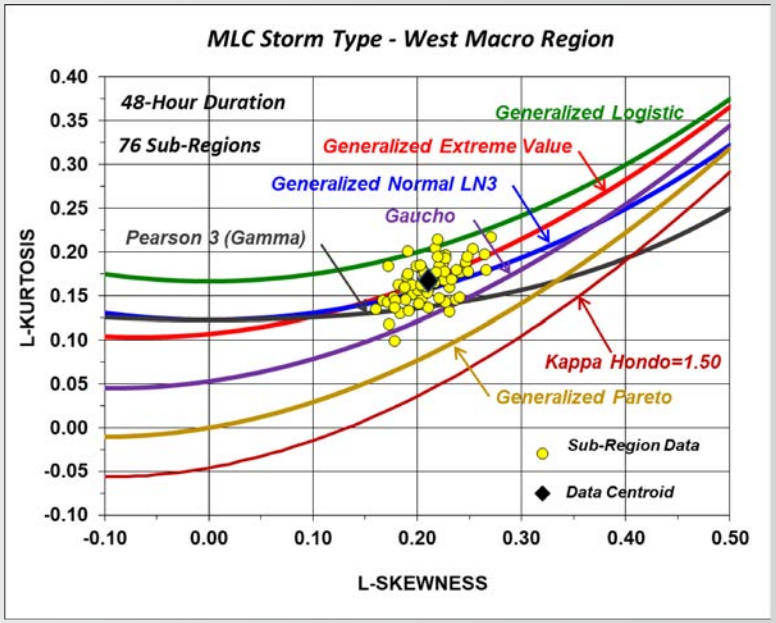
Statistical Mapping

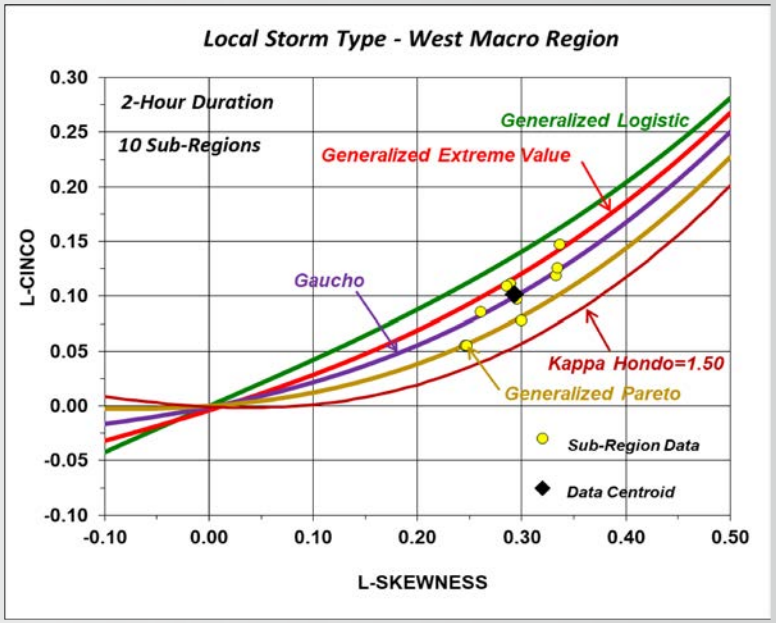
- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
  - Heterogeneous Regions (41)
  - Mapping Areas (12)
  - Macro Regions (3)



Statistical Analysis

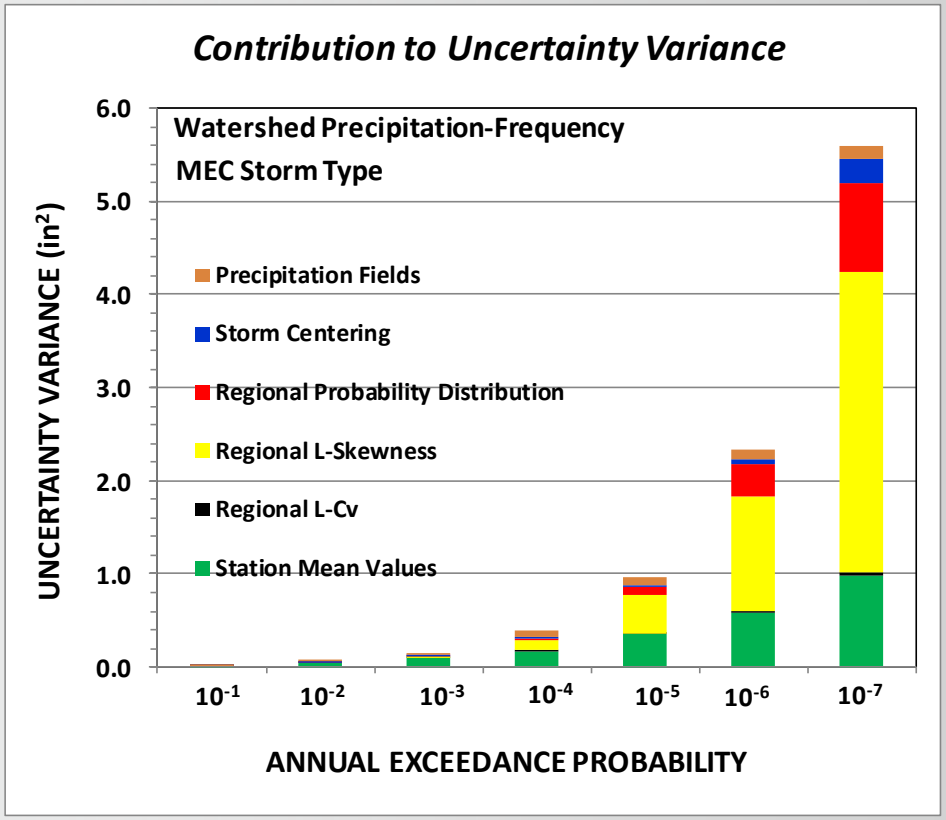
- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
- Statistical Analysis
  - GEV
  - L-Kurtosis
  - L-skewness
  - L-cinco

