Introduction to Hydrology loadings, climate change and extreme precipitation
Probable Maximum Precipitation-20 years of Updating the HMRs and What to Expect through 2100

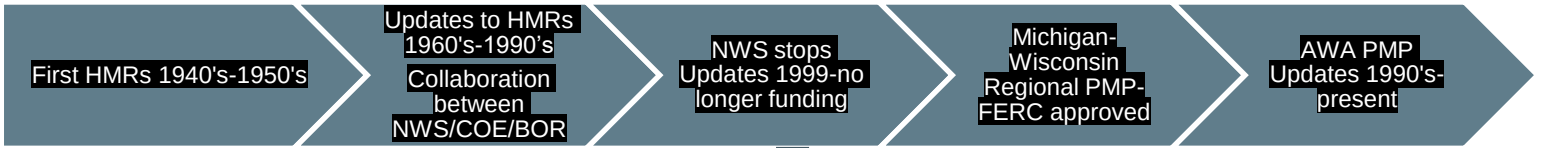
Applied Weather Associates (AWA)

Bill Kappel

National Dam Safety Program Technical Seminar for 2023, Emmitsburg, MD

PMP Development History

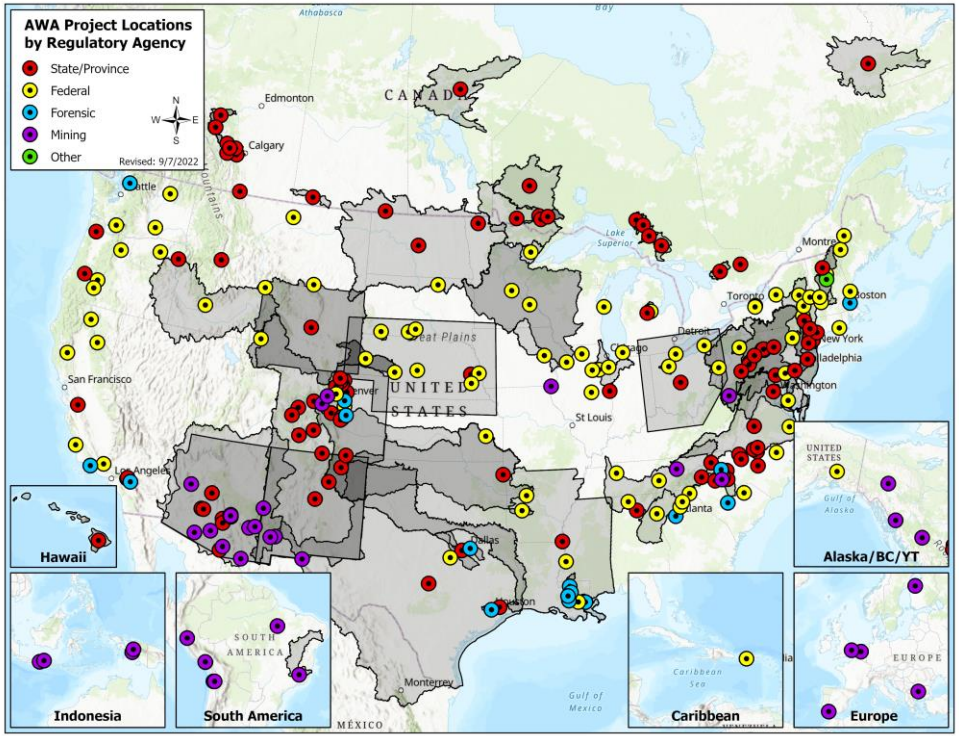
WMO produces Manual for PMP (1973, 1986, 2009)-largely based on HMRs



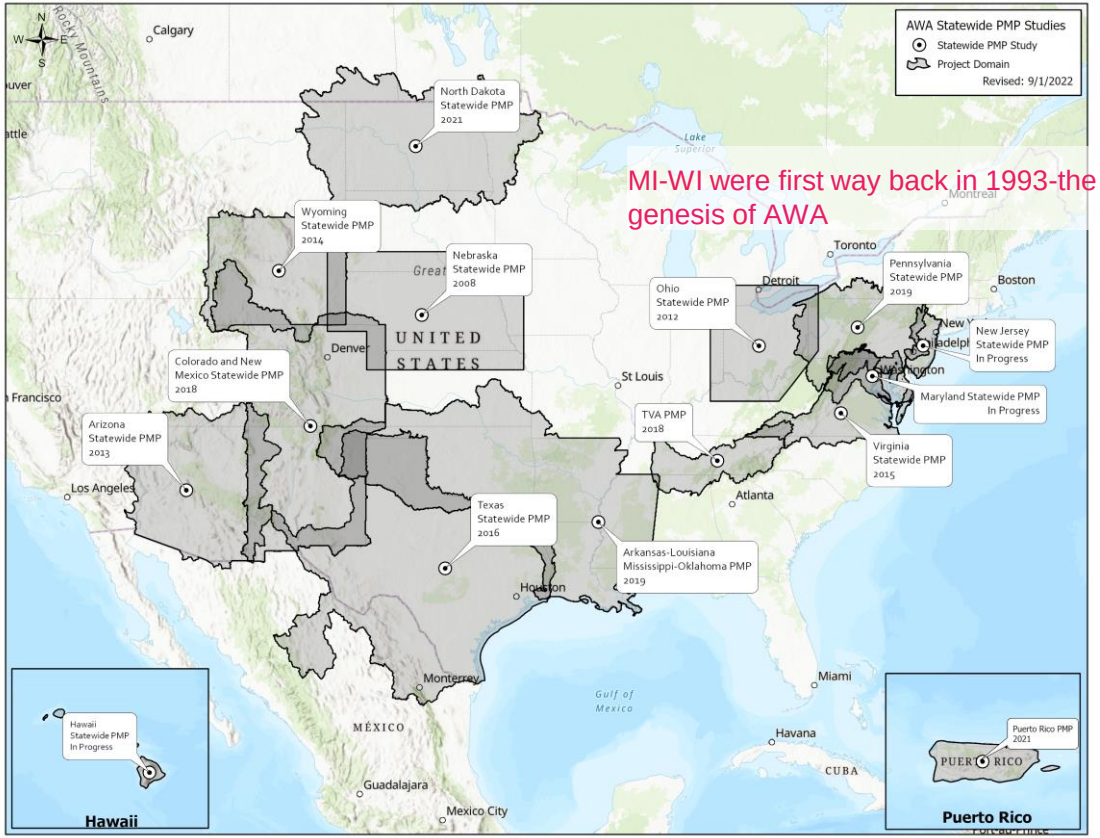
BOR utilizes Probability Assessments
Moving to More Risk Based Processes

Overall PMP Development Today and What's Next

- Statewide studies a big part of the mix
- What's next
  - PRECIP act
  - Public-Private partnership
    - Updates
    - Storage
    - Access

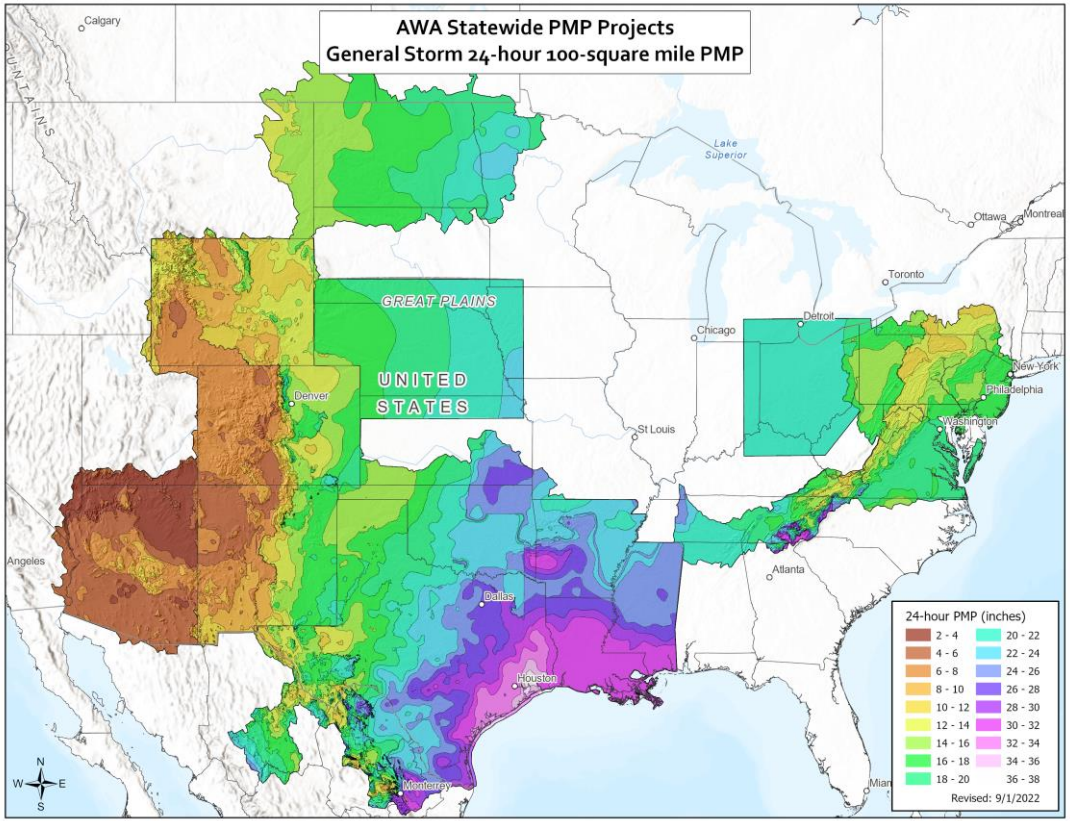


AWA Statewide Project Locations



MI-WI were first way back in 1993-the genesis of AWA

AWA Statewide PMP Depths All together

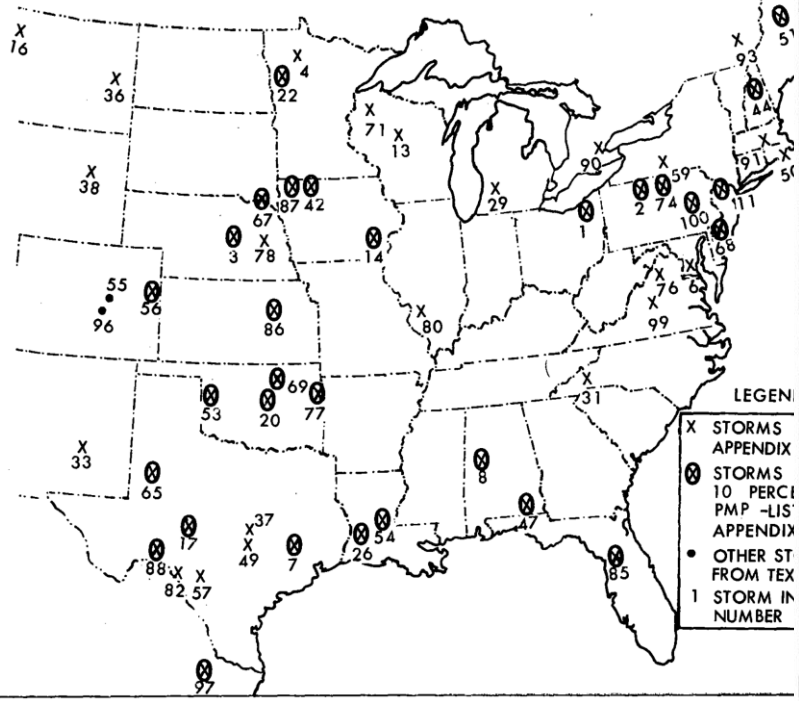


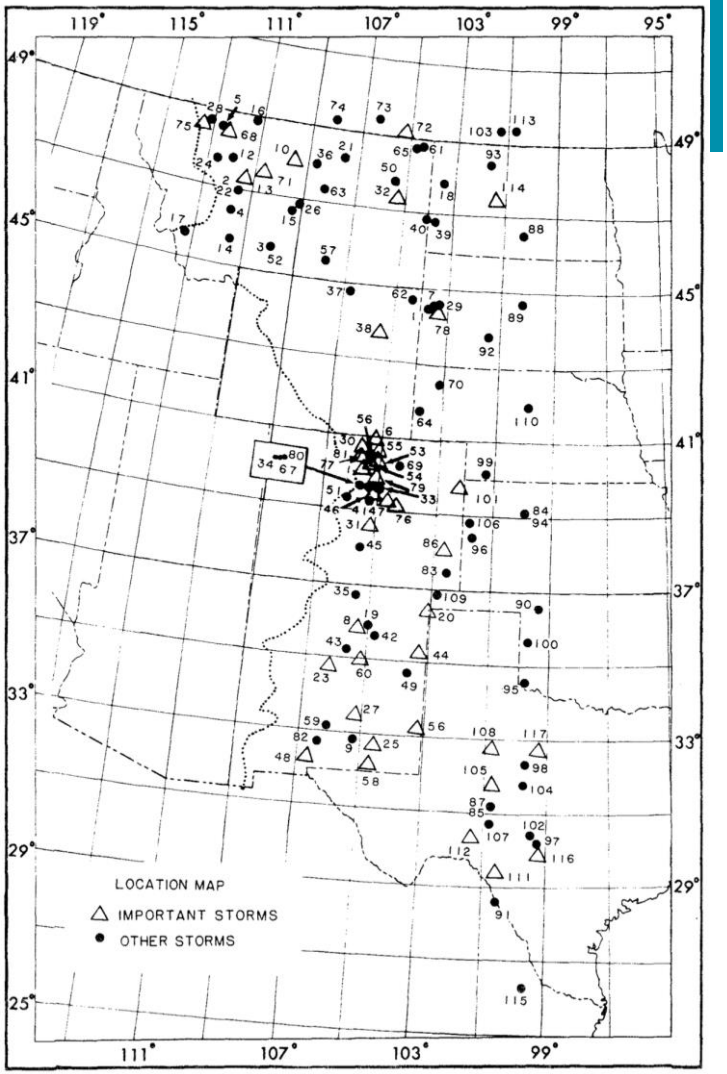
AWA Statewide Progress Improvements

- Continual updates to the storm database
- PMP by storm type and season
- Meteorological analyses of many other aspects
- Storm based temporal patterns
- Storm based spatial patterns
- Input for probabilistic assessments

