Meteorological Inputs to Tailings Storage Facility Assessments and Risk Assessments-Experience and Lessons Learned

Tailings and Mine Waste 2024, Colorado, USA

Applied Weather Associates (AWA)

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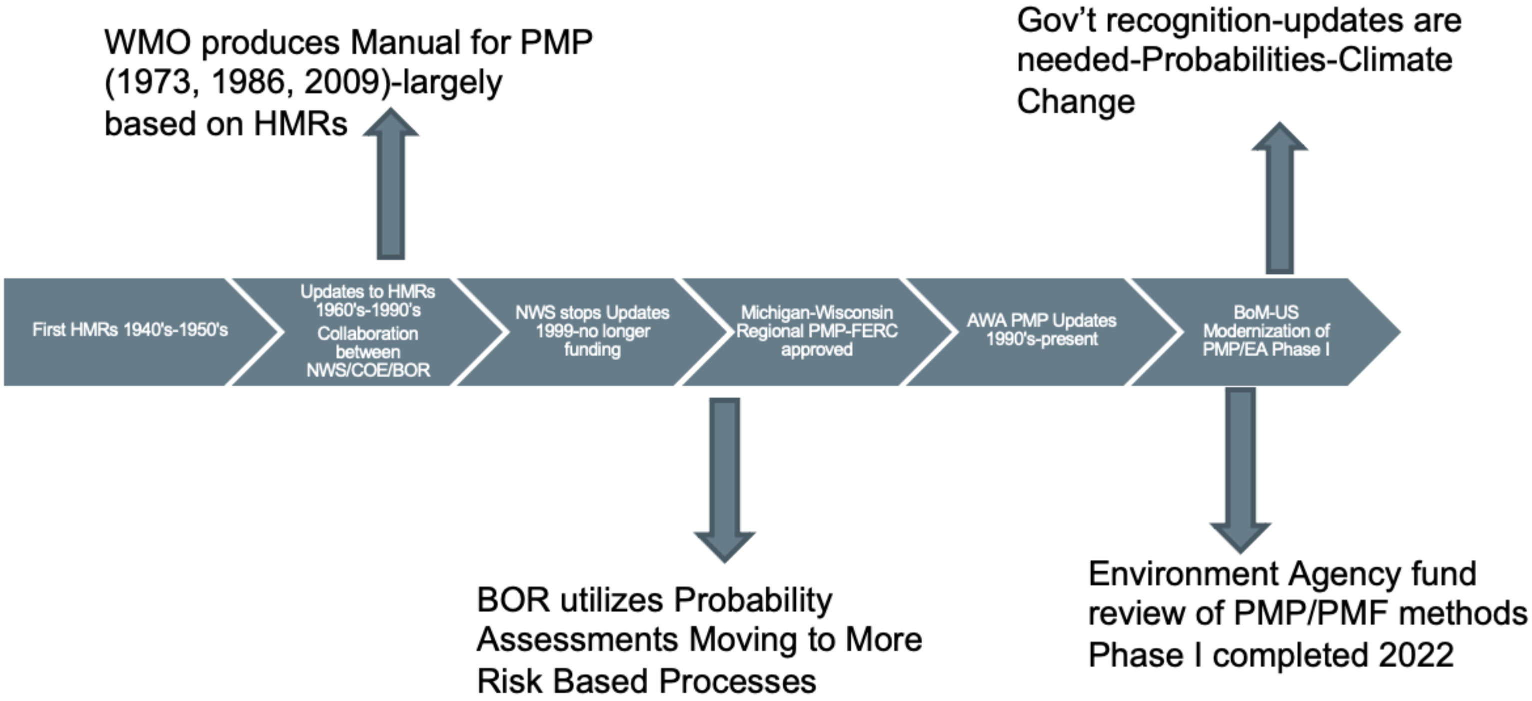
November 12, 2024

Probable Maximum Precipitation Background



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What Is Probable Maximum Precipitation?

"Current" US Definition: The *theoretically* greatest depth of precipitation for a given duration that is *physically possible* over a given storm area at a particular *geographic location* at a certain time of year (HMR 59, 1999)

Recommendation 5-3: NOAA, federal and state agencies involved in dam safety and nuclear regulation, the American Meteorological Society, the American Society of Civil Engineers, and the Association of State Dam Safety Officials should adopt a revised PMP definition: Probable Maximum Precipitation—The depth of precipitation for a particular duration, location and areal extent, such as a drainage basin, with an extremely low annual probability of being exceeded, for a specified climate period.

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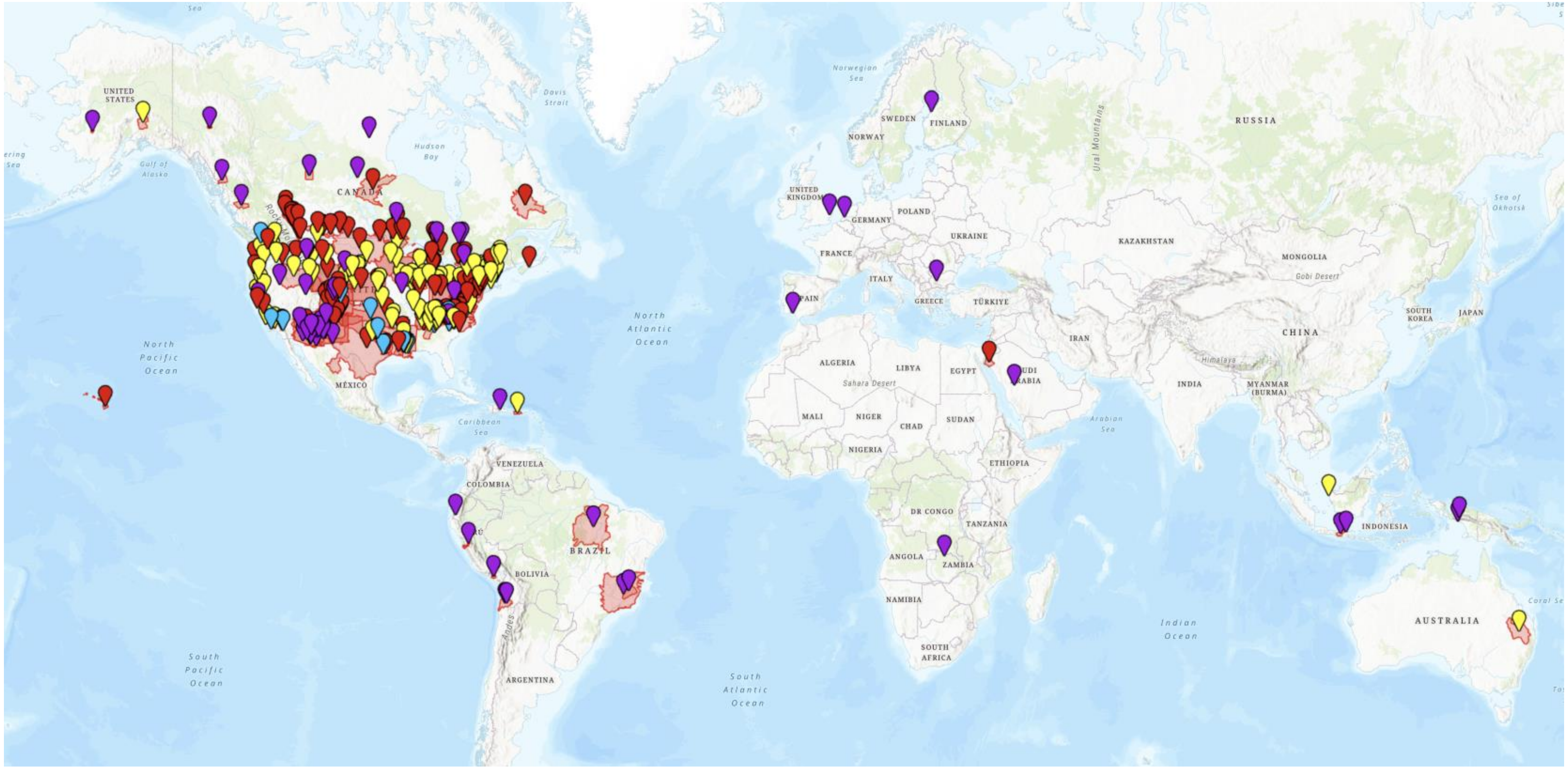
PMP Over The Last 20 Years