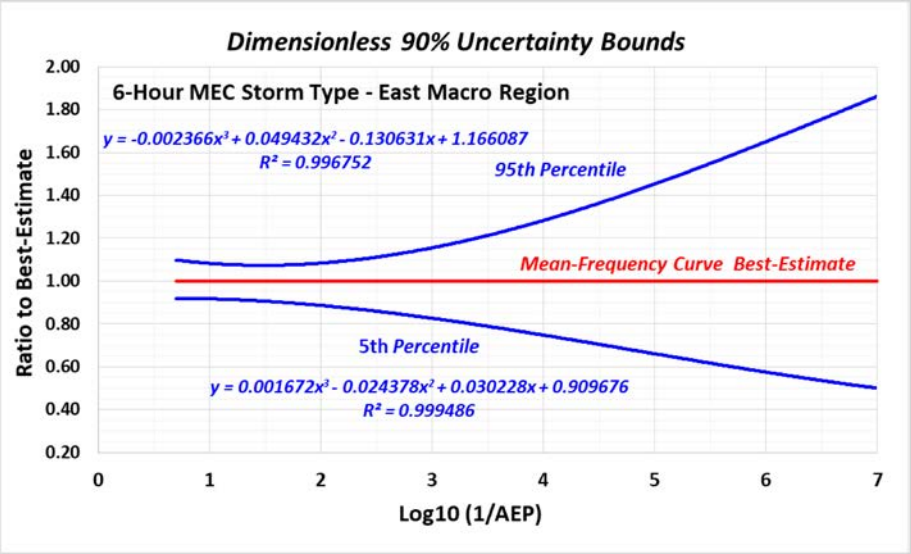




Uncertainty Analysis

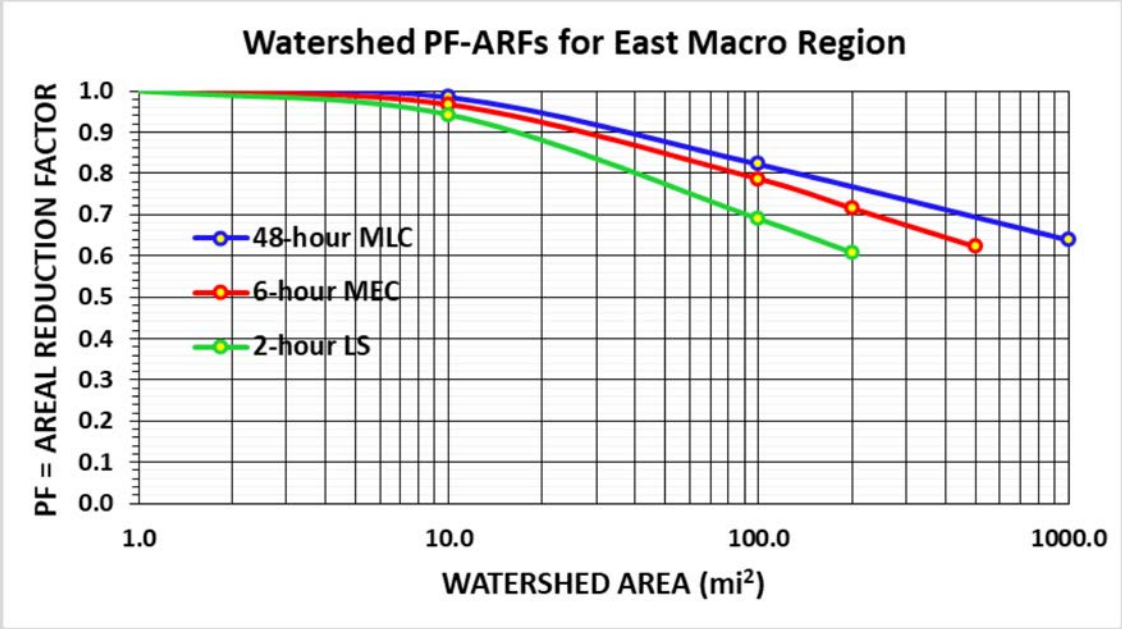
- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets required
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
- Statistical Analysis
- Uncertainty Analysis





Areal Reduction Factors

- Statistical: PMP more rare than NOAA Atlas 14 (AEP 10E-6 or less)
- L-Moment analysis
- Utilize data from existing rain gauge networks
- Homogeneous datasets
- Key Durations: 2, 6, 48 hour
- Storm Typing
- Regional Statistical Mapping
- Statistical Analysis
- Uncertainty Analysis
- Areal reduction factors
  - Watershed PF



MACRO REGION	LS (2-HOUR)	MEC (6-HOUR)	MLC (48-HOUR)
East	Up to 200 mi^2	Up to 500 mi^2	Up to 1,000 mi^2
Rio Grande	Up to 200 mi^2	Up to 500 mi^2	Up to 500 mi^2
West	Up to 100 mi^2	Up to 200 mi^2	Up to 500 mi^2

Results - Web-based Tool

- Storm typing
  - avoids mixed populations
- Spatial mapping
  - Homogeneity
  - Grouping of stations
  - Regional behavior
  - Reduced sampling variability
- Decreased uncertainty
- Point PF
  - User defined point
- Watershed PF
  - User provided watershed

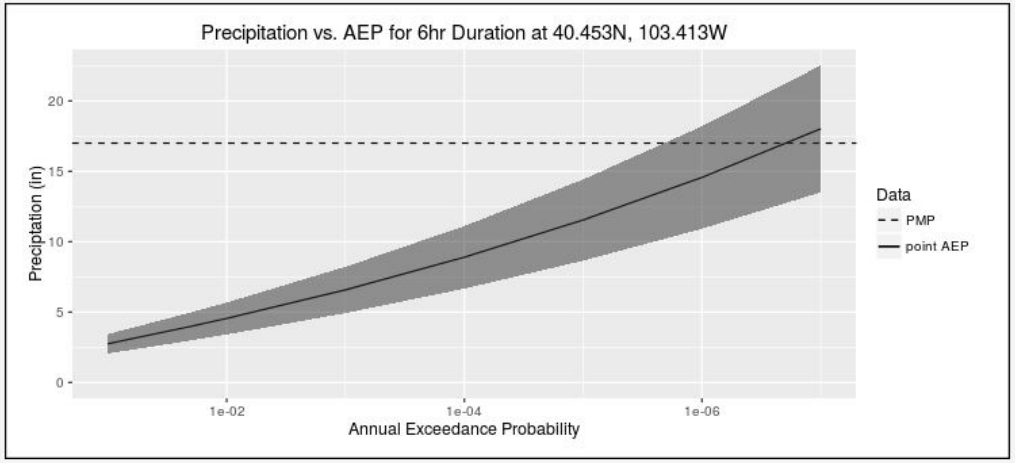
Probable Maximum Precipitation (Inches) -- entered value will plot as dashed line

17

☑ Show Uncertainty Bounds?

Precipitation (in) for 6hr Duration and Given AEP at 40.453N, 103.413W

	lower bound (in)	best estimate (in)	upper bound (in)
AEP=10^-1	2.06	2.75	3.44
AEP=0.02	2.99	3.99	4.98
AEP=10^-2	3.41	4.55	5.69
AEP=10^-3	4.93	6.58	8.22
AEP=10^-4	6.67	8.89	11.12
AEP=10^-5	8.66	11.54	14.43
AEP=10^-6	10.92	14.57	18.21
AEP=10^-7	13.52	18.02	22.53



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Task 3-Dynamical Model Approaches to PMP using the HRRR and WRF

Goal: Perform a feasibility study to test and evaluate the potential benefits of adopting a high-resolution dynamical modeling-based framework for estimating the probable maximum precipitation (PMP) across Colorado and New Mexico.