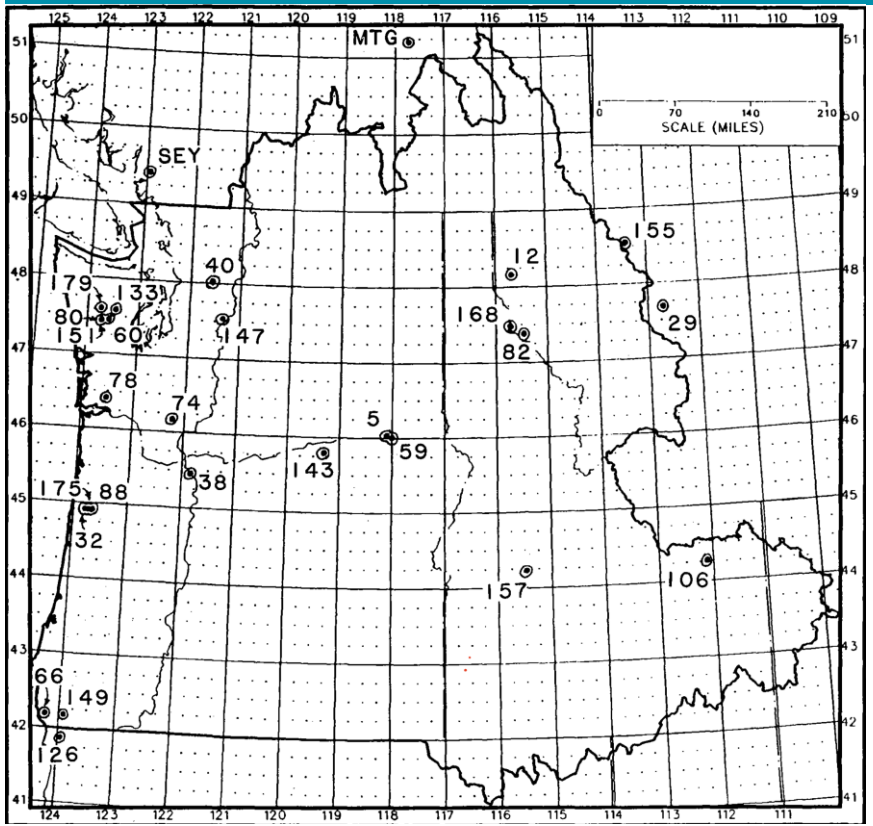
MR Storm Database

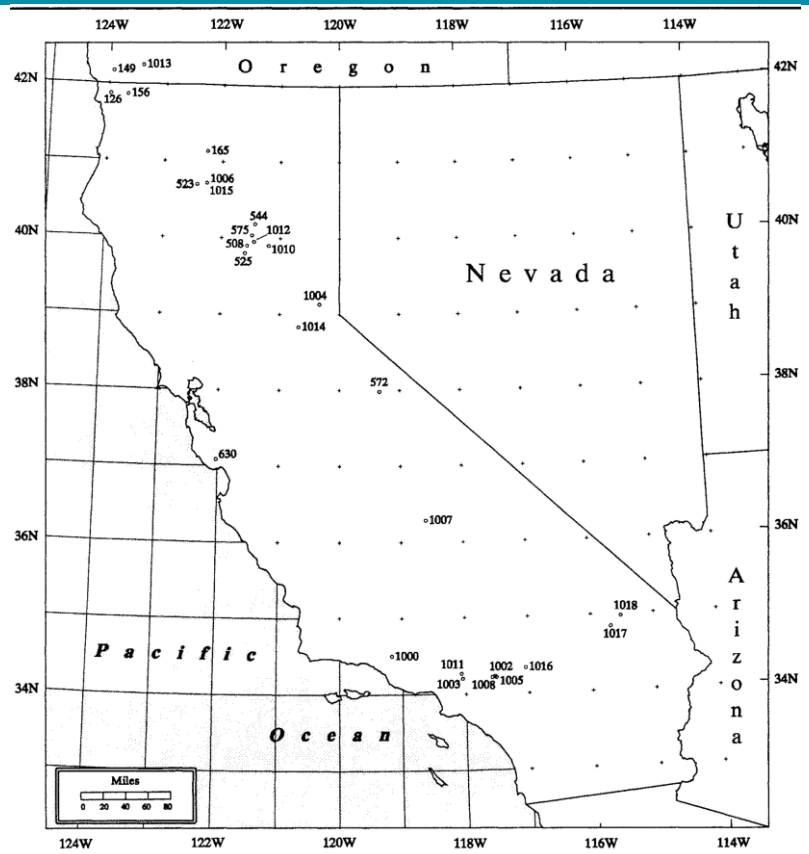
Storm Index No.	Storm Assignment No.	Date
1	OR 9-19	9/10-13/1878
2	SA 1-1	5/30-6/1/1889
3	MR 4-3	6/4-7/1896
4	UMV 1-2	7/18-22/1897
6	NA 1-7B	7/26-29/1897
7	GM 3-4	6/27-7/1/1899
8	LMV 2-5	4/15-18/1900
11	GL 4-9	10/7-11/1903
13	GL 2-12	6/3-8/1905
14	UMV 2-5	6/9-10/1905
16	MR 5-13	6/6-8/1906
17	GM 3-14	8/4-6/1906
20	SW 1-11	10/19-24/1908
22	UMV 1-11A	7/18-23/1909
26	LMV 3-19	3/24-28/1914
29	GL 2-16	8/31-9/1/1914
31	SA 2-9	7/13-17/1916
33	GM 5-15B	9/15-17/1919
36	MR 4-21	6/17-21/1921
37	GM 4-12	9/8-10/1921
38	MR 4-23	9/27-10/1/1923
42	MR 4-24	9/17-19/1926
44	NA 1-17	11/2-4/1927
47	LMV 2-20	3/11-16/1929
49	GM 5-1	6/30-7/2/1932
50	NA 1-20A	9/16-17/1932
51	NA 1-20B	9/16-17/1932
53	SW 2-11	4/3-4/1934
54	LMV 4-21	5/16-20/1935
55	MR 3-28A	5/30-31/1935
56	- -	5/30-31/1935
57	GM 5-20	5/31/1935
59	NA 1-27	7/6-10/1935
65	- -	6/19-20/1939
67	MR 4-5	6/3-4/1940
68	NA 2-4	9/1/1940
69	SW 2-18	9/2-6/1940
71	UMV 1-22	8/28-31/1941
74	OR 9-23	7/17-18/1942
76	SA 1-28A	10/11-17/1942
77	SW 2-20	5/6-12/1943
78	MR 6-15	6/10-13/1944
80	MR 7-28	8/12-16/1946
82	- -	6/23-24/1948
85	SA 5-8	9/3-7/1950
86	MR 10-2	7/9-13/1951
87	MR 10-8	6/7/1953
88	SW 3-22	6/23-28/1954
90	ONT 10-54	10/14-15/1954
91	NA 2-22A	8/17-20/1955
93	QUE 8-57	8/3-4/1957
96	SW 3-23	6/13-20/1965
97	SW 3-24	9/19-24/1967
99	NA 2-23	8/19-20/1969
100	NA 2-24A	6/19-23/1972





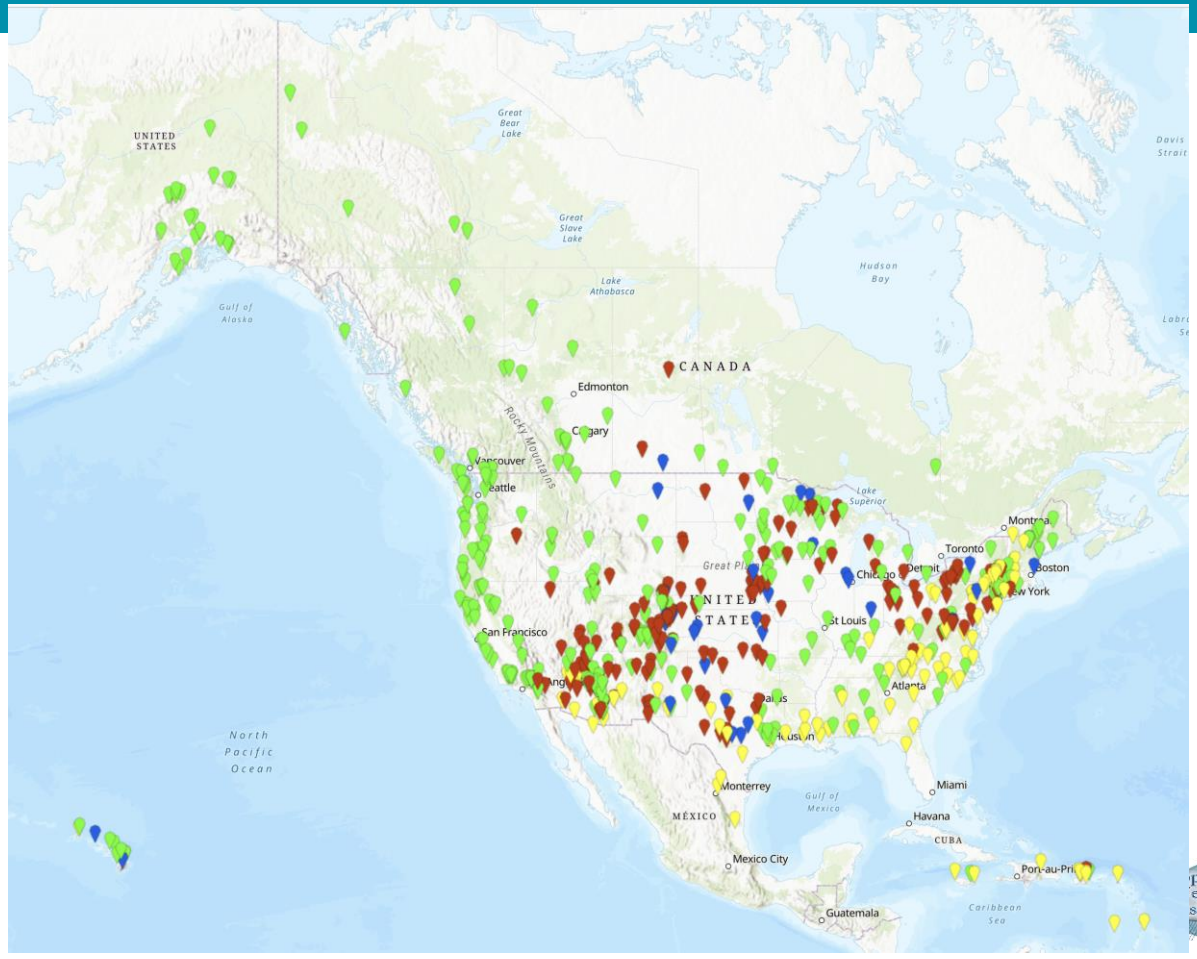
HMR Storm Database (2)



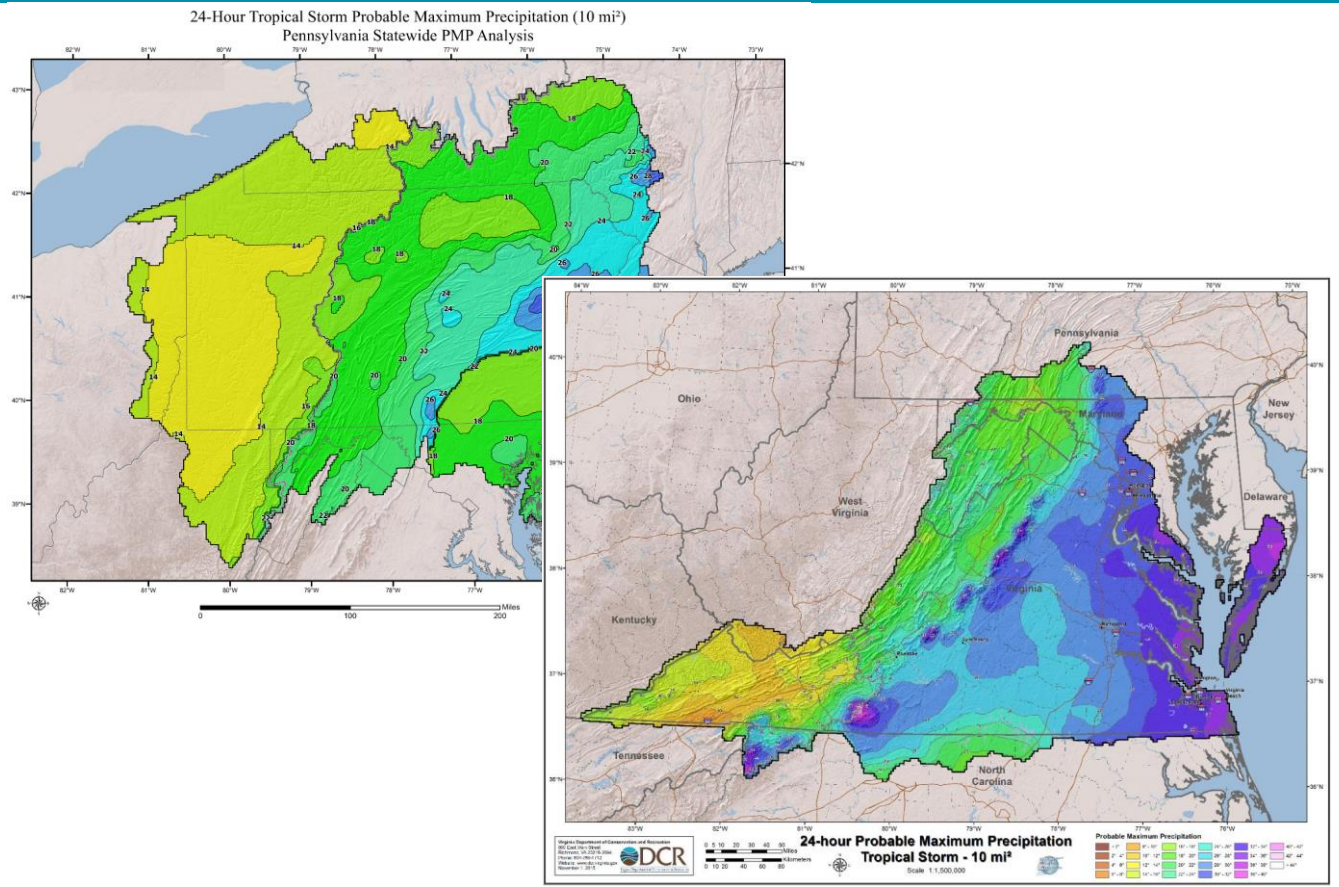


AWA SPAS Storm Database

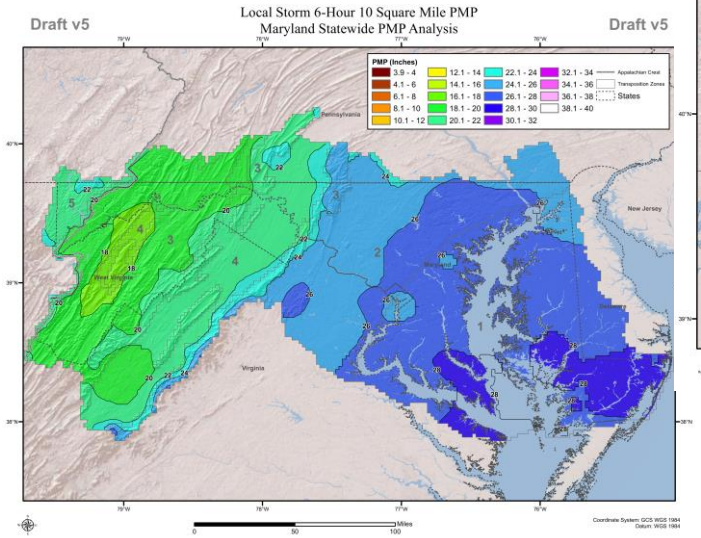
- Nearly 1000 storms analyzed
- Provide numerous outputs
  - For PMP
  - Hydro Calibration
  - Temporal/Spatial
  - ARFs