Rainfall Data Sources-This Is Important

- Availability and quality of rainfall data continues to improve
  - Varies depending on location
  - Work with what you have
  - Observational
  - Satellite/remote
  - Model reanalysis

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Why Needed For TSFs and GISTM?

- Critical input for spillway and volume design
- Need to understand where we are today and where we might need to be
- Important to quantify uncertainty and range of outcomes
- Need to evaluate all site-specific parameters that are relevant to a given location

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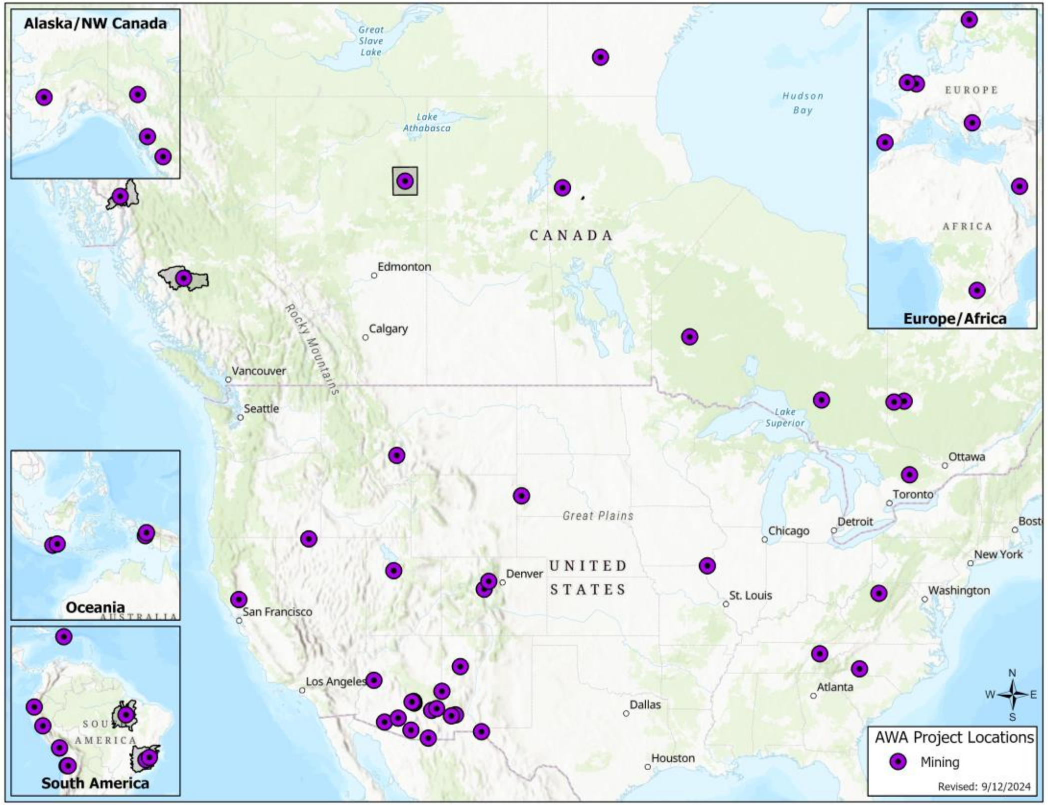
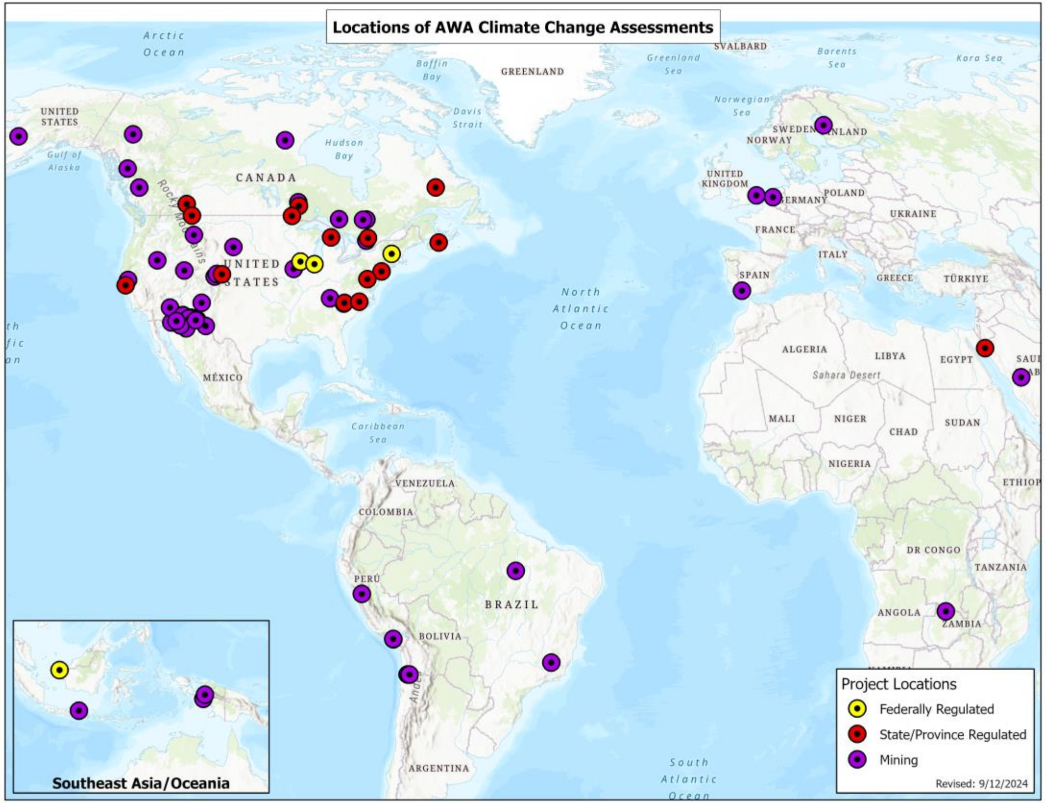
Mining Study Locations