Team:

Kelly Mahoney (NOAA ESRL PSD)

Eric James (NOAA ESRL GSD and CIRES/Univ of CO)

Trevor Alcott (NOAA ESRL GSD)

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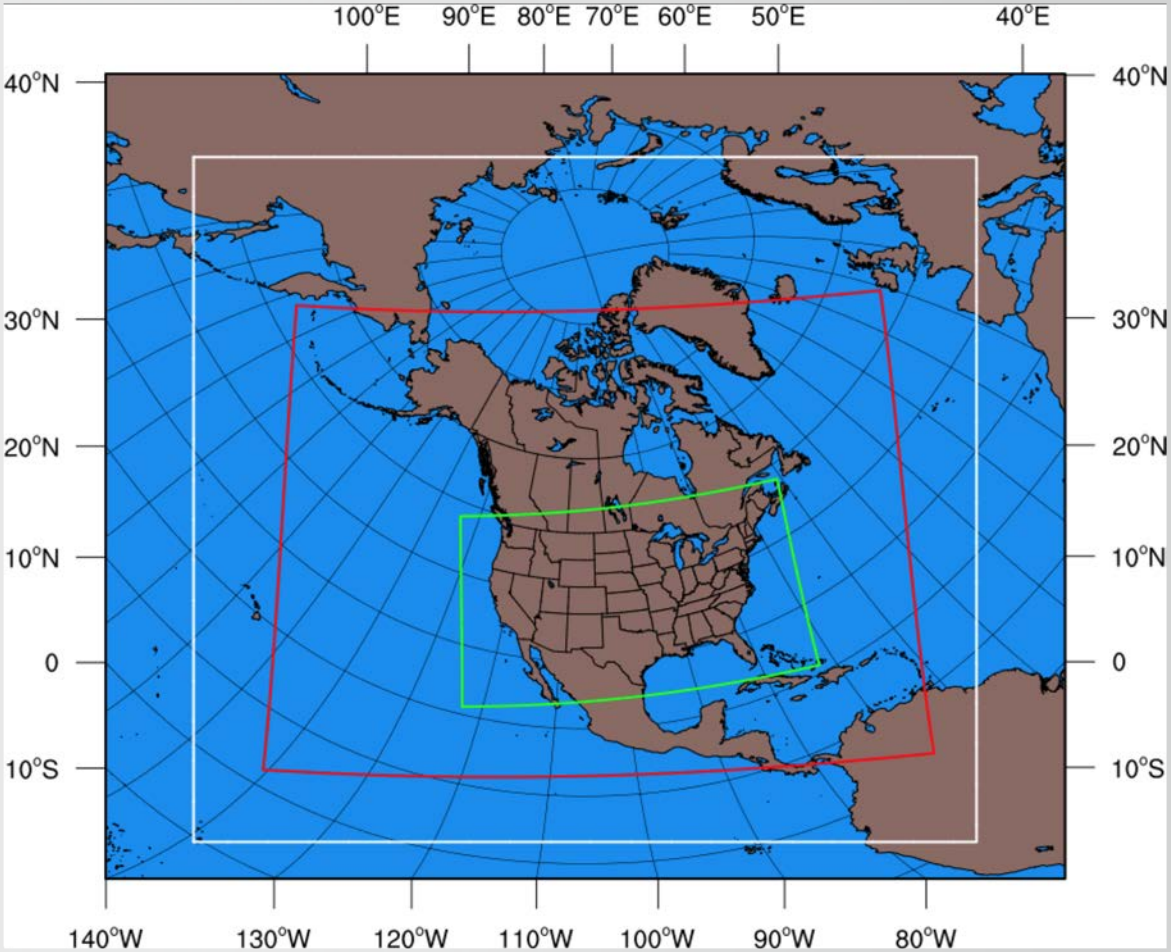
NOAA – HRRR Model Process

Strengths

- 3 km grid, CONUS coverage
- 1-hr forecasts, looking ahead 18 hrs
- Real time data assimilation
- Solves physical equations of the atmosphere
- Fewer assumptions
- Continuous updating & improved since 2012
- Increases in computing power

Weaknesses

- Short period of record
- Rare events not captured
- Not used explicitly for PMP "forecasting" or "estimating"



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Raw Maximum Precipitation

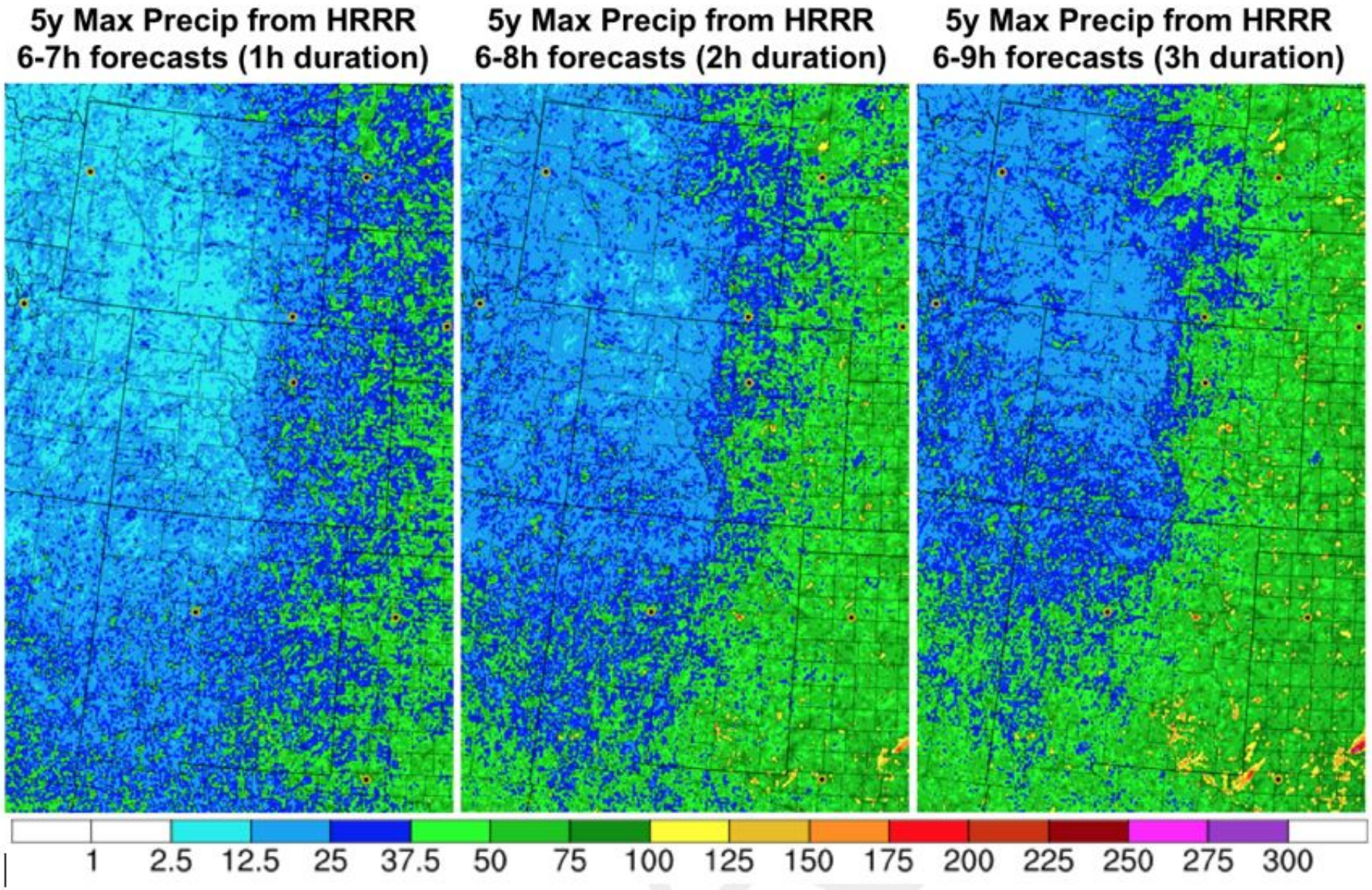


Figure 16. Maximum precipitation (mm) within the 5-year HRRRX dataset occurring for (left) 1 h, (center) 2 h, and (right) 3 h durations.