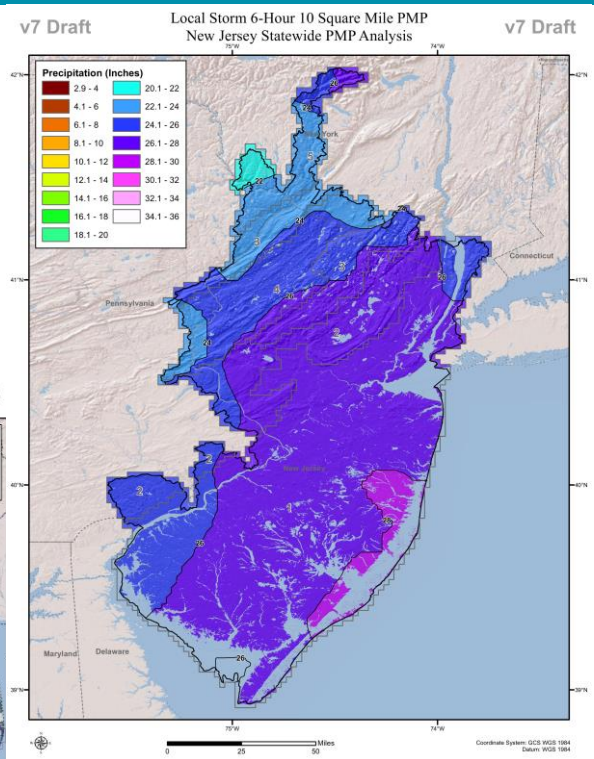


AWA Statewide Output Examples-East



AWA Statewide Output Examples-East (2)

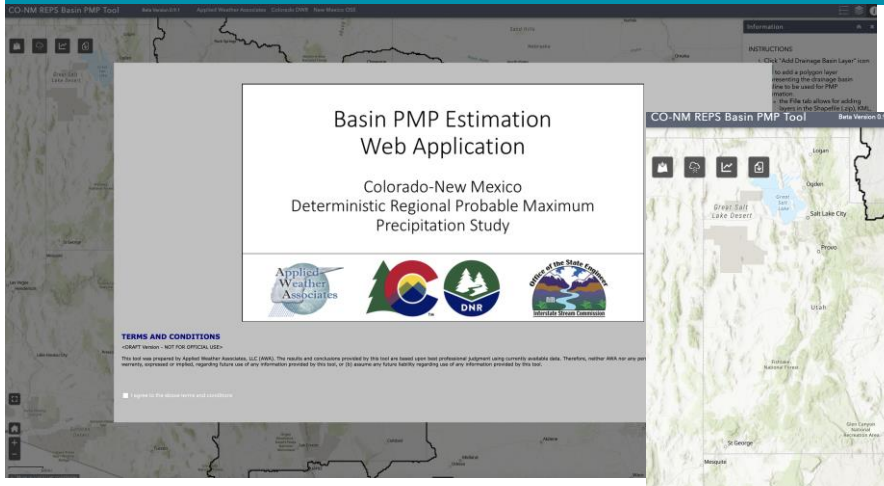


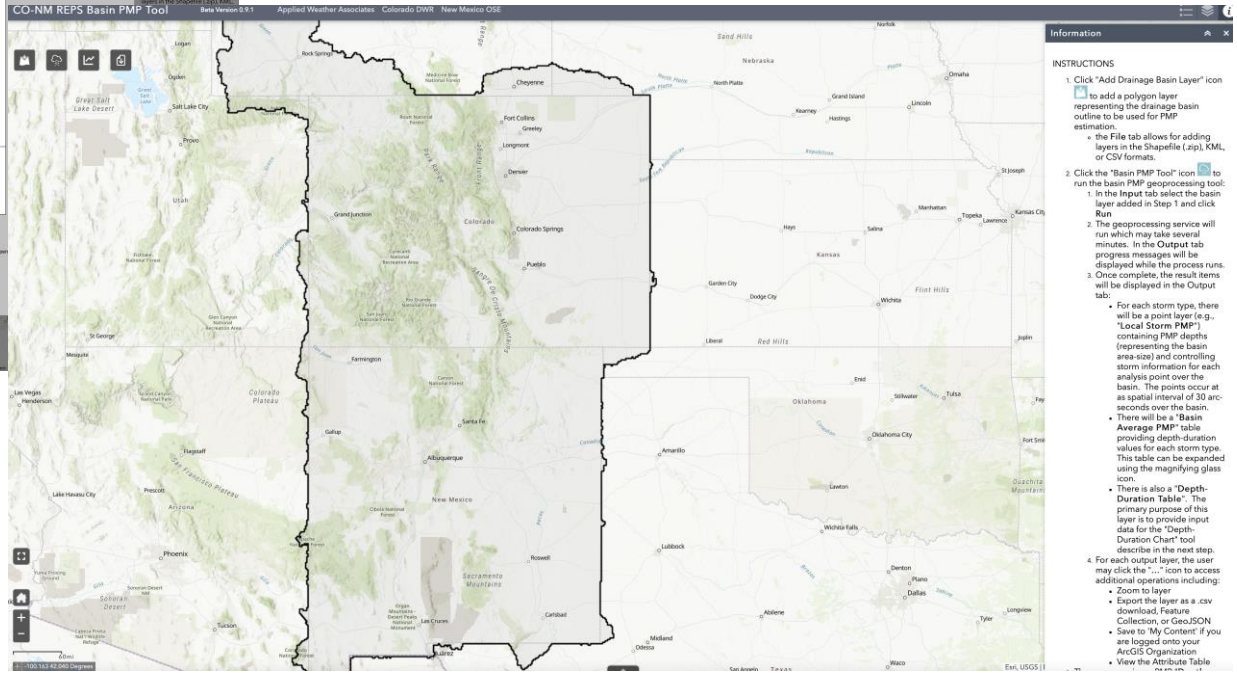


Statewide Projects-Now and What's Next

- Huge amounts of data/results over time
- Web interface for all studies for consistency
- No need desktop GIS
  - Corrects version control
  - Incorporate updates and improvements for all states
  - Include new storms
  - Include updated methods/climate data
- Provide consolidated support and maintenance
- Continually updated storm database

AWA Web PMP Tool Example



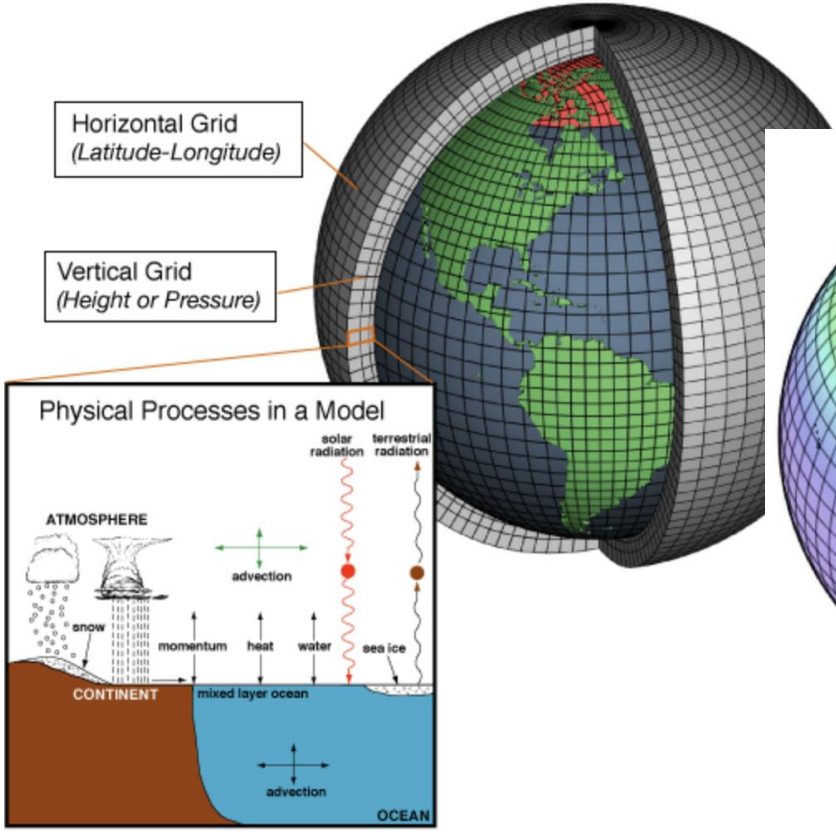


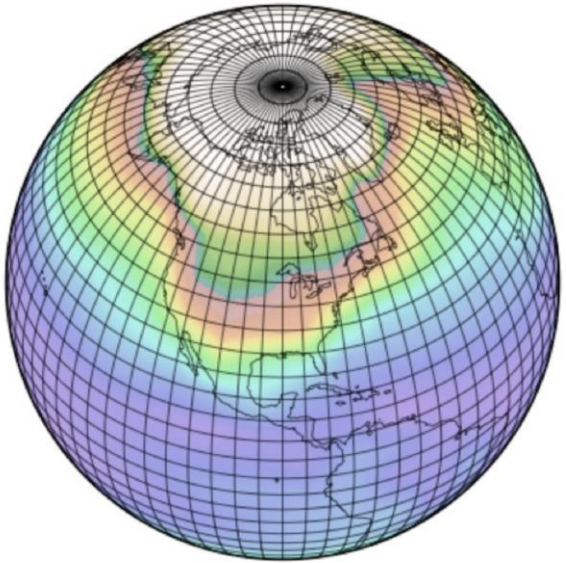
Climate Change, PMP, and Dam Safety

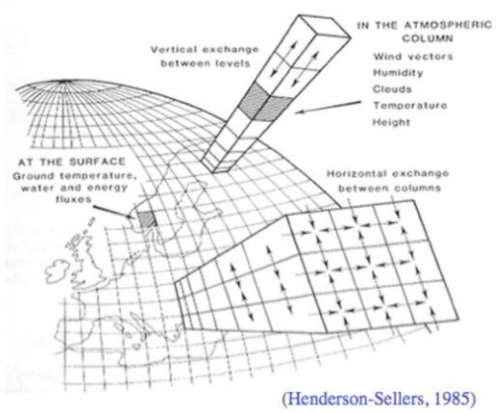
- So what's next? Does PMP change in a changing climate?

Applied Weather Associates

Global Climate Model-General Circulation Model







Climate Model Background

- Global Models are downscaled using Regional Climate Models
  - To better replicate local climate/topography
  - To better capture local meteorological conditions
- Two types of downscaling
  - Statistical
  - Dynamic

Climate Model Background (2)

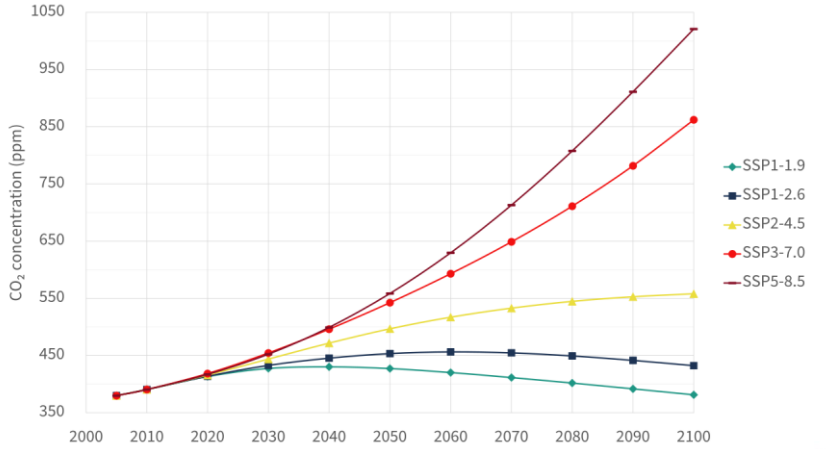
- Various research groups conduct climate change modeling
  - Share data via CMIP6 group
- Shared Socioeconomic Pathway (SSP)
  - SSP account for unknown future GHG emissions
- SSP scenarios used as boundary conditions for CMIP6 GCMs
  - Commonly use SSP 4.5 and 8.5

CMIP6 Climate Model Projections

- The **SSP 4.5** intermediate GHG emissions: CO2 emissions around current levels until 2050, then falling but not reaching net zero by 2100