- Work in all regions
  - Many unique requirements
  - All types of environments
  - Local expertise and data is critical
  - Communication very important



Climate Change Study Locations

- Just like mining
  - Many unique requirements
  - All types of environments
  - Important to accurately quantify baseline climate
  - Need to provide actionable recommendations



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How Do We Do This?

- Storm Based Approach (recommended by WMO, 2009)
- Evaluate previous extreme events in similar region
- Maximize and transposition those events to your location
- Develop PMP and Depth-Area-Duration outputs
- Provide temporal and spatial patterns
- Perform sensitivities and testing
- Work with the hydrologist and engineers
  - Ensure proper application
  - Discuss/quantify uncertainty
  - Help understand unknowns and decisions

There Are Other Methods

- Hershfield method
  - Used at many locations
  - Quick and relatively easy
  - Understanding of meteorology not required

Hershfield, D. M., (1965). Method for estimating probable maximum precipitation, J. Am. Waterworks Assoc., 57, 965-972.
Koutsoyiannis, D. (1999). A probabilistic view of Hershfield's method for estimating probable maximum precipitation. Water Resources Research. 35.

- This introduces issues
  - Highly uncertain results
  - No spatial
  - No temporal
  - No seasonality
  - No Topography

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How Do We Continue To Improve?

- Continual updates to the storm database
- PMP by storm type and season (rain on snow-snowmelt)
- Updated dew point/SST climatologies for maximization
- Precipitation frequency databases
- Storm based temporal patterns
- Storm based spatial patterns
- **Uncertainty quantification**
- **Probability assessments through PMP**
- **Climate change assessments specific to PMP**

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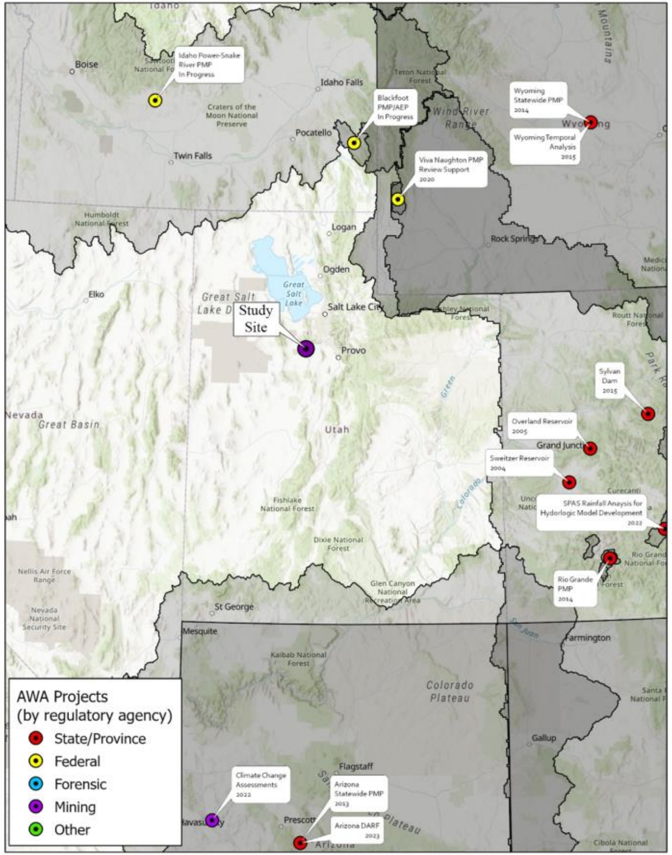
Lots of Data-Complex Region

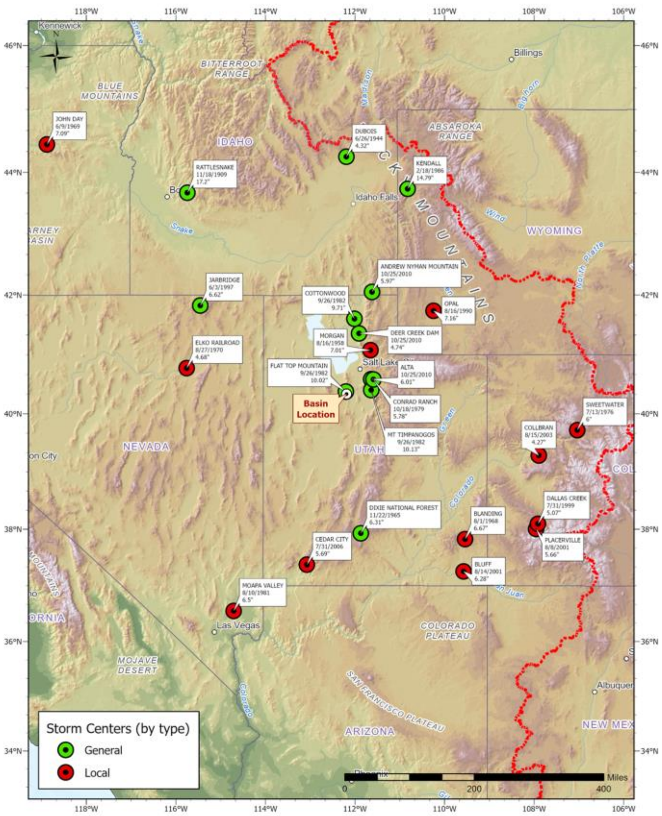
- Dry Climate
- Different storm types
- Good data coverage
- Plenty of previous and concurrent work in the region