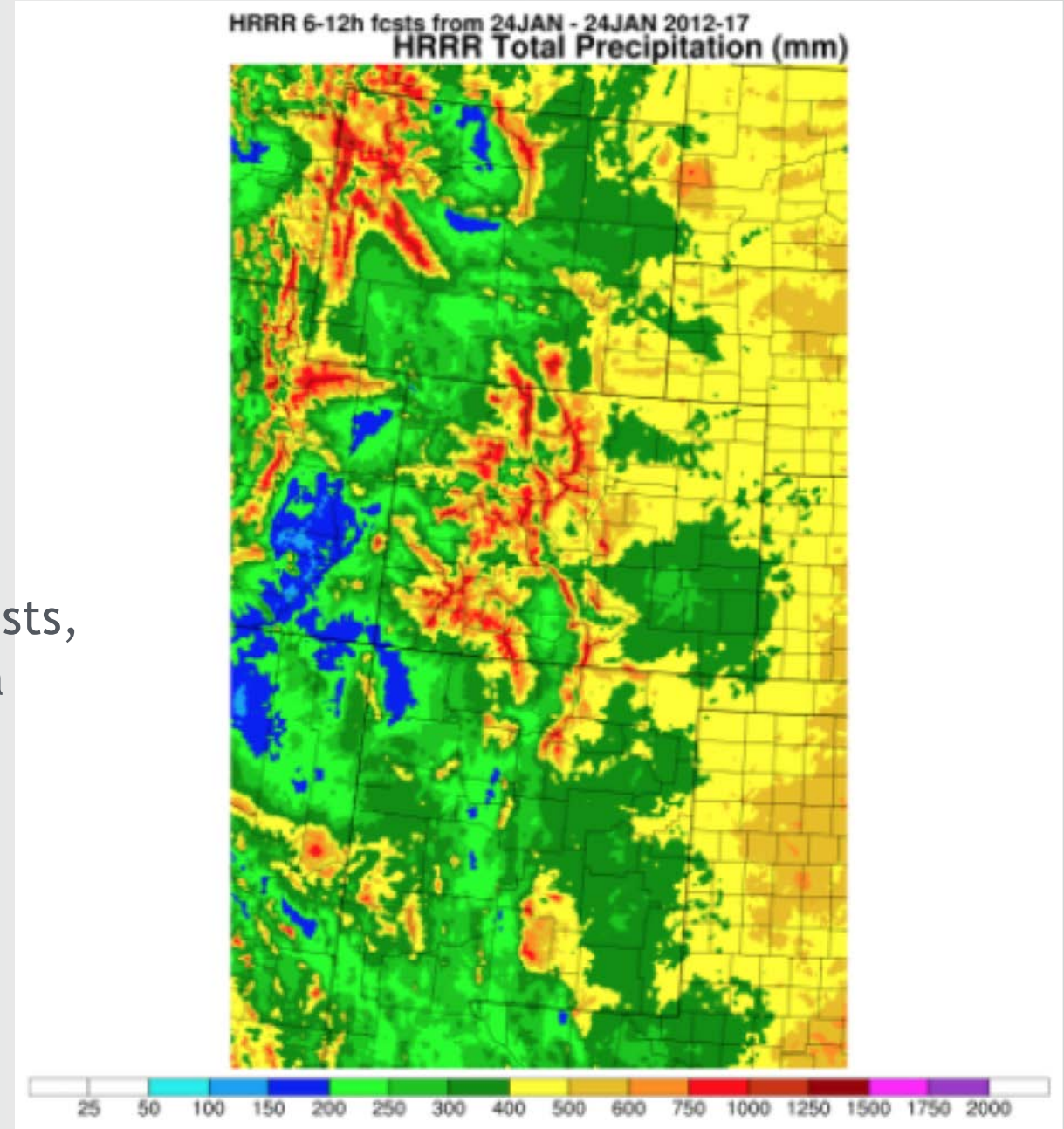
Mean Annual Maximum

<u>Strengths</u>

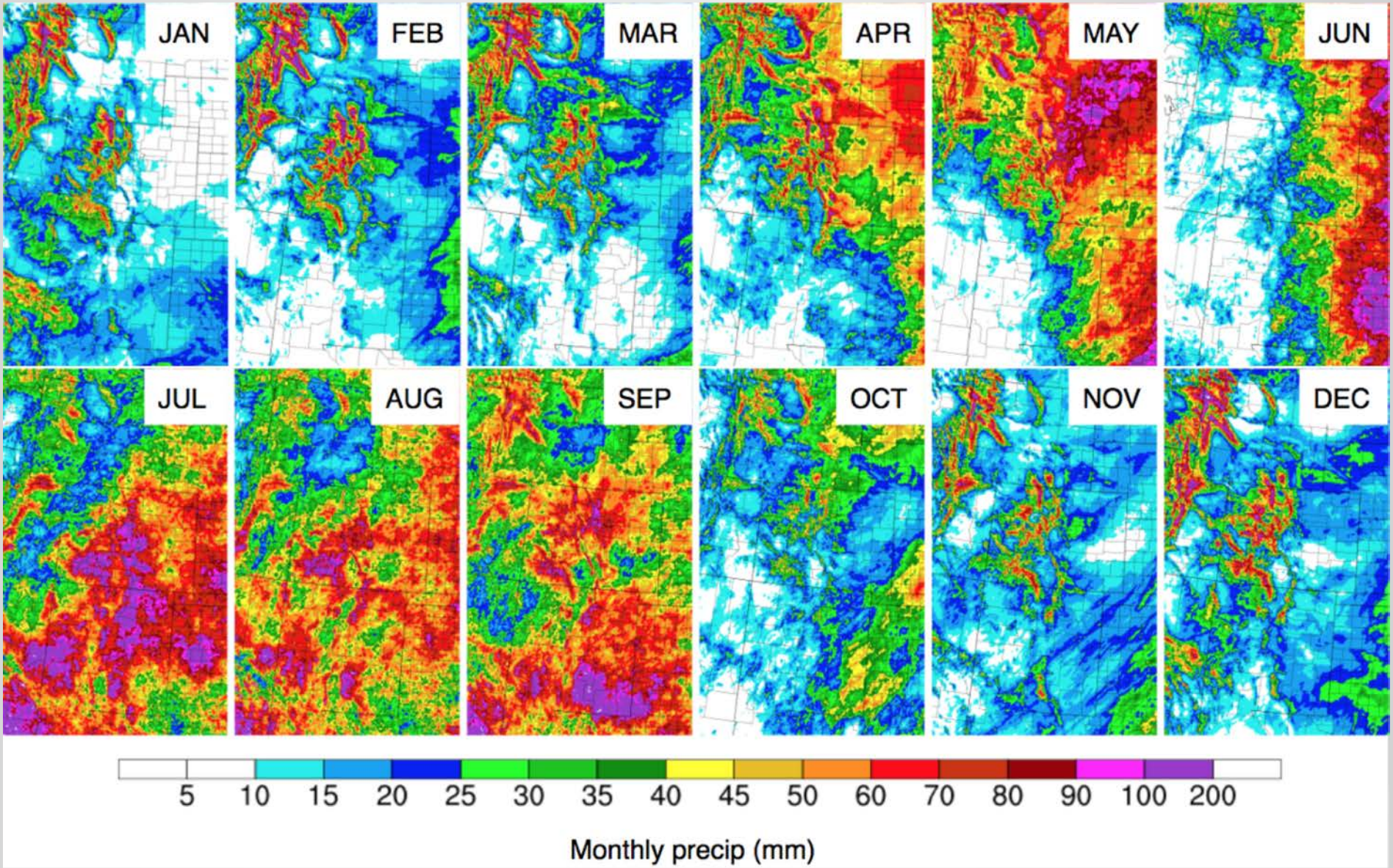
- Multiple 6 hour forecasts summed
- Obvious climatological patterns