- The **SSP 8.5** very high GHG emissions: CO2 emissions triple by 2075

SSP	Scenario	Estimated warming (2041–2060)	Estimated warming (2081–2100)	Very likely range in °C (2081–2100)
SSP1-1.9	very low GHG emissions: CO_2 emissions cut to net zero around 2050	1.6 °C	1.4 °C	1.0 – 1.8
SSP1-2.6	low GHG emissions: CO_2 emissions cut to net zero around 2075	1.7 °C	1.8 °C	1.3 – 2.4
SSP2-4.5	intermediate GHG emissions: CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0 °C	2.7 °C	2.1 – 3.5
SSP3-7.0	high GHG emissions: CO_2 emissions double by 2100	2.1 °C	3.6 °C	2.8 – 4.6
SSP5-8.5	very high GHG emissions: CO_2 emissions triple by 2075	2.4 °C	4.4 °C	3.3 – 5.7

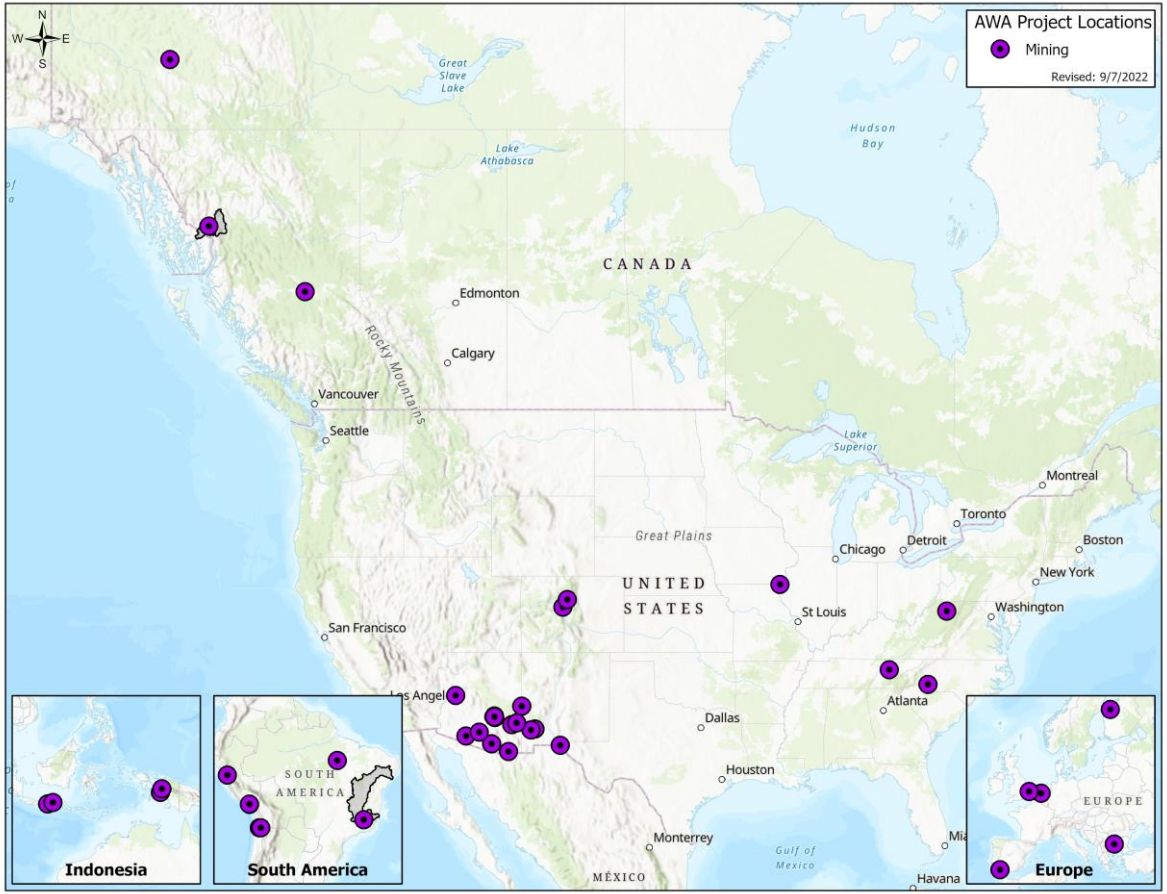


*** SP45 values are “likely” and SP85 “unlikely”

Within Uncertainty" Term

- The meaning of ***"within uncertainty"*** for this analysis
- Multiple sources of uncertainty and varying ranges of uncertainty
  - Gauge/Observed Precipitation
    - Point measurement 5 to 15% percent for long-term series, and as high as 75% for individual storm events
  - Frequency Analysis
    - Typically, 24-hour 100-year error bounds are approximately +/-18%
  - Climate Projections
    - Regional Models can be quite large 20 to >50%
  - PMP Storm In-place Maximization Factor
    - Range between 5 and 30%, with an average around 20%
- Consider +/- 20% to be within uncertainty of the analysis results.

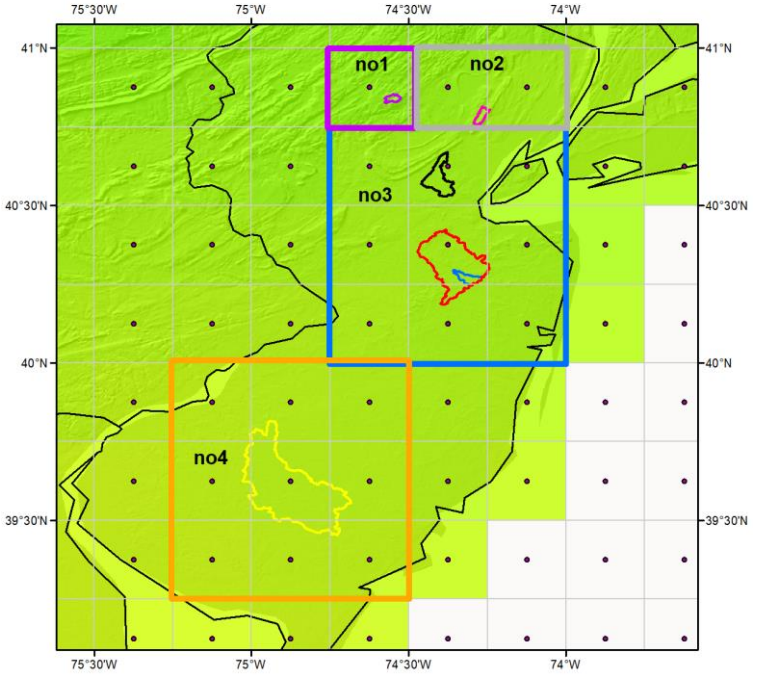
AWA Climate Change Study Locations



CMIP6 Climate Model Projections-NJ Example

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models
- 9 models did not have all data
  - (6) Missing years and/or variables
  - (3) 30-days per month
- Used 26 models on daily time step
  - Temperature
  - Relative humidity
  - Precipitation



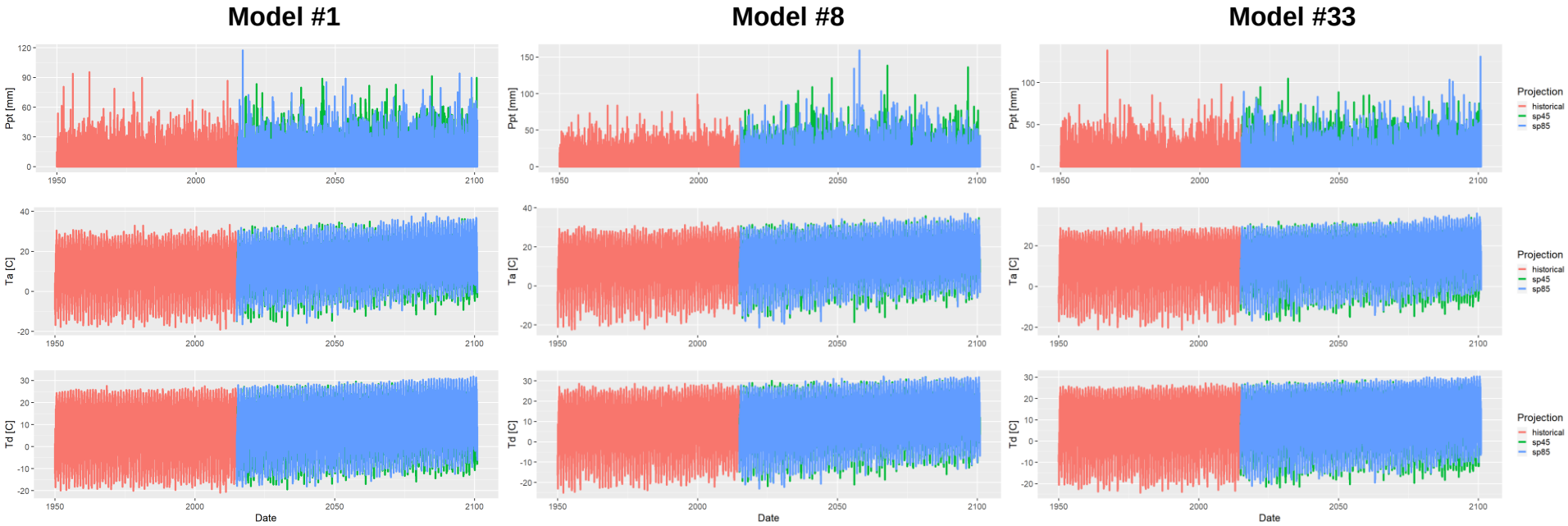
Region#	Basin	Domain
NJ_Region_1	Shongum	41.0, -74.75, 40.75, -74.5
NJ_Region_2	Orange	41.0, -74.5, 40.75, -74.0
NJ_Region_3	New Market, Durernal, Englishtown	40.75, -74.75, 40.0, -74.0
NJ_Region_4	Lenape	40.0, -75.25, 39.25, -74.5

Climate Model Projections Used

- 26 models on daily time step
  - Temperature (tas)
  - Relative humidity (hurs)
  - Precipitation (pr)

Model #	MODEL NAME	*Relative Humidity (hurs)*			*Precipitation (pr)*			*Temperature (tas)*		
		HISTORICAL	SSP45	SSP85	HISTORICAL	SSP45	SSP85	HISTORICAL	SSP45	SSP85
1	ACCESS-CM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
2	ACCESS-ESM1-5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
4	CanESM5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
5	CESM2-WACCM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
6	CESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
7	CMCC-CM2-SR5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
8	CMCC-ESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
9	CNRM-CM6-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
10	CNRM-ESM2-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
11	EC-Earth3-Veg-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
12	EC-Earth3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
13	FGOALS-g3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
14	GFDL-CM4_gr1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
15	GFDL-CM4_gr2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
16	GFDL-ESM4	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
17	GISS-E2-1-G	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
21	INM-CM4-8	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
22	INM-CM5-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
23	IPSL-CM6A-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
26	MIROC-ES2L	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
27	MIROC6	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
28	MPI-ESM1-2-HR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
29	MPI-ESM1-2-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
30	MRI-ESM2-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
33	NorESM2-MM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
34	TaiESM1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100

Climate Model Analysis Input (Model 1, 8, 33)



Climate Change Analysis Methods

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Model projections (Historic, SSP45, SSP85)
  - All Season, Summer, Winter

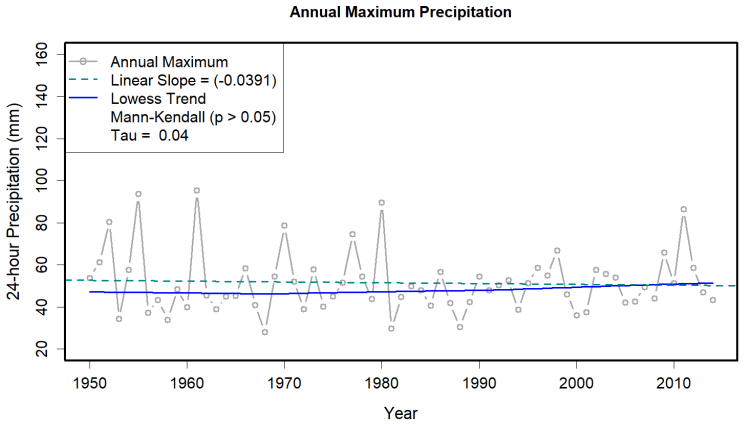
- **2) Monthly Analysis**
  - Model projections (Historic, SSP45, SSP85)
  - Precipitation and temperature

- 3**) Precipitation Frequency Analysis** for 1-day, 3-day, and Annual
  - All Season, Summer, and Winter
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes

Model Trend Analysis (1-day Example)

- 1-day AMS Trend Analysis (Mann-Kendall)

- 1) Model 1
  - trend depends on period investigated
    - Historical: **no trend**
    - SP45: **no trend**
    - SP85: **increasing trend**
- 2) Model 2
  - trend depends on period investigated
    - Historical: **no trend**
    - SP45: **no trend**
    - SP85: **no trend**
- 3) Model 4
  - trend depends on period investigated
    - Historical: **no trend**
    - SP45: **no trend**
    - SP85: **increasing trend**



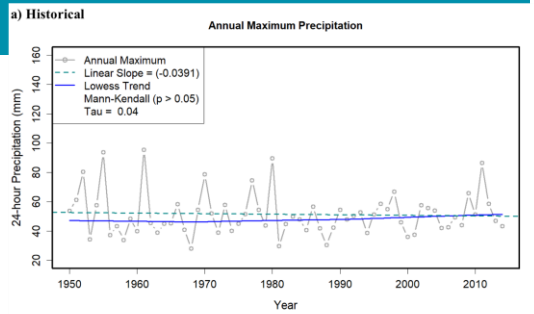
- 4) Model 5
  - trend depends on period investigated
    - Historical: **no trend**
    - SP45: **increasing trend**
    - SP85: **no trend**

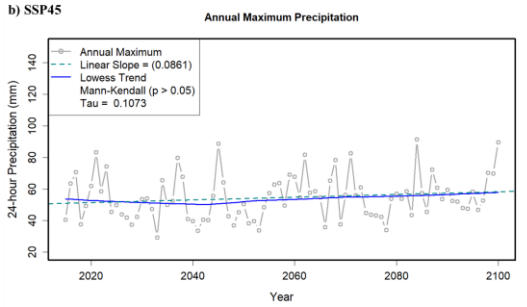
- 5) Model 6
  - trend depends on period investigated
    - Historical: **no trend**
    - SP45: **no trend**
    - SP85: **no trend**