Storm Data Very Important

- Local and General storms
  - Remnant Tropical too
- North American Monsoon
- Winter frontal
- Many storms from previous and ongoing studies
- Transposition regions are key to define

Locations of Short List Storm Centers - All Storm Types



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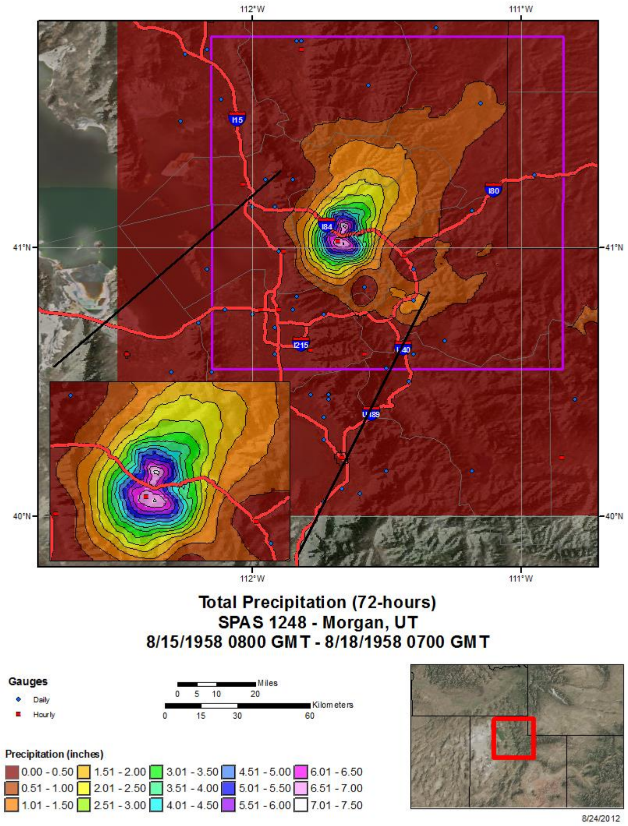
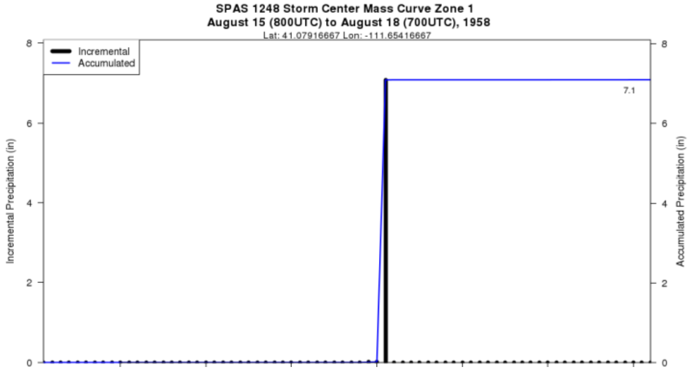
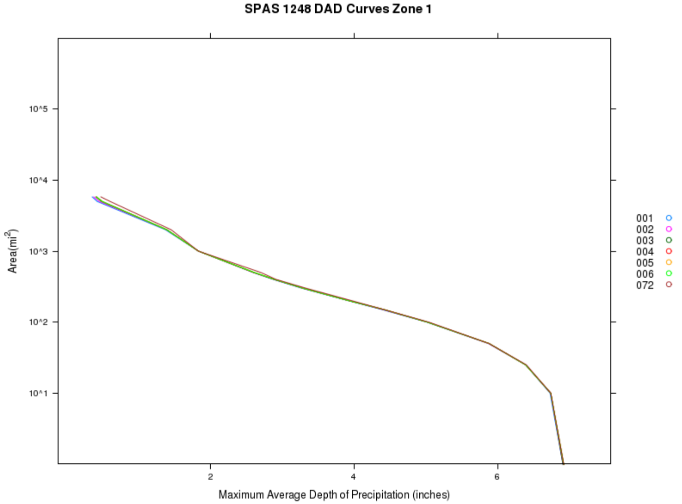
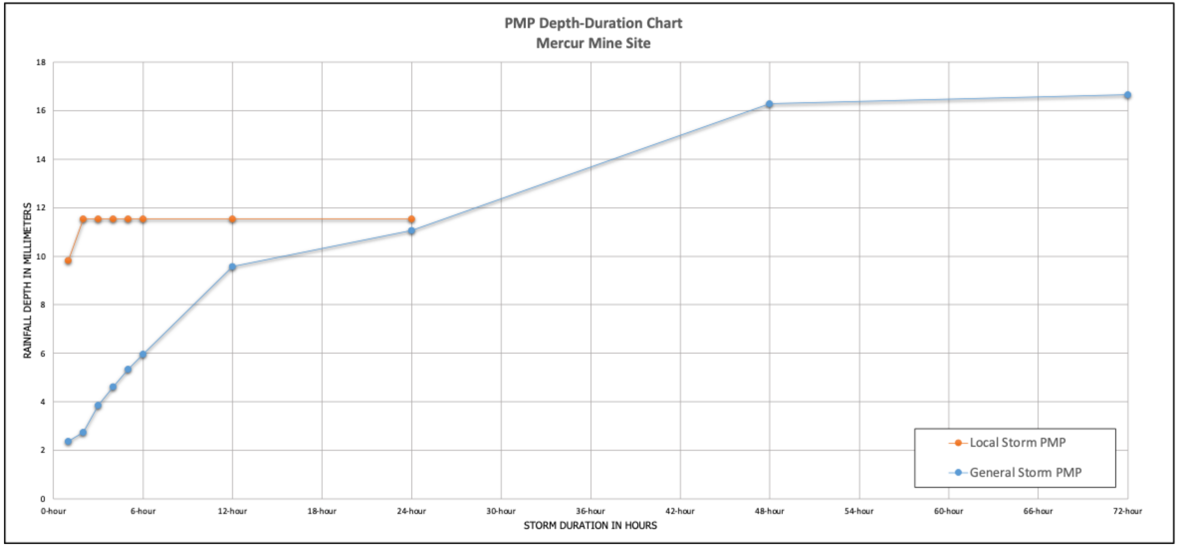
SPAS Analysis Example Outputs







PMP Example Outputs



- Unique accumulation characteristics from sea level to >4000m
- Represents topographical changes
- Gridded approach allows all areas sizes to be analyzed
- Hourly timesteps allows all durations