<u>Weaknesses</u>

- Missing HRRRX 6-hr forecasts, results in incomplete data (30% complete)

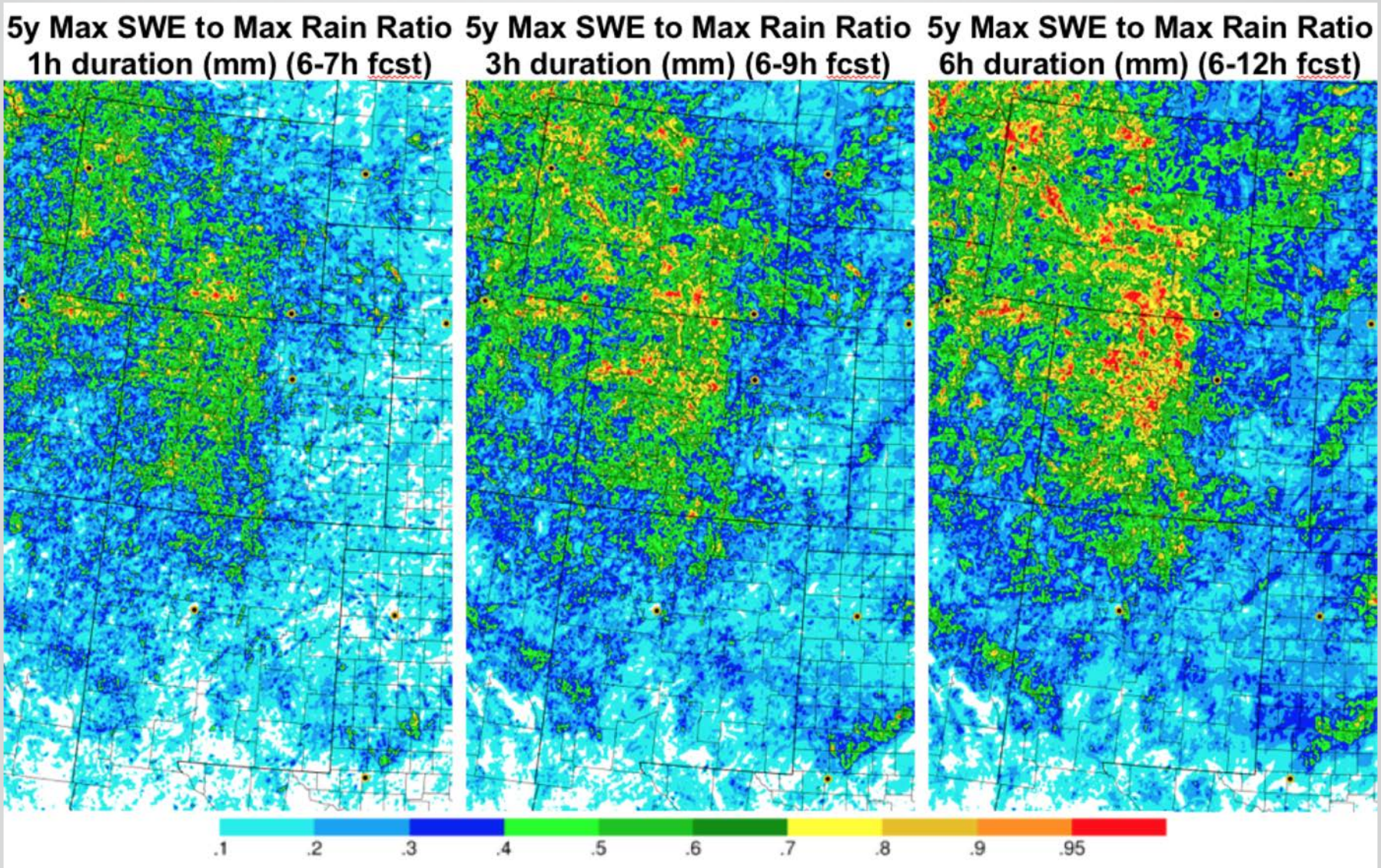


Seasonality



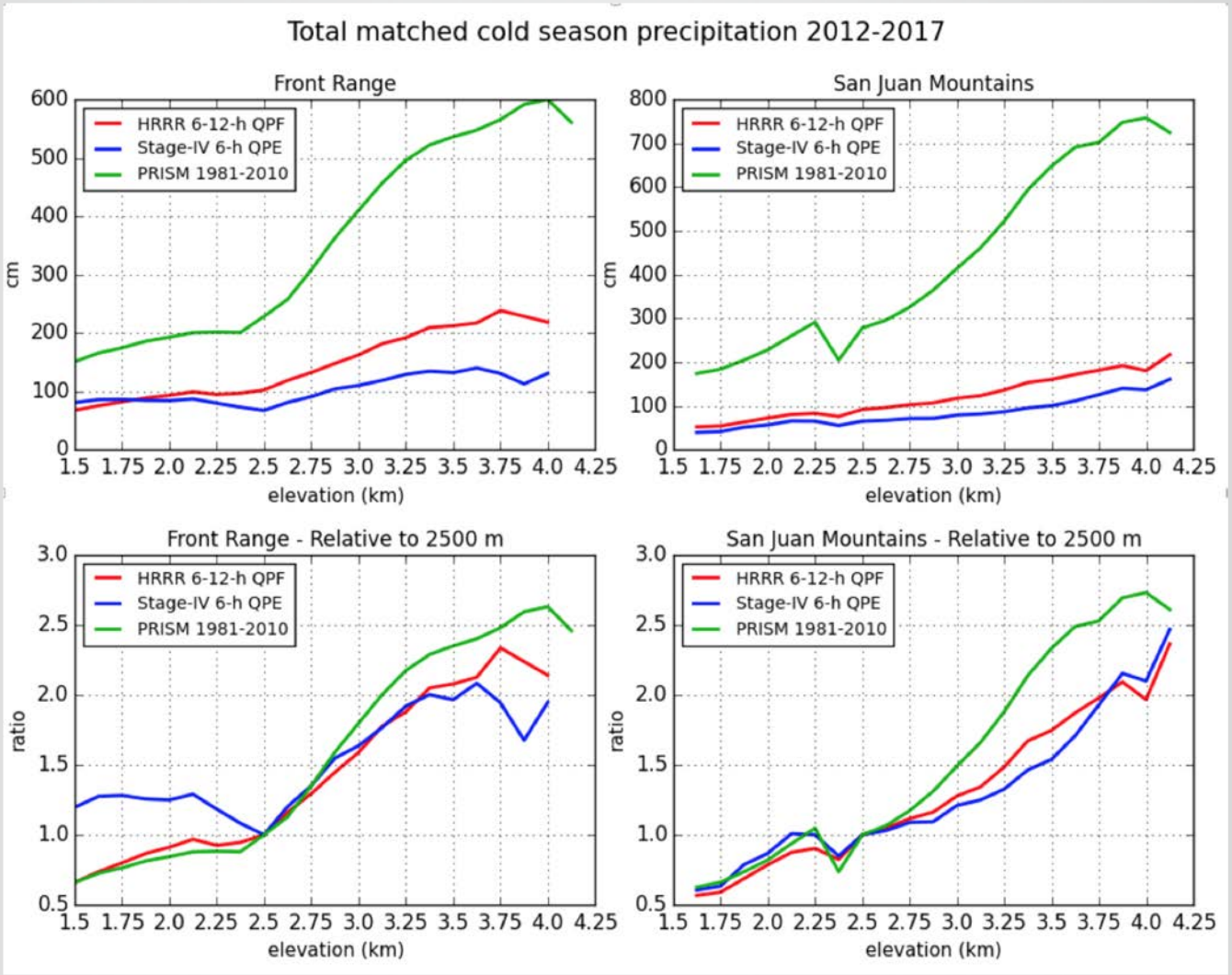
Mean monthly precipitation form the HRRRX dataset (constructed from 6-12-h forecasts

Rain vs Snow



Ratio of 5-year maximum snow water equivalent (SWE) to 5-year-maximum precipitation from the HRRR model dataset for (left) 1-h, (center) 3-h, and (right) 6-h durations. Red colors indicate that the maximum precipitation during these 5 years occurred in the form of snow.

Elevation Analysis



Precipitation-altitude relationship for the Front Range and San Juan Mountain regions of Colorado, in the HRRR 6-12-h QPF, Stage-IV QPE, and the PRISM climatological precipitation datasets, showing similar changes in total precipitation for the HRRR forecasts and Stage-IV analysis in both regions.