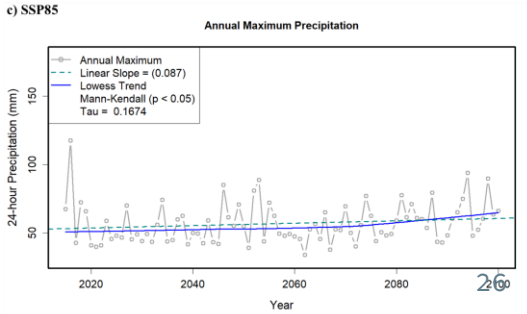
Completed for 1-day, 3-day, annual, and by season

Climate Model Trend Results

	Precipitation			Temperature
	1-day	3-day	Annual	1-day
Historic	24 – no trend 1 – increase 1 – decrease	26 – no trend 0 – increase 0 – decrease	26 – no trend 0 – increase 0 – decrease	7 – no trend 19 – increase 0 – decrease
SSP45	20 – no trend 6 – increase 0 – decrease	18 – no trend 4 – increase 0 – decrease	17 – no trend 9 – increase 0 – decrease	1 – no trend 25 – increase 0 – decrease
SSP85	11 – no trend 15 – increase 0 – decrease	14 – no trend 12 – increase 0 – decrease	4 – no trend 22 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

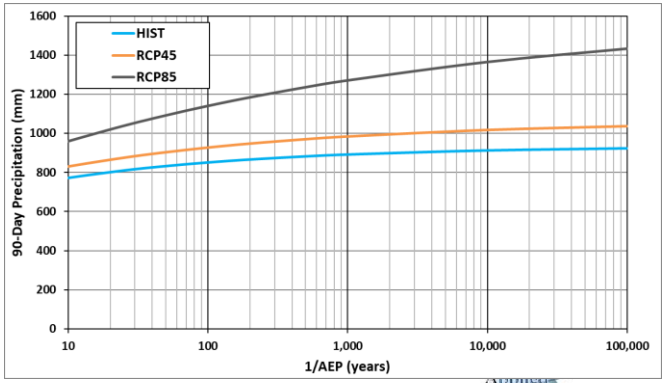




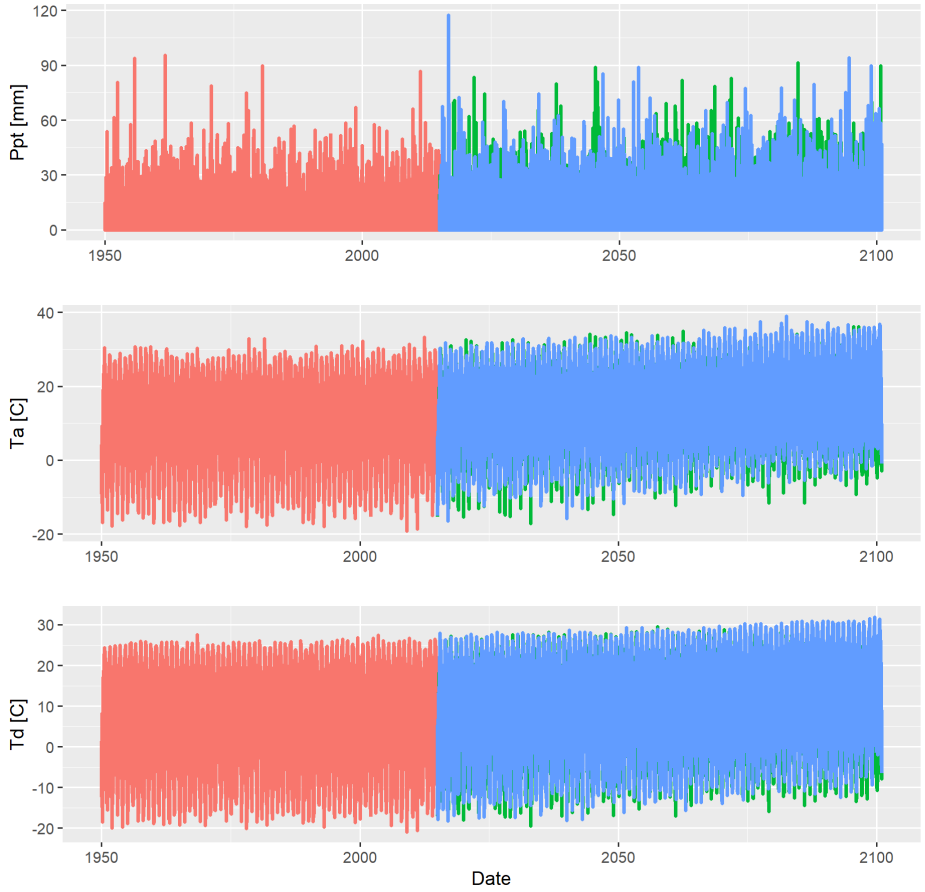


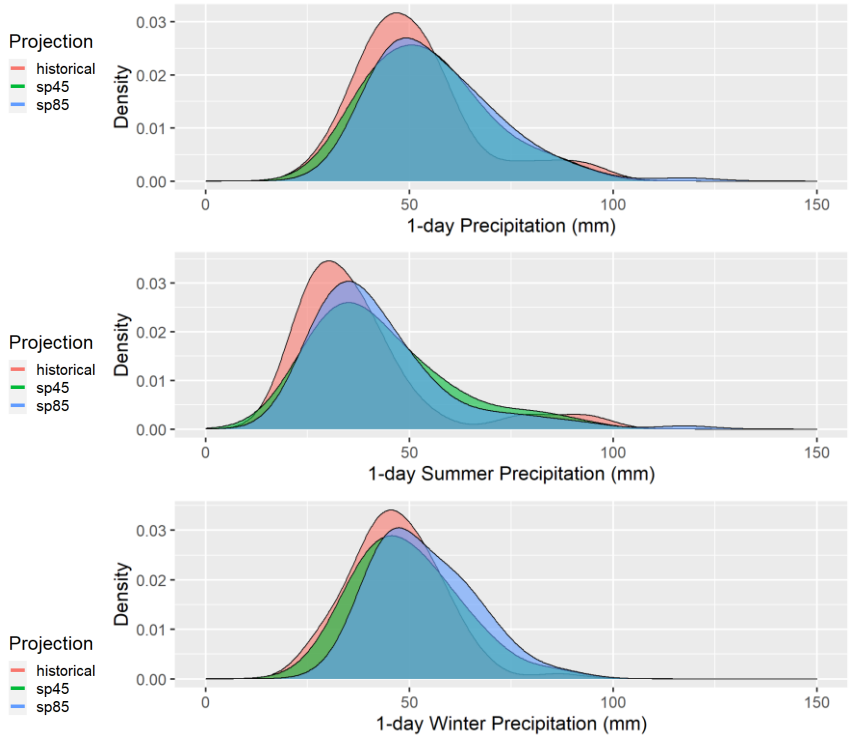
Frequency Analysis (L-moments)

- 1-day, 3-day, 365-day L-moment Frequency Analysis (Historic, SSP45, SSP85)
- All Precipitation, Summer, Winter
  - Identification of Probability Distribution
  - Goodness-of-fit measures
  - L-moment Ratio Diagram
    - The regional weighted average L-Skewness and L-Kurtosis tend to be near the GEV distribution
  - Derivation of Uncertainty bounds
    - Monte-carlo simulation
  - Point Value Annual Exceedance Estimates
  - Compare 10-, 50-, 100-, 500-, and 1000-year AEPs



Climate Model (Model 1)





Frequency Analysis (Model 1 Example)

*** 1-Day Precipitation											
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	70.1	92.8	103.5	131.1	144.3	-	-	-	-	-	
SP45	73.7	90.7	97.5	112.5	118.5	105%	98%	94%	86%	82%	**93%**
SP85	76.1	99.1	109.9	137.6	150.9	108%	107%	106%	105%	105%	**106%**

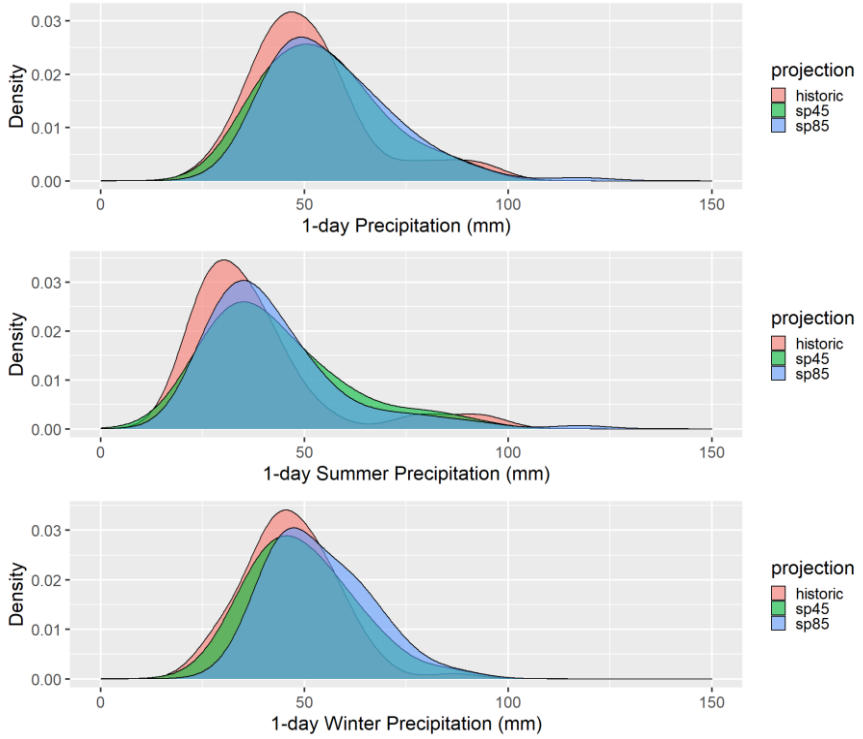
*** 1-Day Summer											
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	56.4	92.4	114.3	188.1	233.4	-	-	-	-	-	
SP45	63.8	91.3	104.8	141.4	159.7	113%	99%	92%	75%	68%	**89%**
SP85	62.2	93.9	111.3	163.5	192.4	110%	102%	97%	87%	82%	**96%**

*** 1-Day Winter											
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	61.0	70.6	73.9	80.1	82.3	-	-	-	-	-	
SP45	66.9	81.6	87.4	99.8	104.8	110%	116%	118%	125%	127%	**119%**
SP85	69.6	84.5	90.6	104.3	109.9	114%	120%	123%	130%	134%	**124%**

*** 3-Day Precipitation											
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	103.1	135.3	149.9	186.1	202.7	-	-	-	-	-	
SP45	110.2	137.5	148.7	173.7	184.2	107%	102%	99%	93%	91%	**98%**
SP85	120.1	157.5	174.1	214.8	233.2	116%	116%	116%	115%	115%	**116%**

* 3-Day Summer											
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	86.9	133.2	160.3	247.7	299.3	-	-	-	-	-	
SP45	96.2	128.8	143.5	180.0	196.8	111%	97%	90%	73%	66%	**87%**
SP85	99.2	142.1	163.9	224.5	255.7	114%	107%	102%	91%	85%	**100%**

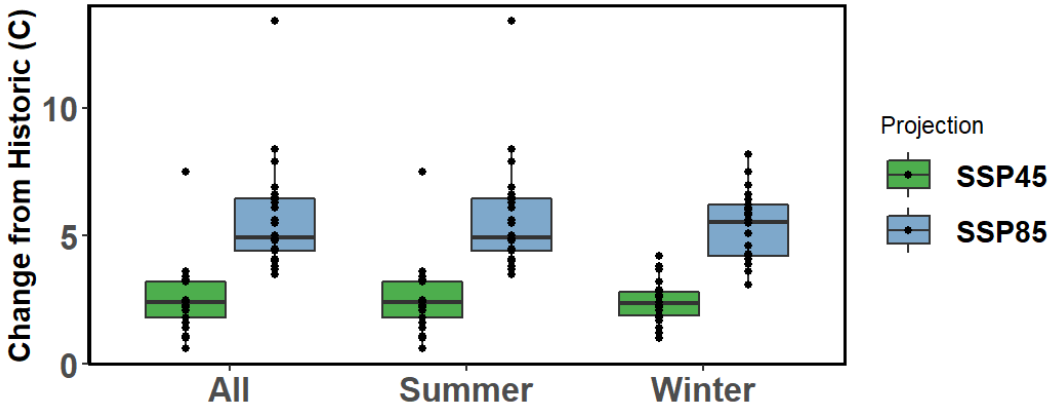
* 3-Day Winter											
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	91.9	123.6	138.9	179.6	199.7	-	-	-	-	-	
SP45	101.0	130.2	142.8	172.3	185.2	110%	105%	103%	96%	93%	**101%**
SP85	110.0	146.3	163.3	206.8	227.5	120%	118%	118%	115%	114%	**117%**



*** 365-Day												
	10yr	50yr	100yr	500yr	1000yr	Pct Change						Average
Historical	1379	1462	1486	1526	1538	-	-	-	-	-		
SP45	1517	1626	1658	1708	1722	110%	111%	112%	112%	112%		**111%**
SP85	1571	1691	1728	1792	1812	114%	116%	116%	117%	118%		**116%**