Local Storm PMP

Duration	1-hour	2-hour	3-hour	4-hour	5-hour	6-hour	12-hour	24-hour
PMP	9.8"	11.5"	11.5"	11.5"	11.5"	11.5"	11.5"	11.5"
Controlling Storm	Moapa Valley, NV - Aug, 1981	John Day, OR - Jun, 1969	John Day, OR - Jun, 1969	John Day, OR - Jun, 1969	John Day, OR - Jun, 1969	John Day, OR - Jun, 1969	John Day, OR - Jun, 1969	John Day, OR - Jun, 1969

General Storm PMP

Duration	1-hour	2-hour	3-hour	4-hour	5-hour	6-hour	12-hour	24-hour	48-hour	72-hour
PMP	2.4"	2.7"	3.9"	4.6"	5.3"	6.0"	9.6"	11.1"	16.3"	16.7"
Controlling Storm	Jarbridge, NV - Jun, 1997	Rattlesnake, ID - Nov, 1909	Kendall, WY - Feb, 1986	Rattlesnake, ID - Nov, 1909	Rattlesnake, ID - Nov, 1909	Rattlesnake, ID - Nov, 1909	Rattlesnake, ID - Nov, 1909	Rattlesnake, ID - Nov, 1909	Rattlesnake, ID - Nov, 1909	Rattlesnake, ID - Nov, 1909

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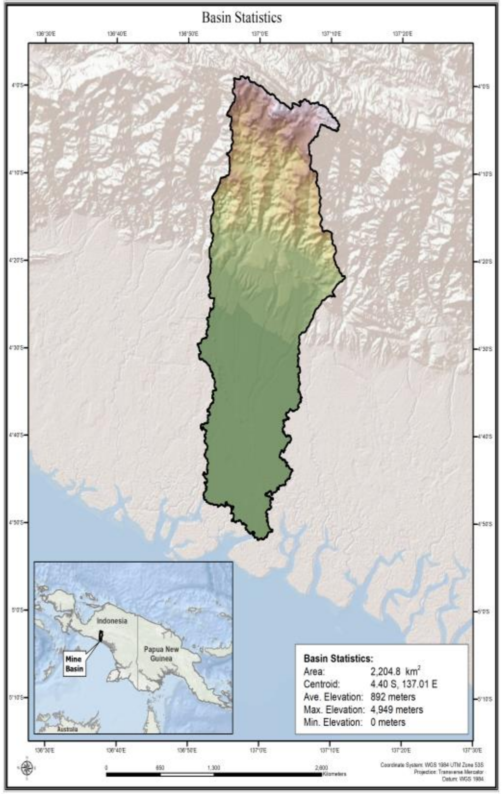
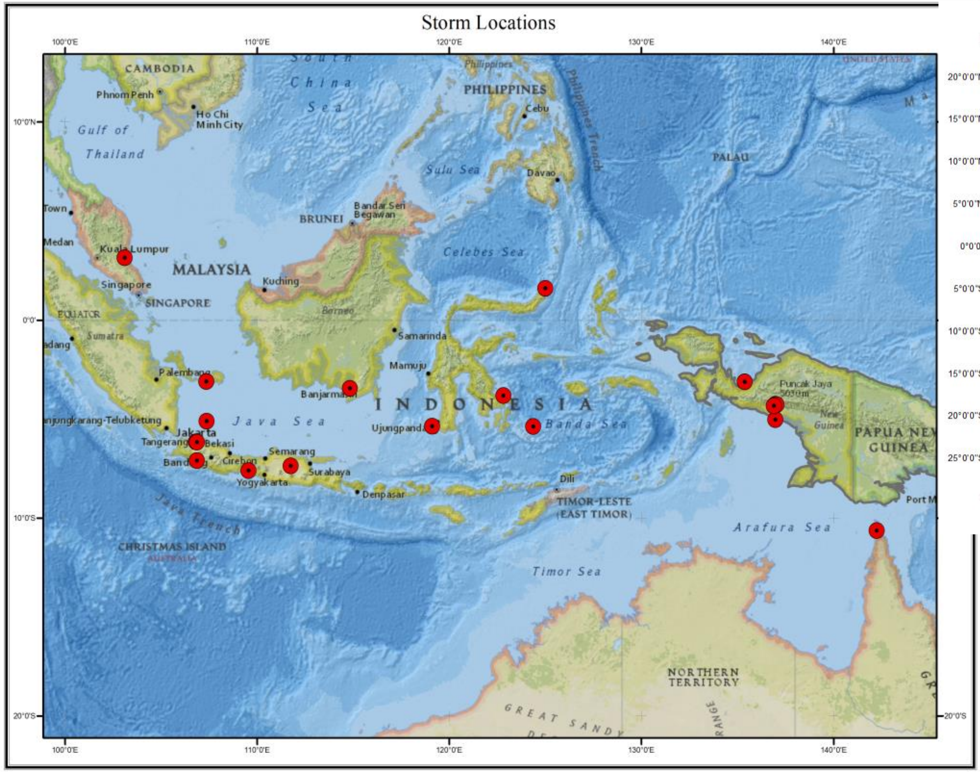
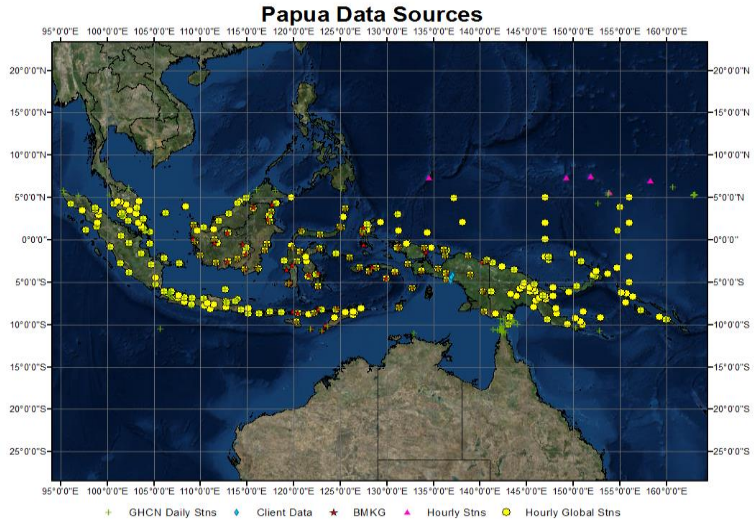
Data Limited-Highly Complex Region