Storm Re-Analysis, WRF Model

Specific storms of interest for CO-NM REPS were initially selected by Task 1's assessment of:

- Importance in existing (previous) PMP values,
- Lack of observations from which to derive robust storm patterns and magnitudes, and
- Uncertainty in the previous analysis results from the USACE/USBR/NWS
- Uncertainty in the previous basemap utilized by AWA to accurately capture the spatial distribution
- Limited surface observation data for rainfall analysis and storm maximization

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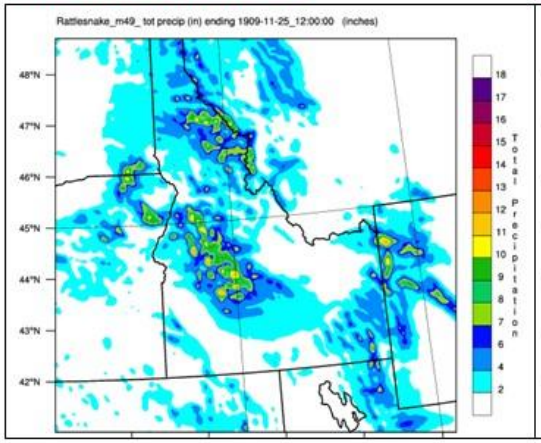
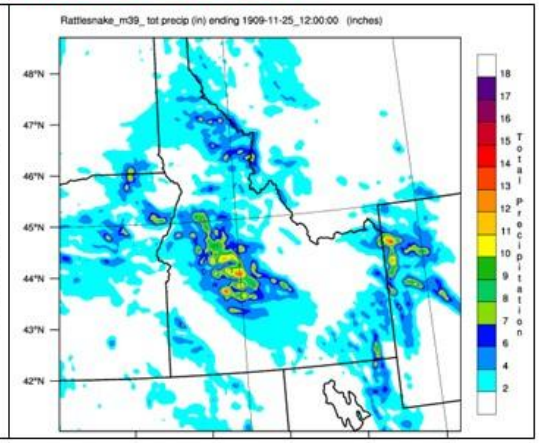
Storm Re-Analysis, WRF Model