Summary Temperature Annual Maximum

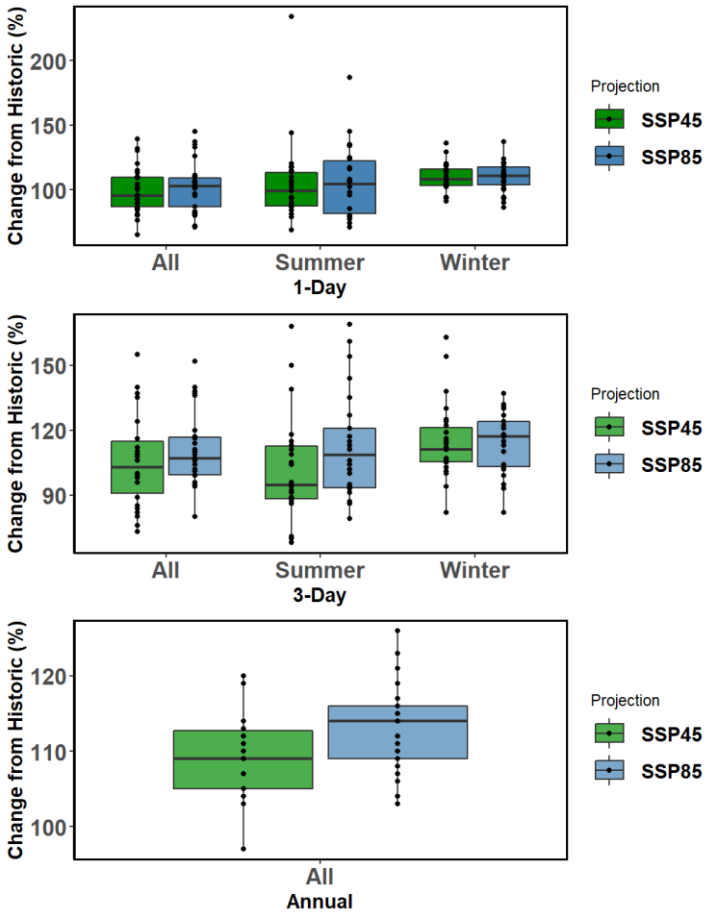
- **1-day (ssp45; ssp85)**
  - All = 2.4 C; 4.9 C
  - Summer = 2.4 C; 4.9 C
  - Winter = 2.4 C; 5.5 C



*** Frequency based results, 26 RCM
+++ Boxplots based on these data

Summary Precipitation Frequency

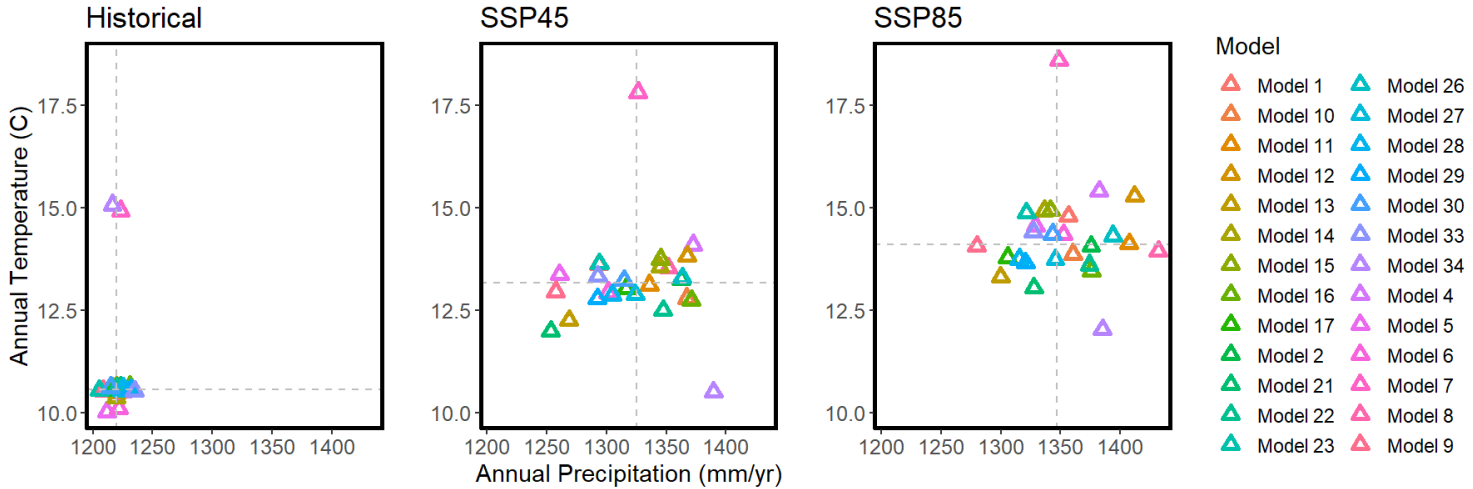
- **1-day (sp45; sp85)**
  - All = -4%; 3%
  - Summer = -1%; 4%
  - Winter = 8%; 11%
- **3-day**
  - All = 3%; 7%
  - Summer = -5%; 9%
  - Winter = 11%; 17%
- **Annual**
  - All = 9%; 14%



*** Frequency based results, 26 RCM
+++ Boxplots based on these data

Summary Annual Temperature and Precipitation

- **Annual Climatology (temp, ppt)**
  - Historical = 10.6 C; 1220 mm
  - SSP45 = 13.2 C; 1325 mm (2.6 C; 109%)
  - SSP85 = 14.1 C; 1347 mm (3.5 C; 110%)



*** Climatology, based on 26 RCM

Application of Climate Change Results

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Temperature 1-Day; C	**2.5**	**2.4**	0.6	7.5	**5.6**	**4.9**	3.5	13.4
Temperature 1-Day Summer; C	**2.5**	**2.4**	0.6	7.5	**5.6**	**4.9**	3.5	13.4
Temperature 1-Day Winter PF; C	**2.4**	**2.4**	1.0	4.2	**5.4**	**5.5**	3.1	8.2
Precipitation 1-Day PF; %	**-1**	**-4**	-35	39	**2**	**3**	-29	45
Precipitation 1-Day Summer PF; %	**4**	**-1**	-31	134	**6**	**4**	-29	87
Precipitation 1-Day Winter PF; %	**9**	**8**	-9	36	**10**	**11**	-14	37
Precipitation 3-Day PF; %	**5**	**3**	-27	55	**11**	**7**	-20	52
Precipitation 3-Day Summer PF; %	**3**	**-5**	-32	68	**13**	**9**	-21	69
Precipitation 3-Day Winter PF; %	**14**	**11**	-18	63	**15**	**17**	-18	37
Precipitation Annual PF; %	**9**	**9**	-3	20	**14**	**14**	3	26

Climate Change Projections from 2015 through 2100

Application of Climate Change Results (2)

- Results are presented as median values based on model ensemble
- Design Storm and Routing Applications
  - Recommend SSP45 climate scenario as “likely”, SSP85 as “unlikely”
- Results are through 2100 and can be scaled to other periods
  - Example, for 2050 adjustment scale 2100 results by 0.59.

	2050	2100
1-Day Summer PF; %	-1	-1
1-Day Winter PF; %	5	8
3-Day Summer PF; %	-3	-5
3-Day Winter PF; %	7	11

Climate Change Projections from 2015 through 2100

Conclusion

TREND

- **Increase** in Ta and Td
- SSP45 Ppt – most show No Trend/Change
- SSP85 Ppt - most show increase trend

FREQUENCY

- 1-day – SSP45 and SSP85 confidence for **no change** in summer or winter season Ppt magnitude by 2100
  - greatest change most likely in winter seasons
- 3-day – SSP45 and SSP85 confidence for **no change** in summer or winter season in Ppt magnitude by 2100
  - greatest change most likely in winter season
- Annual – SSP45 and SSP85 confidence for **no change** of Ppt magnitude by 2100 and **increase** Temp by 2100

CLIMATOLOGY

- Monthly Climatology – slight **increase** (<20%) in Ppt and **increase** Temp by 2100
- Annual Climatology – slight **increase** (<20%) in annual Ppt and **increase** in annual Temp by 2100

Questions

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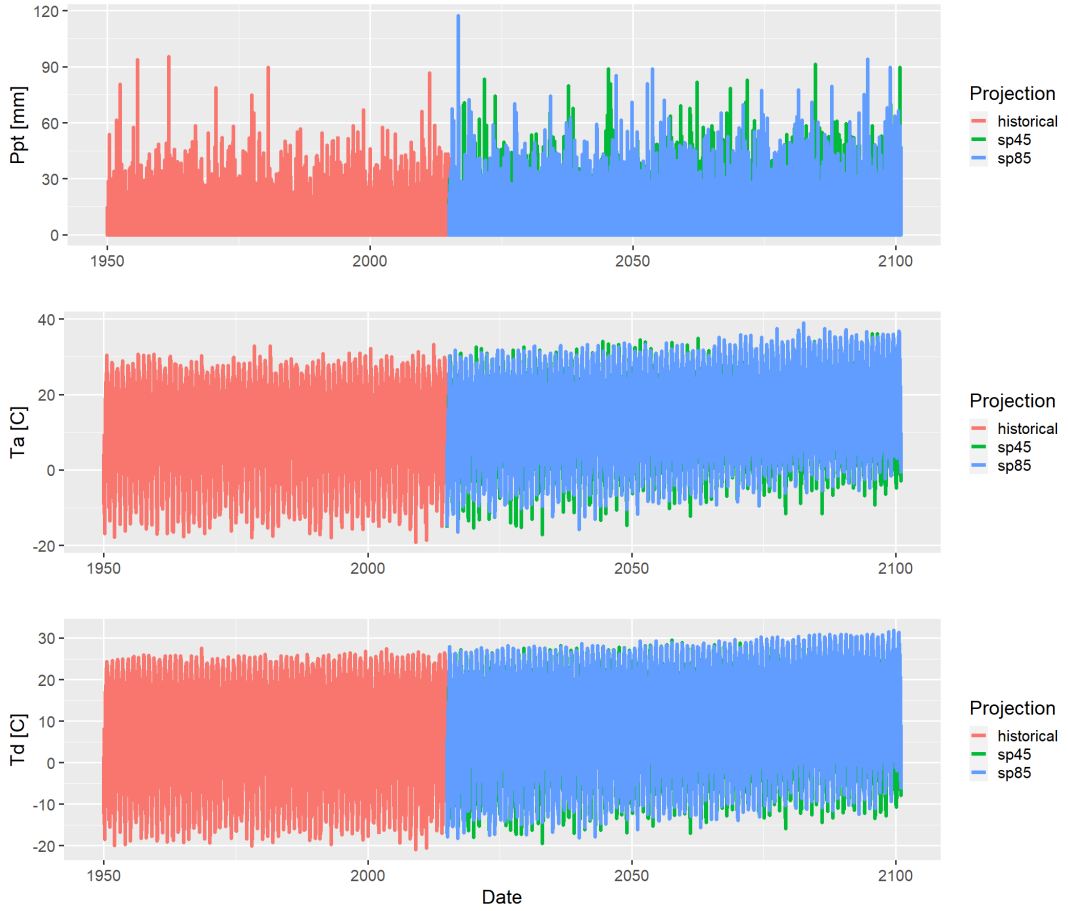
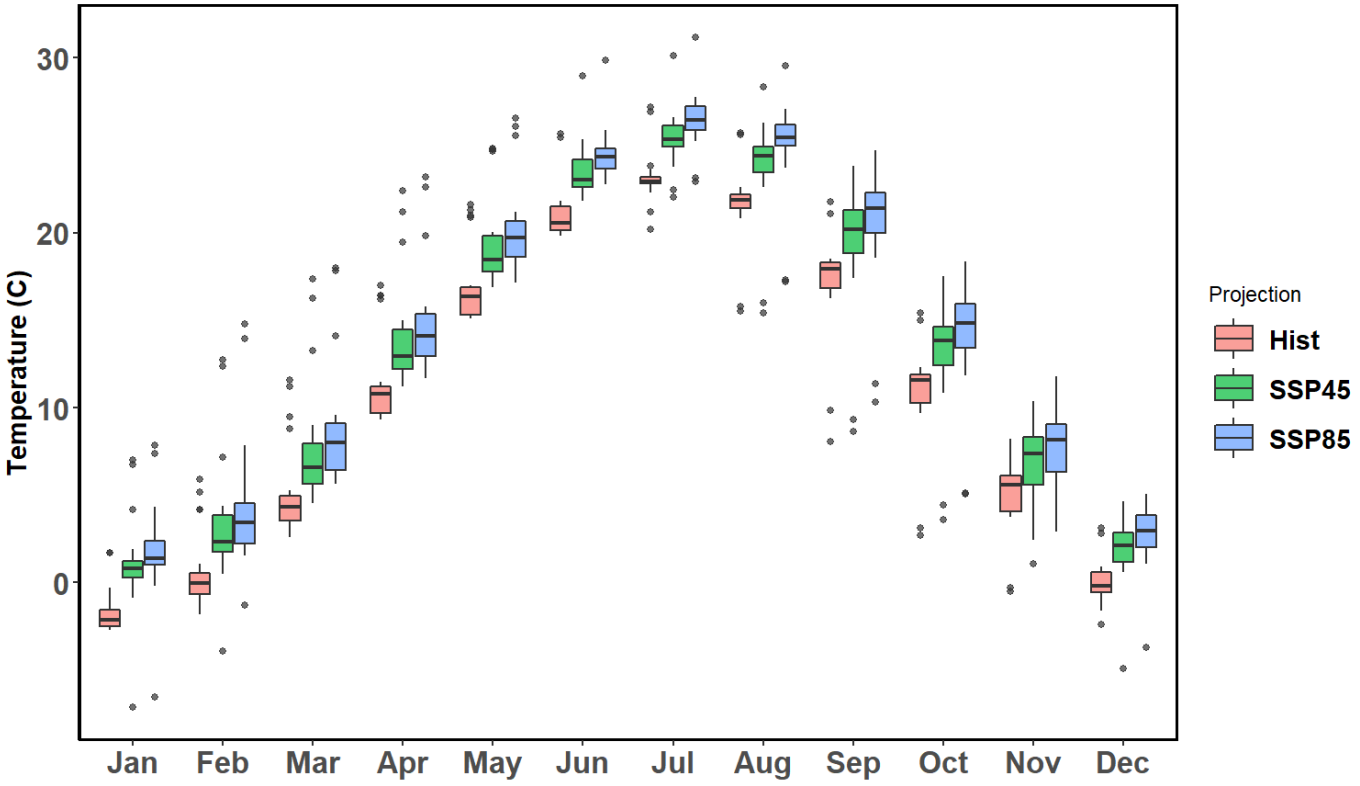
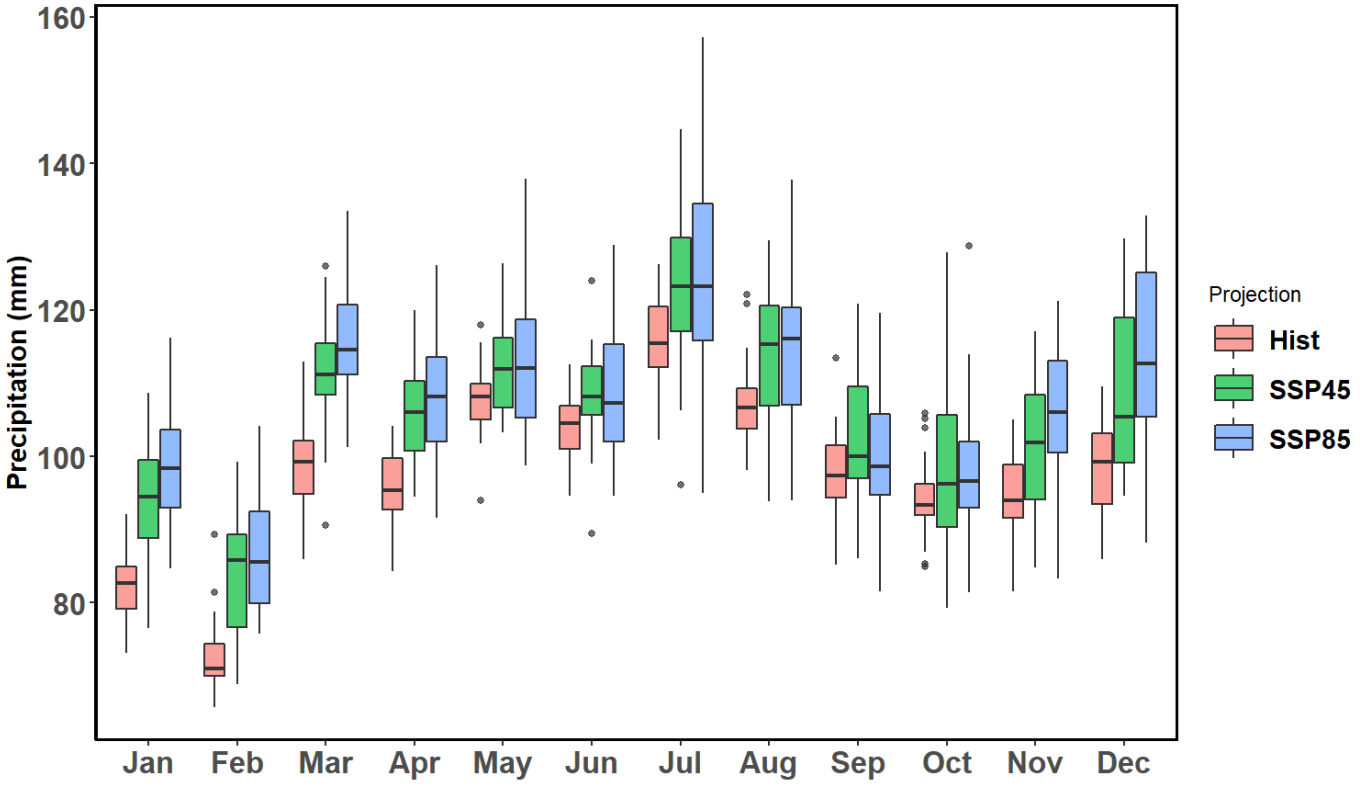