- Tropical Climate
- Two wet/monsoon seasons
- Limited data, especially sub daily
- Utilize remote sensing
- Extreme topography ~4000 meters to sea level over short distance



Storm Data Very Important





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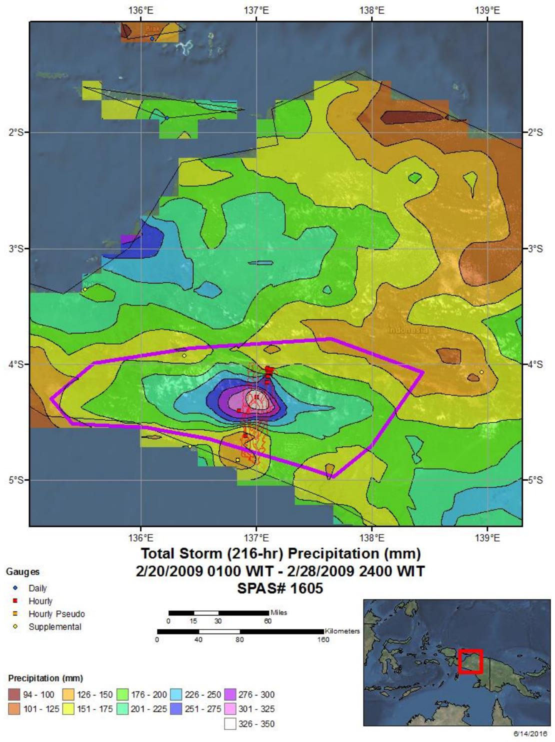

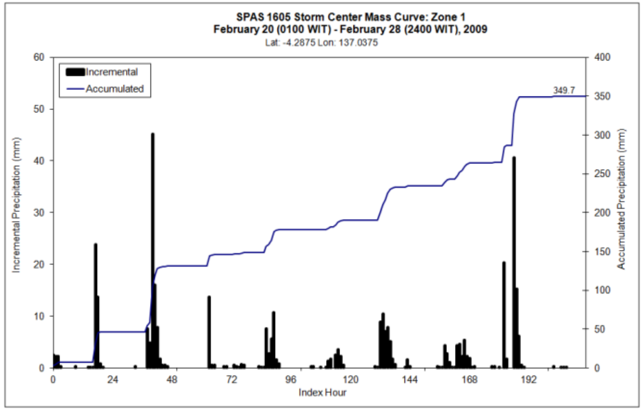

Storm 1605 - February 20 (0100 WIT) - February 28 (2400 WIT), 2009															
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (MM)															
Area (km^2)	Duration (hours)														
	1	2	3	4	5	6	12	18	24	36	48	72	96	120	Total
1.0	46.7	61.5	69.3	82.0	93.2	94.0	101.4	124.2	131.3	132.3	170.2	238.8	289.6	300.5	350.0
2.0	46.7	61.5	69.3	82.0	93.2	93.7	101.4	124.2	131.3	132.3	170.2	238.3	289.6	300.2	350.0
5.0	46.7	61.2	69.3	82.0	93.2	93.7	101.1	124.0	131.3	132.1	169.9	238.0	289.3	300.2	349.8
10.0	46.5	61.2	69.1	81.8	93.2	93.7	101.1	124.0	131.1	132.1	169.9	237.7	289.1	300.0	349.8
25.0	46.5	61.2	69.1	81.5	92.7	93.2	100.6	123.4	130.8	131.6	169.2	237.0	288.0	299.0	349.3
50.0	46.2	61.0	68.8	81.0	92.2	92.7	100.1	122.7	130.3	130.6	168.4	236.0	286.5	297.4	348.5
100.0	45.5	60.2	68.1	80.0	90.9	91.7	98.8	121.2	129.0	129.3	166.4	233.4	282.7	294.6	347.0
200.0	44.5	58.2	66.0	78.2	89.2	89.7	96.8	120.1	124.7	127.5	163.1	227.8	277.9	289.8	343.4
500.0	41.7	50.6	54.1	73.7	83.8	84.3	90.7	116.3	124.0	125.0	154.7	212.9	262.1	275.6	332.0
1000.0	38.4	44.5	49.8	68.1	70.4	78.2	86.6	113.3	120.4	121.9	144.3	198.1	240.0	253.0	317.8
2000.0	34.0	39.1	46.0	62.7	66.8	73.7	81.5	108.0	115.6	116.3	128.0	173.7	206.3	226.6	296.4
2205.0	33.3	38.1	42.9	62.0	66.6	72.6	80.5	106.7	114.6	115.8	127.8	163.3	202.4	226.3	293.4
2500.0	32.3	36.6	42.9	61.0	66.0	71.6	80.0	104.4	113.0	113.8	127.3	158.5	198.4	221.2	288.5
3000.0	30.5	35.8	42.7	59.4	65.0	70.4	79.0	103.1	111.0	112.3	126.5	155.5	186.9	216.9	280.9
5000.0	25.7	31.8	40.4	54.1	59.2	64.3	72.9	94.2	102.6	103.9	111.3	137.2	167.9	198.4	261.4
10000.0	18.8	22.9	31.0	41.2	45.0	47.5	53.3	76.2	79.3	85.3	87.4	123.4	147.3	172.5	235.2
20000.0	11.7	11.7	17.8	24.6	27.2	27.2	29.7	54.4	58.2	64.8	70.6	101.9	120.4	152.2	209.8