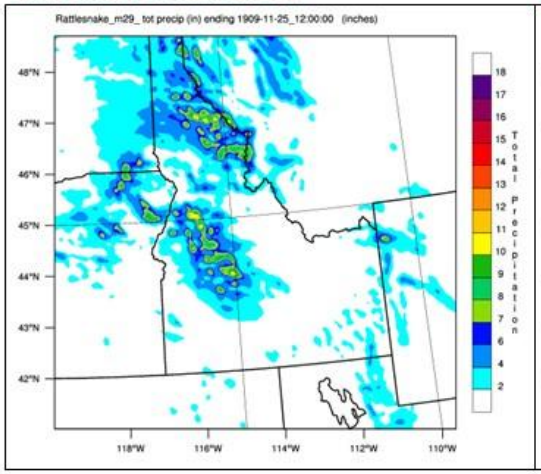
Ensemble Member 1



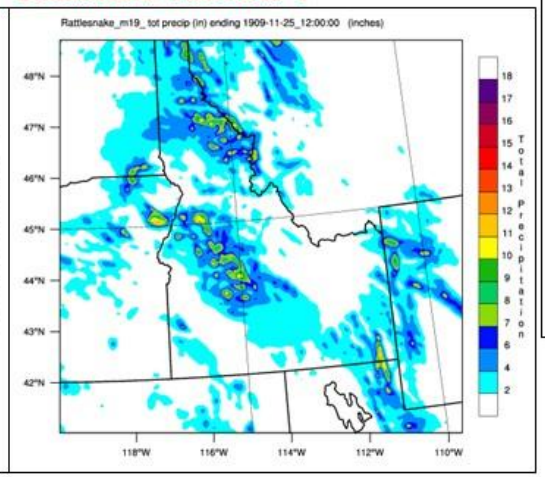
Ensemble Member 2



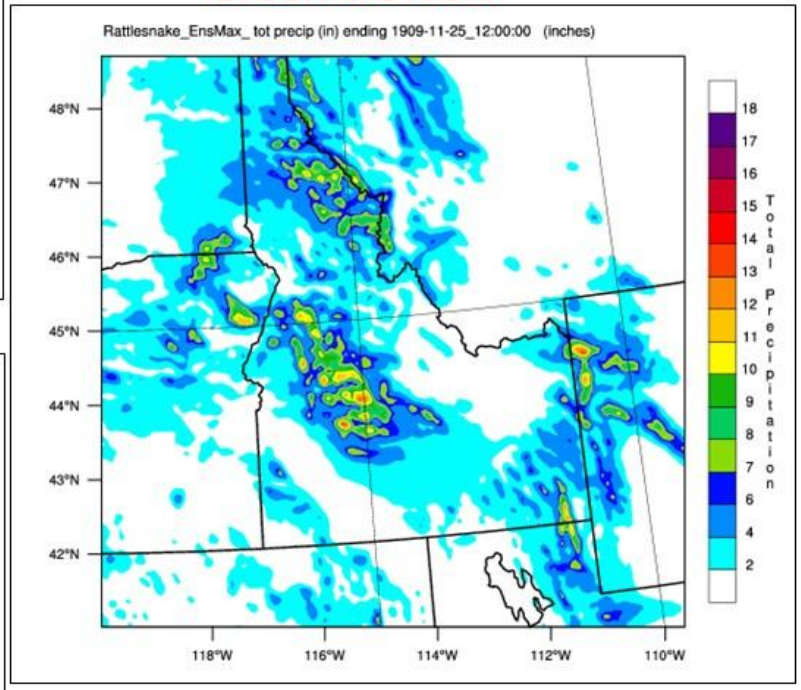
Ensemble Member 3



Ensemble Member 4



Ensemble Max



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Climate Change and PMP WWA & NOAA

Colorado – New Mexico
Regional Extreme Precipitation Study

Summary Report

Volume VI

Considering Climate Change in the Estimation of Extreme Precipitation for Dam Safety

Prepared by:
Kelly Mahoney,
NOAA Earth Systems Research Laboratory, Physical Sciences Division
Jeff Lukas,
Western Water Assessment, CIRES, University of Colorado Boulder

September 25, 2018

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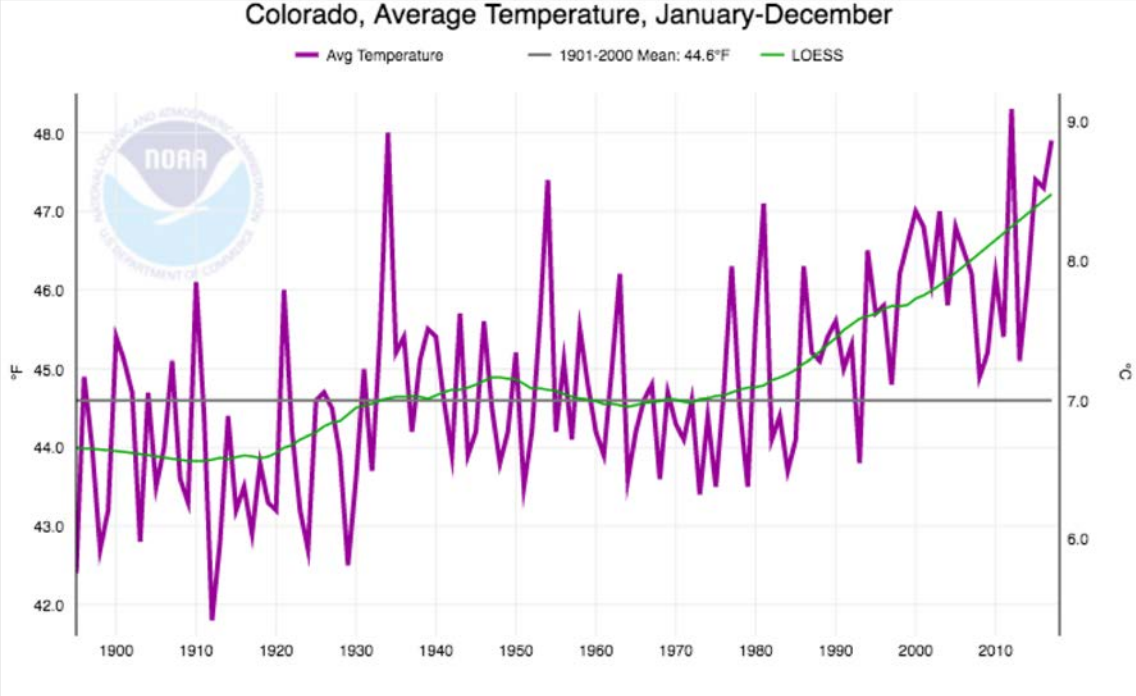
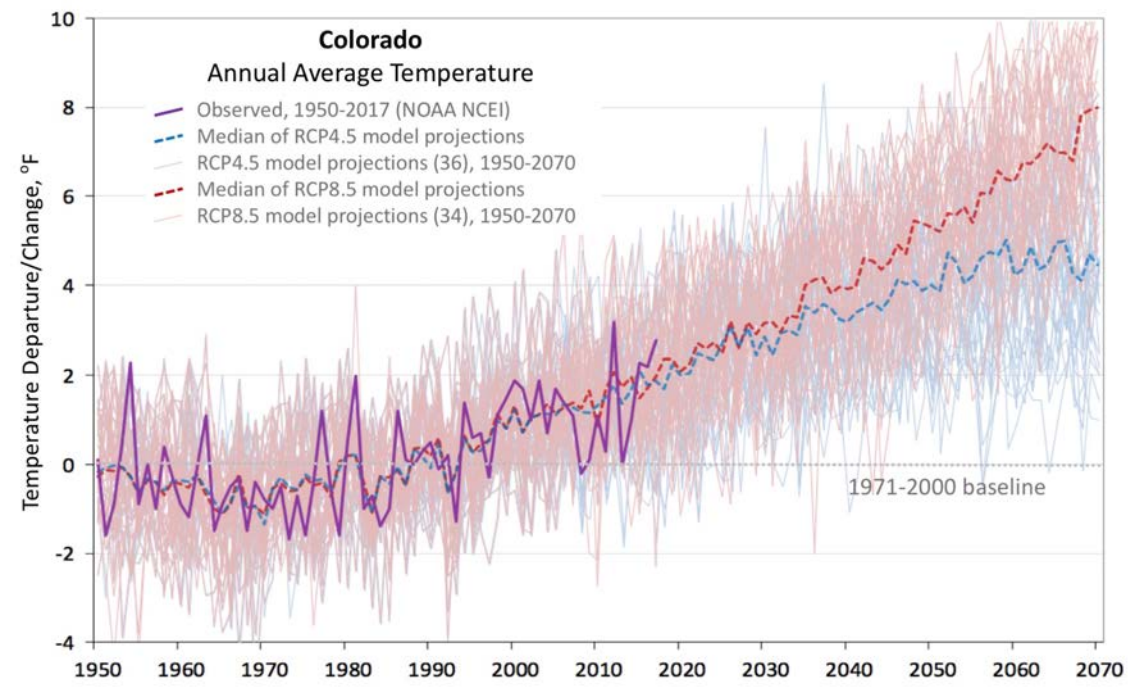
Office of the State Engineer
Interstate Stream Commission