Summary Monthly Temperature



*** Climatology, based on 26 RCM

Summary Monthly Precipitation



*** Climatology, based on 26 RCM

Application of Climate Change Results (3)

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	-1.7	-2.2	0.9	0.8	1.7	1.4	***2.6***	***3.4***	***3.0***	***3.5***
February	0.5	-0.1	3.2	2.4	4.1	3.5	***2.7***	***3.6***	***2.4***	***3.5***
March	5.0	4.4	7.6	6.6	8.6	8.0	***2.6***	***3.6***	***2.3***	***3.7***
April	11.3	10.8	13.9	12.9	14.8	14.1	***2.6***	***3.5***	***2.2***	***3.3***
May	16.8	16.4	19.2	18.5	20.1	19.7	***2.4***	***3.3***	***2.1***	***3.4***
June	21.1	20.6	23.5	23.0	24.5	24.4	***2.5***	***3.5***	***2.5***	***3.8***
July	23.2	22.9	25.4	25.4	26.5	26.4	***2.3***	***3.3***	***2.5***	***3.5***
August	21.6	21.9	23.8	24.4	25.0	25.4	***2.2***	***3.4***	***2.5***	***3.6***
September	17.2	17.9	19.3	20.2	20.6	21.4	***2.1***	***3.4***	***2.3***	***3.5***
October	10.8	11.6	13.0	13.9	14.1	14.9	***2.1***	***3.3***	***2.3***	***3.3***
November	4.9	5.6	6.8	7.4	7.7	8.1	***1.9***	***2.8***	***1.8***	***2.5***
December	0.0	-0.2	2.0	2.1	2.7	3.0	***1.9***	***2.7***	***2.3***	***3.2***

Climate Change Projections from 2015 through 2100

Application of Climate Change Results (4)

Monthly Precipitation Analysis

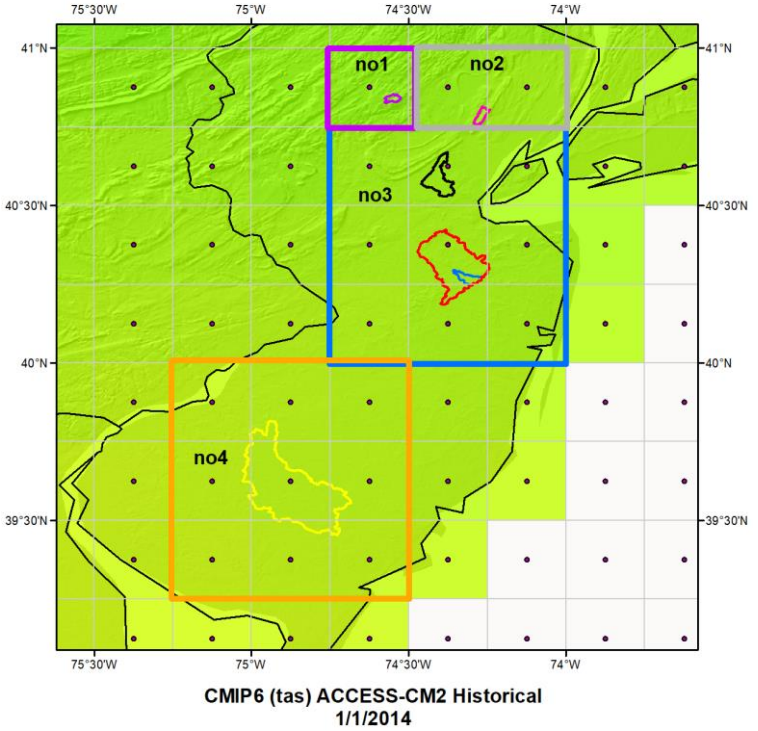
	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	82.3	82.7	93.8	94.5	98.0	98.4	***1.14***	***1.14***	***1.14***	***1.19***
February	72.7	71.0	84.4	85.9	86.5	85.6	***1.16***	***1.21***	***1.21***	***1.21***
March	98.6	99.3	111.2	111.2	115.6	114.5	***1.13***	***1.12***	***1.12***	***1.15***
April	95.7	95.3	106.4	106.1	108.4	108.1	***1.11***	***1.11***	***1.11***	***1.13***
May	107.9	108.2	112.0	112.0	112.9	112.0	***1.04***	***1.04***	***1.04***	***1.04***
June	104.1	104.5	108.5	108.1	108.8	107.2	***1.04***	***1.03***	***1.03***	***1.03***
July	115.5	115.5	123.0	123.2	124.6	123.2	***1.06***	***1.07***	***1.07***	***1.07***
August	107.1	106.7	113.2	115.4	114.8	116.0	***1.06***	***1.08***	***1.08***	***1.09***
September	97.3	97.4	102.5	100.0	99.7	98.7	***1.05***	***1.03***	***1.03***	***1.01***
October	94.5	93.3	97.9	96.2	98.5	96.7	***1.04***	***1.03***	***1.03***	***1.04***
November	94.7	94.0	101.2	101.8	105.1	106.1	***1.07***	***1.08***	***1.08***	***1.13***
December	97.8	99.3	108.4	105.4	113.3	112.7	***1.11***	***1.06***	***1.06***	***1.13***

Climate Change Projections from 2015 through 2100

Region 2 - Climate Change Results

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models
- 9 models did not have all data
  - (6) Missing years and/or variables
  - (3) 30-days per month
- Used 26 models on daily time step
  - Temperature
  - Relative humidity
  - Precipitation



Region#	Basin	Domain
NJ_Region_1	Shongum	41.0, -74.75, 40.75, -74.5
NJ_Region_2	Orange	41.0, -74.5, 40.75, -74.0
NJ_Region_3	New Market, Durernal, Englishtown	40.75, -74.75, 40.0, -74.0
NJ_Region_4	Lenape	40.0, -75.25, 39.25, -74.5

Climate Change Analysis Methods (2)

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Model projections (Historic, SSP45, SSP85)
  - All Season, Summer, Winter

- **2) Monthly Analysis**
  - Model projections (Historic, SSP45, SSP85)
  - Precipitation and temperature

- 3**) Precipitation Frequency Analysis** for 1-day, 3-day, and Annual
  - All Season, Summer, and Winter
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes

Region 2 - Trend Results

	Precipitation			Temperature
	1-day	3-day	Annual	1-day
Historic	24 – no trend 1 – increase 1 – decrease	24 – no trend 1 – increase 1 – decrease	26 – no trend 0 – increase 0 – decrease	7 – no trend 19 – increase 0 – decrease
SSP45	19 – no trend 7 – increase 0 – decrease	20 – no trend 6 – increase 0 – decrease	15 – no trend 11 – increase 0 – decrease	1 – no trend 25 – increase 0 – decrease
SSP85	9 – no trend 17 – increase 0 – decrease	13 – no trend 13 – increase 0 – decrease	3 – no trend 23 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Region 2 - Climate Change Results (3)

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Temperature 1-Day; C	**2.5**	**2.3**	0.7	7.3	**5.5**	**4.9**	3.3	12.6
Temperature 1-Day Summer; C	**2.5**	**2.3**	0.7	7.3	**5.5**	**4.9**	3.3	12.6
Temperature 1-Day Winter PF; C	**2.4**	**2.4**	1.2	4.2	**5.4**	**5.6**	3.1	8.6
Precipitation 1-Day PF; %	**0**	**-5**	-31	36	**3**	**2**	-29	43
Precipitation 1-Day Summer PF; %	**1**	**-4**	-31	83	**3**	**-1**	-33	75
Precipitation 1-Day Winter PF; %	**8**	**6**	-10	29	**10**	**12**	-19	26
Precipitation 3-Day PF; %	**4**	**2**	-31	66	**10**	**10**	-15	53
Precipitation 3-Day Summer PF; %	**1**	**-7**	-36	52	**11**	**3**	-28	64
Precipitation 3-Day Winter PF; %	**14**	**11**	-16	61	**15**	**15**	-12	52
Precipitation Annual PF; %	**9**	**9**	-3	22	**14**	**14**	2	26

Climate Change Projections from 2015 through 2100

Region 2 - Application of Climate Change Results

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	-0.6	-0.9	2.1	2.0	2.9	2.7	***2.7***	***3.5***	***2.9***	***3.6***
February	1.5	1.0	4.2	3.5	5.1	4.5	***2.7***	***3.6***	***2.5***	***3.4***
March	5.9	5.3	8.4	7.4	9.4	8.8	***2.6***	***3.5***	***2.1***	***3.5***
April	12.0	11.6	14.6	13.6	15.4	14.5	***2.6***	***3.4***	***2.0***	***2.9***
May	17.5	17.1	19.9	19.1	20.8	20.3	***2.4***	***3.3***	***2.1***	***3.2***
June	21.9	21.4	24.3	24.0	25.3	25.1	***2.5***	***3.5***	***2.6***	***3.7***
July	24.0	23.9	26.3	26.3	27.4	27.3	***2.3***	***3.4***	***2.4***	***3.4***
August	22.6	22.9	24.8	25.3	25.9	26.3	***2.2***	***3.3***	***2.5***	***3.4***
September	18.2	19.0	20.3	21.2	21.5	22.2	***2.1***	***3.3***	***2.2***	***3.2***
October	11.9	12.7	14.1	15.0	15.2	16.0	***2.1***	***3.2***	***2.3***	***3.3***
November	6.1	6.8	7.9	8.5	8.9	9.4	***1.8***	***2.8***	***1.8***	***2.6***
December	1.2	1.1	3.2	3.5	3.9	4.2	***2.0***	***2.7***	***2.4***	***3.1***

Climate Change Projections from 2015 through 2100

Region 2 - Application of Climate Change Results (2)

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	82.3	82.6	93.7	93.9	97.3	97.7	***1.14***	***1.14***	***1.14***	***1.18***
February	73.6	72.0	86.0	86.8	87.6	86.2	***1.17***	***1.20***	***1.20***	***1.20***
March	99.7	100.9	112.5	111.4	117.1	116.4	***1.13***	***1.10***	***1.10***	***1.15***
April	95.3	94.3	105.0	103.5	107.9	108.0	***1.10***	***1.10***	***1.10***	***1.14***
May	104.6	104.3	108.9	109.5	109.5	107.7	***1.04***	***1.05***	***1.05***	***1.03***
June	99.9	99.9	103.0	104.2	104.4	103.3	***1.03***	***1.04***	***1.04***	***1.03***
July	111.9	111.5	119.1	118.6	120.4	117.8	***1.06***	***1.06***	***1.06***	***1.06***
August	105.4	104.9	111.7	112.8	113.5	114.0	***1.06***	***1.08***	***1.08***	***1.09***
September	93.8	93.2	100.0	97.8	96.6	95.2	***1.07***	***1.05***	***1.05***	***1.02***
October	92.6	92.6	95.5	94.6	97.2	94.9	***1.03***	***1.02***	***1.02***	***1.02***
November	94.0	94.0	100.9	101.1	104.8	104.1	***1.07***	***1.08***	***1.08***	***1.11***
December	98.5	99.4	108.7	106.4	114.1	113.3	***1.10***	***1.07***	***1.07***	***1.14***