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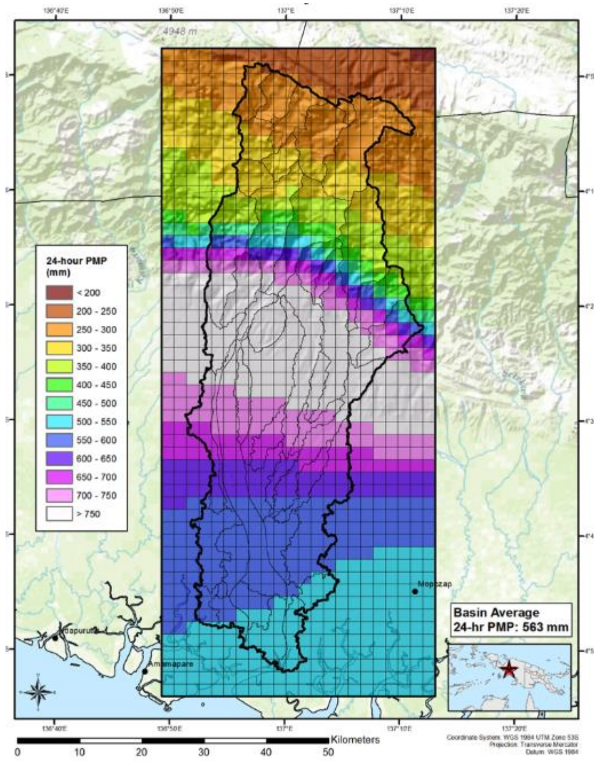
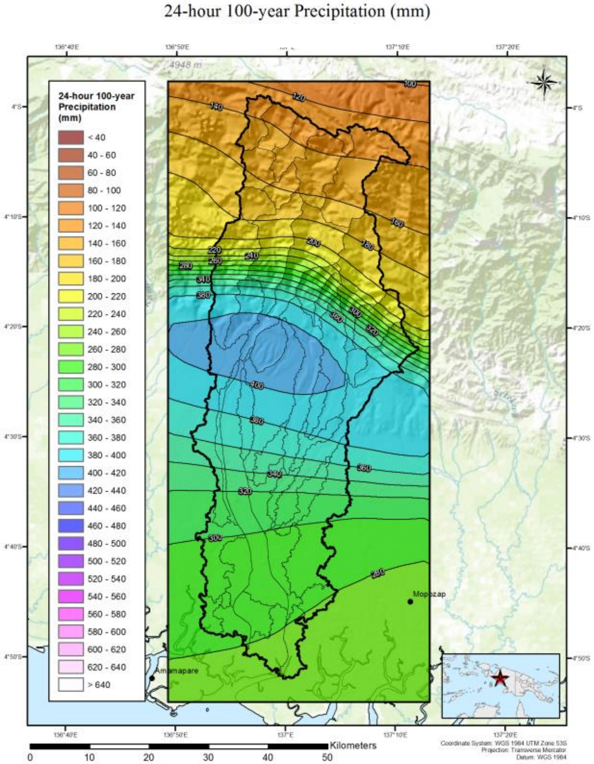
PMP Example Outputs





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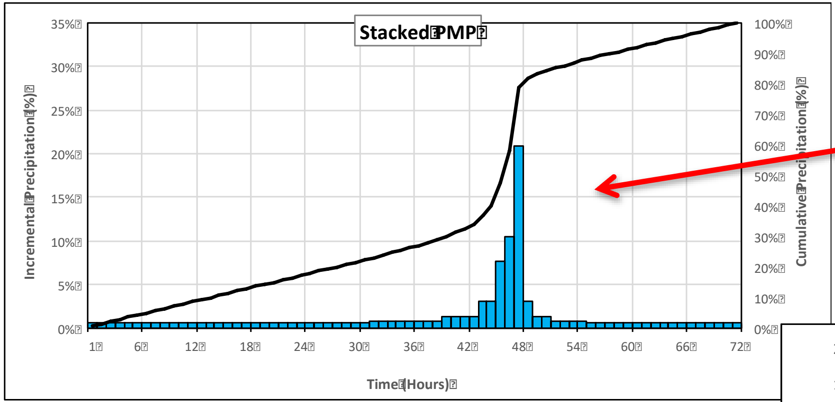
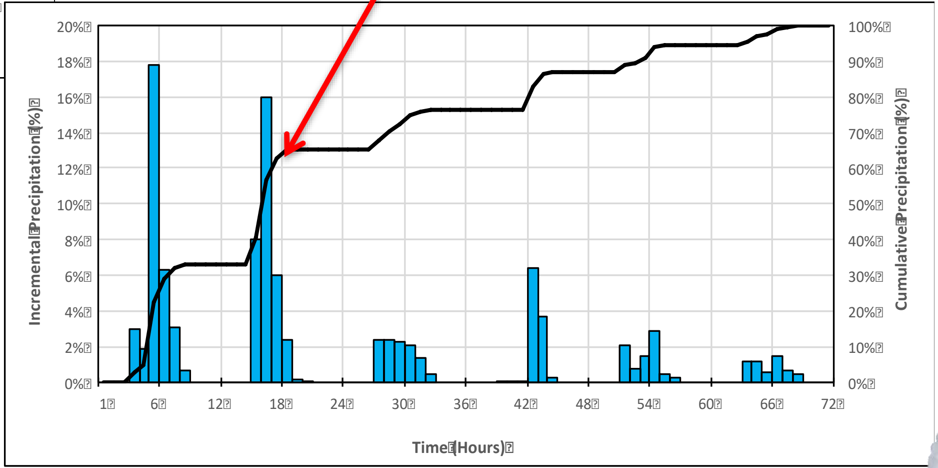


- Temporal pattern can make a big difference
- Utilize actual storm data for best information



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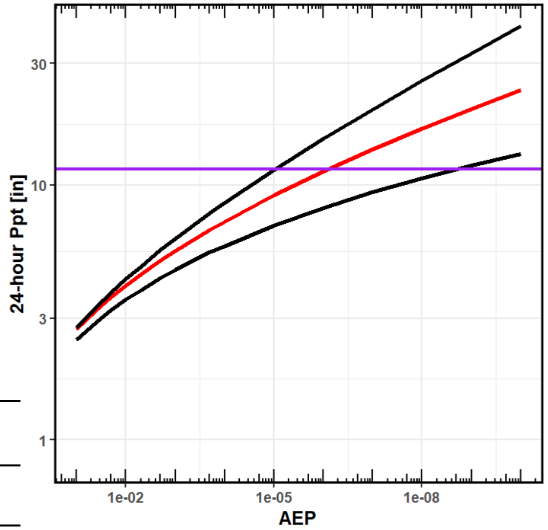
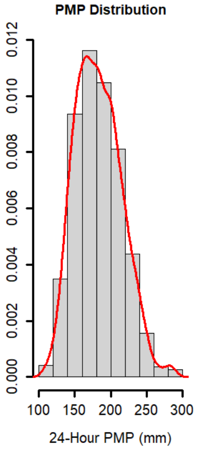
Annual Exceedance Probability of PMP