Increase in Temperature



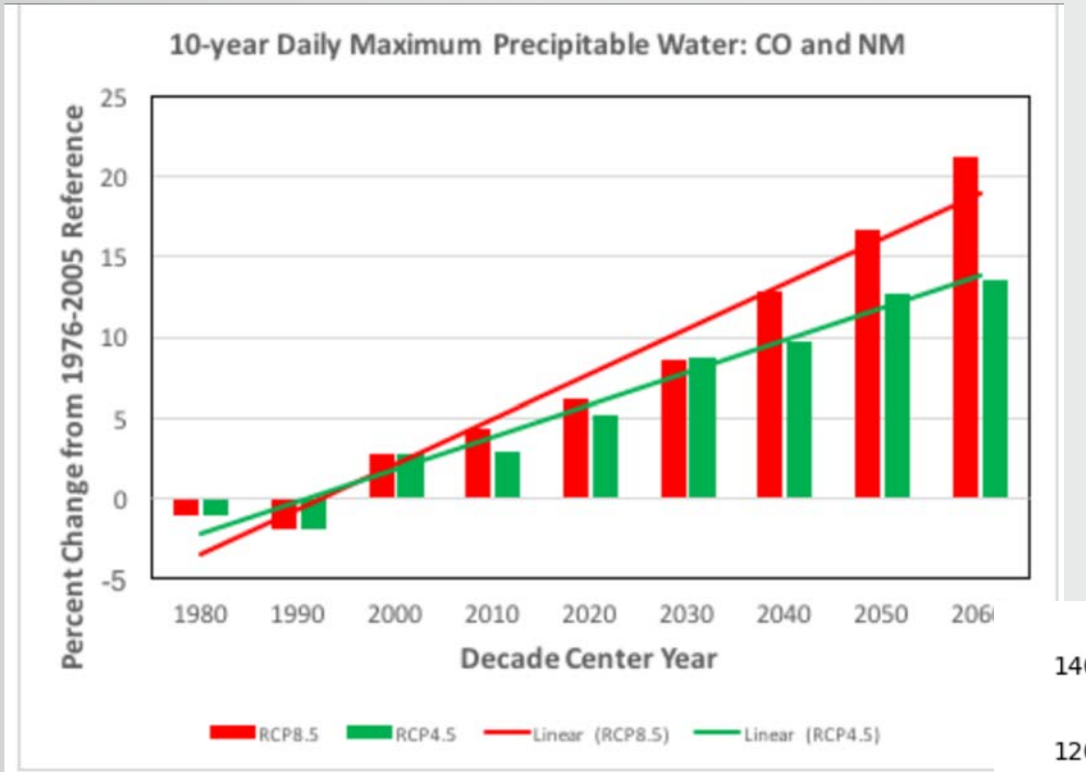
- *Extensive Literature review*
- *Search for Operations methods being used by others*
- *Qualitative or quantitative*
- *Some policy statements, no operational methods*



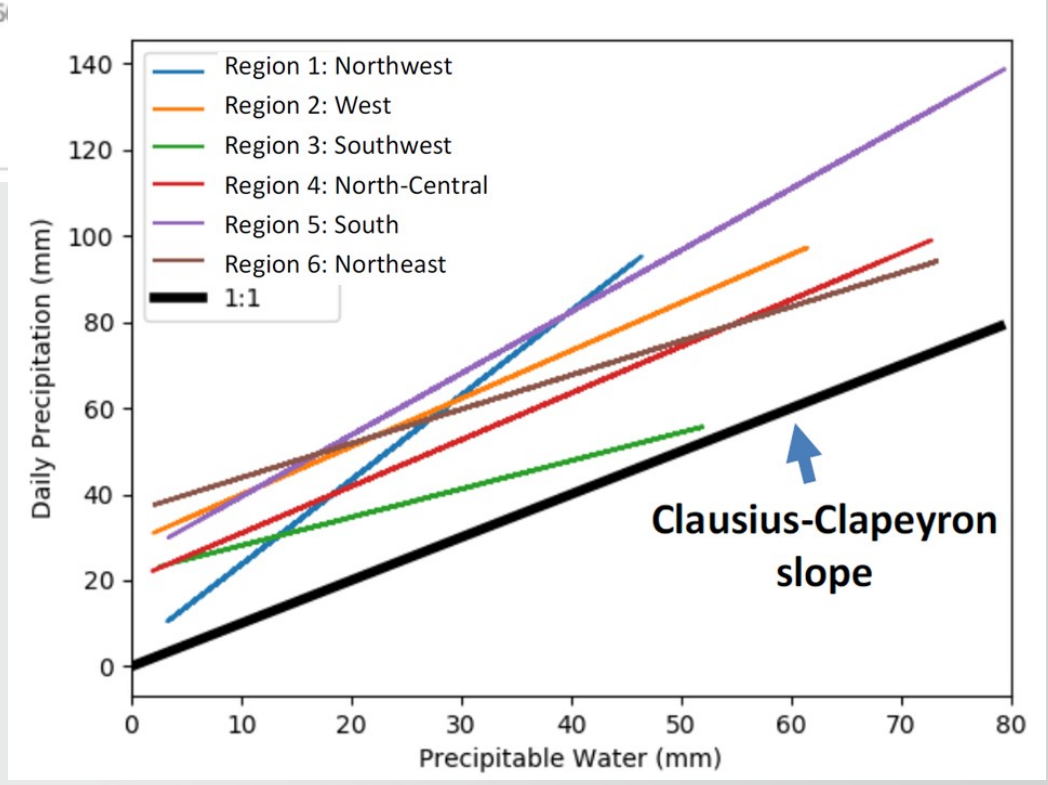
Summary of Findings - Others

Study	Region of study	Projected change in PMP due to climate change
Kunkel et al. (2013a)	US	Changes in maximum water vapor concentrations, which are a principal input to PMP estimation techniques, will change by an 20%–30% by 2071–2100
Beauchamp et al. (2013)	Canada (Summer-Fall PMPs)	+0.5–6% over 2071–2100 period
Stratz and Hossain (2014)	South Holston Dam in Tennessee, Folsom Dam in California, and Owyhee Dam in Oregon	Significant increase over current PMP values when future changes in dew points extrapolated from observational trends or numerical models are taken into account
Ishida et al. (2016)	Northern California	+14.6% by middle of 21st century +27.3% by end of 21st century
Rastogi et al. (2017)	Alabama-Coosa-Tallapoosa River basin (southeastern US)	+20% in 2021–2050 near-future +44% in 2071–2100 far-future periods
Chen et al. (2017)	Pacific Northwest	+50% ± 30% by 2099 under RCP8.5 scenario
Clavet-Gaumont et al. (2017)	Canada	Projected increases in spring PMP except for the most northern basin.

Increase in Moisture



- *Numerical modeling shows potential*
- *No "one-size-fits-all" approach available*
- *Paper provides 3 "families" of recommended approaches*



Recommended approaches

- *Qualitative-standards based*
- *Quantitative-standards based*
- *Quantitative probabilistic*

Thank You,
Questions?
CO Eastern Plains, evening of 4/2/15
Photo credit, Darcy Janssen, Cheyenne County EM Director