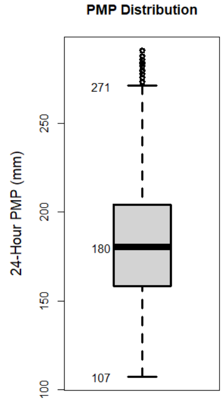
Study Site		24-hour			72-hour		
ARI	AEP	50%	5%	95%	50%	5%	95%
1	9.9^{-1}	0.9	0.8	1.0	1.3	1.1	1.4
2	5.0^{-1}	1.8	1.6	1.8	2.6	2.4	2.6
5	2.0^{-1}	2.3	2.1	2.4	3.4	3.1	3.5
10	1.0^{-1}	2.7	2.5	2.8	4.0	3.7	4.1
25	4.0^{-2}	3.2	2.9	3.3	4.8	4.3	5.0
50	2.0^{-2}	3.6	3.2	3.8	5.4	4.8	5.7
100	1.0^{-2}	4.0	3.5	4.3	6.1	5.3	6.4
200	5.0^{-3}	4.5	3.9	4.8	6.7	5.8	7.2
500	2.0^{-3}	5.0	4.3	5.5	7.6	6.5	8.4
1,000	1.0^{-3}	5.5	4.6	6.2	8.4	7.0	9.3
5,000	2.0^{-4}	6.7	5.4	7.7	10.2	8.3	11.8
10,000	1.0^{-4}	7.2	5.8	8.5	11.0	8.8	13.0
100,000	1.0^{-5}	9.1	6.9	11.5	14.0	10.7	17.6
1,000,000	1.0^{-6}	11.3	8.1	15.2	17.5	12.6	23.5
10,000,000	1.0^{-7}	13.8	9.4	19.7	21.5	14.6	30.8
100,000,000	1.0^{-8}	16.6	10.6	25.6	26.0	16.7	40.1
1,000,000,000	1.0^{-9}	19.9	11.9	32.9	31.3	18.8	51.9
10,000,000,000	1.0^{-10}	23.5	13.2	42.1	37.4	21.0	66.7

Basin	PMP (24hr, 72hr)		AEP (24hr, 72hr)		AEP Upper (24hr, 72hr)		AEP Lower (24hr, 72hr)	
Study site	11.5	16.7	10^{-7}	10^{-6}	10^{-6}	10^{-5}	10^{-9}	10^{-9}

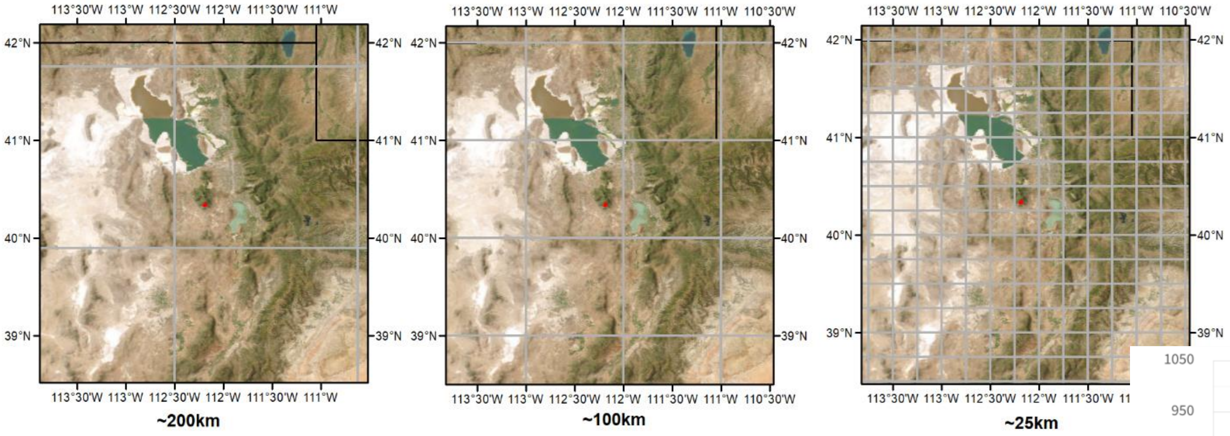
- Regional Lmoments
- Uncertainty
  - Check range of outcomes related to all PMP input parameters
- Sensitivity of PMP
- 100, 1000, 10000-yr depths for various duration





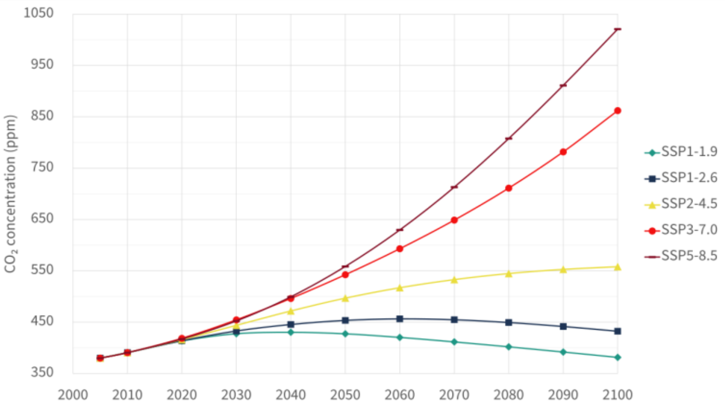


What About Climate Change and PMP



Global and Regional Climate Model Resolution

- Regional downscaled models-CMIP6
- Which emissions scenarios
- Need baseline climate to understand changes and uncertainty
- Evaluate with different methods
  - Trend
  - Frequency
  - Moisture maximization



How Do We Communicate Likely Outcomes?

- Uncertainty in context of current climate
- How do the ensemble model outputs compare to each other
- What are the ranges and skew of the projections
- What is the current design of the TSF and what is your future needs?
- What are the regulatory requirements?

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**2.8**	**2.8**	1.7	3.8	**6.3**	**6.5**	4.2	8.0
Temperature 1-Day Summer; C	**2.8**	**2.8**	1.7	3.8	**6.3**	**6.5**	4.1	8.0
Temperature 1-Day Winter PF; C	**3.0**	**3.2**	1.9	3.9	**6.6**	**6.4**	5.0	8.8
*Precipitation 1-Day PF; %	**12**	**9**	-1	27	**14**	**13**	0	25
Precipitation 1-Day Summer PF; %	**8**	**12**	-6	19	**12**	**12**	-4	28
Precipitation 1-Day Winter PF; %	**13**	**12**	-1	26	**18**	**20**	3	34
*Precipitation 3-Day PF; %	**23**	**18**	1	37	**29**	**24**	3	63
Precipitation 3-Day Summer PF; %	**15**	**9**	-7	49	**20**	**19**	-7	47
Precipitation 3-Day Winter PF; %	**20**	**21**	-6	45	**29**	**28**	2	60
Precipitation 30-Day PF; %	**14**	**13**	-4	27	**21**	**20**	-1	48
Precipitation 90-Day PF; %	**15**	**13**	-2	32	**19**	**17**	-1	41
Precipitation Annual PF; %	**10**	**10**	-5	27	**15**	**11**	0	34
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Questions

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