Climate Change Projections from 2015 through 2100

Region 2 - Conclusion

TREND

- **Increase** in Ta and Td
- SSP45 Ppt – most show No Trend/Change
- SSP85 Ppt - most show increase trend

FREQUENCY

- 1-day – SSP45 and SSP85 confidence for **no change** in summer or winter season Ppt magnitude by 2100
  - greatest change most likely in winter seasons
- 3-day – SSP45 and SSP85 confidence for **no change** in summer or winter season in Ppt magnitude by 2100
  - greatest change most likely in winter season
- Annual – SSP45 and SSP85 confidence for **no change** of Ppt magnitude by 2100 and **increase** Temp by 2100

CLIMATOLOGY

- Monthly Climatology – slight **increase** (<20%) in Ppt and **increase** Temp by 2100
- Annual Climatology – slight **increase** (<20%) in annual Ppt and **increase** in annual Temp by 2100

Region 3 - Climate Change Results

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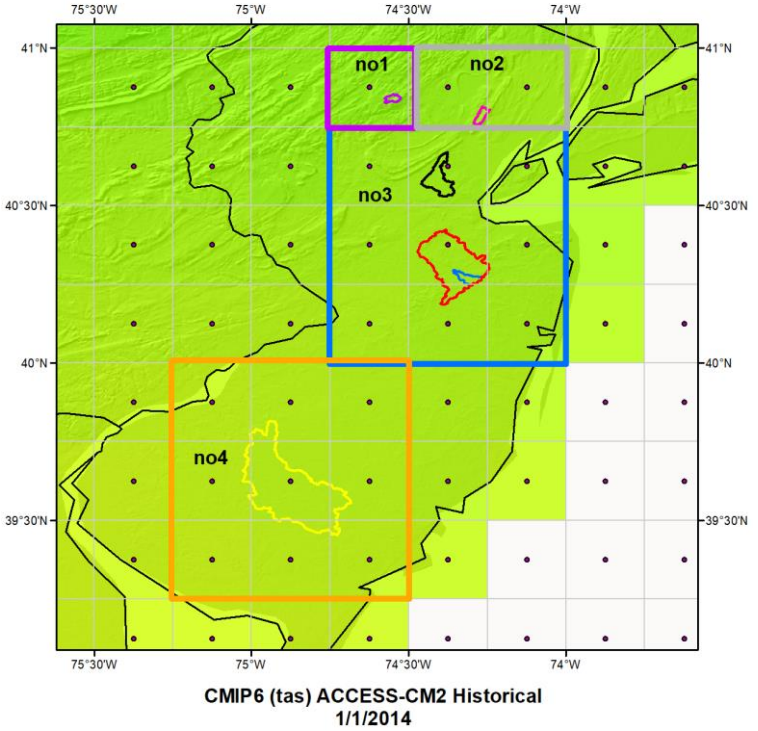

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  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes

Region 3 - Trend Results

	Precipitation			Temperature
	1-day	3-day	Annual	1-day
Historic	24 – no trend 1 – increase 1 – decrease	26 – no trend 0 – increase 0 – decrease	26 – no trend 0 – increase 0 – decrease	6 – no trend 20 – increase 0 – decrease
SSP45	18 – no trend 8 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease
SSP85	9 – no trend 17 – increase 0 – decrease	13 – no trend 13 – increase 0 – decrease	5 – no trend 21 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Region 3 - Climate Change Results (2)

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Temperature 1-Day; C	**2.4**	**2.2**	0.5	6.3	**5.4**	**4.9**	3.3	11.1
Temperature 1-Day Summer; C	**2.4**	**2.2**	0.5	6.3	**5.4**	**4.9**	3.3	11.1
Temperature 1-Day Winter PF; C	**2.5**	**2.5**	1.1	4.0	**5.3**	**5.5**	2.9	8.1
Precipitation 1-Day PF; %	**-3**	**-7**	-23	28	**1**	**0**	-27	42
Precipitation 1-Day Summer PF; %	**1**	**-6**	-35	59	**5**	**5**	-39	54
Precipitation 1-Day Winter PF; %	**5**	**4**	-17	36	**7**	**9**	-24	26
Precipitation 3-Day PF; %	**2**	**1**	-33	44	**10**	**4**	-18	67
Precipitation 3-Day Summer PF; %	**-2**	**-7**	-44	43	**9**	**5**	-23	61
Precipitation 3-Day Winter PF; %	**9**	**7**	-16	63	**12**	**10**	-15	43
Precipitation Annual PF; %	**9**	**10**	-6	21	**14**	**14**	-2	31

Climate Change Projections from 2015 through 2100

Region 3 - Application of Climate Change Results

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	0.3	0.1	2.9	2.9	3.7	3.5	***2.6***	***3.4***	***2.8***	***3.5***
February	2.4	2.0	4.9	4.2	5.8	5.1	***2.6***	***3.4***	***2.2***	***3.1***
March	6.6	6.0	9.1	8.1	10.0	9.5	***2.5***	***3.4***	***2.1***	***3.5***
April	12.5	12.1	15.0	14.1	15.8	14.9	***2.5***	***3.3***	***2.1***	***2.8***
May	17.8	17.6	20.2	19.5	21.1	20.7	***2.4***	***3.3***	***1.9***	***3.1***
June	22.3	21.9	24.7	24.2	25.6	25.4	***2.4***	***3.3***	***2.4***	***3.6***
July	24.5	24.3	26.6	26.7	27.7	27.8	***2.2***	***3.2***	***2.4***	***3.5***
August	23.1	23.4	25.2	25.8	26.3	26.8	***2.1***	***3.2***	***2.4***	***3.5***
September	18.9	19.7	20.9	21.9	22.1	23.0	***2.0***	***3.2***	***2.2***	***3.3***
October	12.6	13.4	14.7	15.7	15.8	16.6	***2.1***	***3.2***	***2.3***	***3.2***
November	6.9	7.5	8.8	9.4	9.7	10.2	***1.9***	***2.8***	***1.9***	***2.7***
December	2.1	2.0	4.1	4.4	4.8	5.1	***2.0***	***2.7***	***2.4***	***3.1***

Climate Change Projections from 2015 through 2100

Region 3 - Application of Climate Change Results (2)

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	82.2	82.5	92.8	94.6	96.9	95.9	***1.13***	***1.15***	***1.15***	***1.16***
February	72.1	71.5	83.5	82.9	85.2	84.7	***1.16***	***1.16***	***1.16***	***1.19***
March	98.1	98.4	108.8	108.5	113.6	113.8	***1.11***	***1.10***	***1.10***	***1.16***
April	91.4	89.5	100.6	98.8	103.5	102.3	***1.10***	***1.10***	***1.10***	***1.14***
May	97.0	95.8	101.8	102.0	101.5	101.2	***1.05***	***1.06***	***1.06***	***1.06***
June	96.9	97.3	101.4	99.9	101.8	101.2	***1.05***	***1.03***	***1.03***	***1.04***
July	113.6	113.9	120.7	120.6	121.3	120.8	***1.06***	***1.06***	***1.06***	***1.06***
August	106.1	107.0	113.0	115.3	113.7	116.7	***1.07***	***1.08***	***1.08***	***1.09***
September	89.2	90.0	95.4	95.0	92.3	91.7	***1.07***	***1.06***	***1.06***	***1.02***
October	86.3	86.3	88.7	87.2	90.6	89.5	***1.03***	***1.01***	***1.01***	***1.04***
November	89.8	89.1	95.3	93.9	97.9	97.8	***1.06***	***1.05***	***1.05***	***1.10***
December	96.2	96.7	106.5	104.6	111.5	110.9	***1.11***	***1.08***	***1.08***	***1.15***

Climate Change Projections from 2015 through 2100

Region 3 - Conclusion

TREND

- **Increase** in Ta and Td
- SSP45 Ppt – most show No Trend/Change
- SSP85 Ppt - most show increase trend

FREQUENCY

- 1-day – SSP45 and SSP85 confidence for **no change** in summer or winter season Ppt magnitude by 2100
  - greatest change most likely in winter seasons
- 3-day – SSP45 and SSP85 confidence for **no change** in summer or winter season in Ppt magnitude by 2100
  - greatest change most likely in winter season
- Annual – SSP45 and SSP85 confidence for **no change** of Ppt magnitude by 2100 and **increase** Temp by 2100

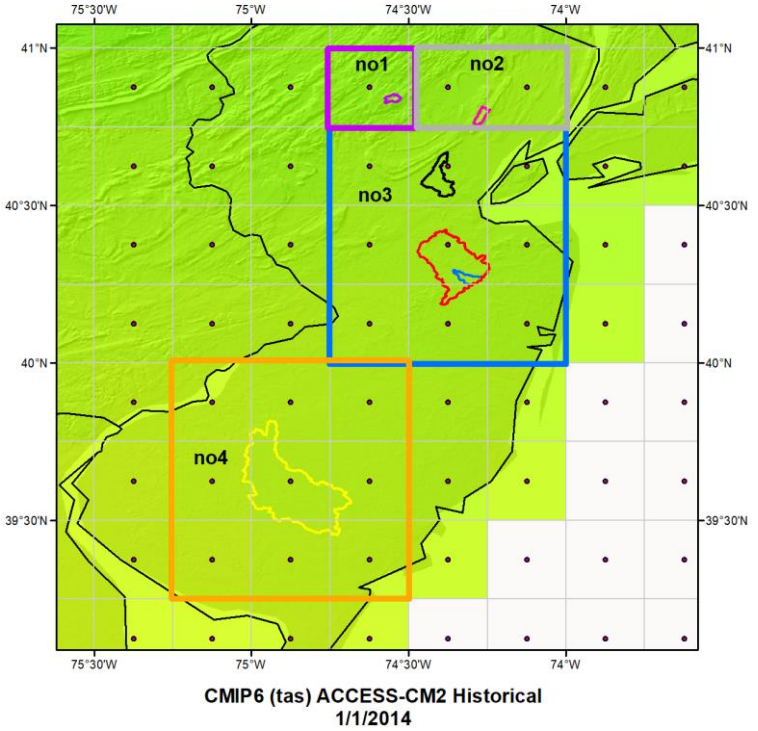
CLIMATOLOGY

- Monthly Climatology – slight **increase** (<20%) in Ppt and **increase** Temp by 2100
- Annual Climatology – slight **increase** (<20%) in annual Ppt and **increase** in annual Temp by 2100

Region 4 - Climate Change Results

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models
- 9 models did not have all data
  - (6) Missing years and/or variables
  - (3) 30-days per month
- Used 26 models on daily time step
  - Temperature
  - Relative humidity
  - Precipitation



Region#	Basin	Domain
NJ_Region_1	Shongum	41.0, -74.75, 40.75, -74.5
NJ_Region_2	Orange	41.0, -74.5, 40.75, -74.0
NJ_Region_3	New Market, Durernal, Englishtown	40.75, -74.75, 40.0, -74.0
NJ_Region_4	Lenape	40.0, -75.25, 39.25, -74.5

Climate Change Analysis Methods (5)

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Model projections (Historic, SSP45, SSP85)
  - All Season, Summer, Winter

- **2) Monthly Analysis**
  - Model projections (Historic, SSP45, SSP85)
  - Precipitation and temperature

- 3**) Precipitation Frequency Analysis** for 1-day, 3-day, and Annual
  - All Season, Summer, and Winter
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes

Region 4- Trend Results

	Precipitation			Temperature
	1-day	3-day	Annual	1-day
Historic	24 – no trend 2 – increase 0 – decrease	26 – no trend 0 – increase 0 – decrease	26 – no trend 0 – increase 0 – decrease	6 – no trend 20 – increase 0 – decrease
SSP45	17 – no trend 9 – increase 0 – decrease	21 – no trend 5 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	2 – no trend 24 – increase 0 – decrease
SSP85	10 – no trend 16 – increase 0 – decrease	13 – no trend 13 – increase 0 – decrease	9 – no trend 17 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Region 4 - Climate Change Results (2)

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Temperature 1-Day; C	**2.3**	**2.2**	0.4	5.8	**5.3**	**4.9**	3.0	10.4
Temperature 1-Day Summer; C	**2.3**	**2.2**	0.4	5.8	**5.3**	**4.9**	3.0	10.4
Temperature 1-Day Winter PF; C	**2.4**	**2.4**	1.1	3.7	**5.1**	**5.3**	2.9	7.4
Precipitation 1-Day PF; %	**-6**	**-8**	-30	32	**-4**	**-6**	-25	30
Precipitation 1-Day Summer PF; %	**0**	**-1**	-37	72	**-1**	**-5**	-32	42
Precipitation 1-Day Winter PF; %	**3**	**-3**	-19	44	**4**	**1**	-15	38
Precipitation 3-Day PF; %	**-1**	**-3**	-32	53	**7**	**6**	-28	49
Precipitation 3-Day Summer PF; %	**1**	**1**	-40	58	**8**	**9**	-33	59
Precipitation 3-Day Winter PF; %	**3**	**4**	-16	28	**9**	**9**	-28	54
Precipitation Annual PF; %	**9**	**9**	-7	23	**13**	**13**	-6	32

Climate Change Projections from 2015 through 2100

Region 3 - Application of Climate Change Results (3)

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	1.2	0.8	3.7	3.6	4.4	4.2	***2.5***	***3.2***	***2.8***	***3.4***
February	3.1	2.7	5.6	4.9	6.4	5.7	***2.5***	***3.3***	***2.3***	***3.1***
March	7.4	7.0	9.9	9.0	10.8	9.9	***2.5***	***3.4***	***2.0***	***2.9***
April	13.2	12.8	15.7	14.8	16.4	15.7	***2.5***	***3.2***	***2.0***	***2.9***
May	18.5	18.2	20.7	19.8	21.7	21.2	***2.3***	***3.2***	***1.6***	***3.0***
June	23.0	22.6	25.3	24.9	26.2	26.0	***2.3***	***3.2***	***2.3***	***3.4***
July	24.9	24.9	27.0	27.2	28.0	28.1	***2.1***	***3.1***	***2.4***	***3.2***
August	23.7	23.9	25.6	26.2	26.7	27.2	***1.9***	***3.0***	***2.3***	***3.3***
September	19.6	20.5	21.5	22.6	22.7	23.6	***2.0***	***3.1***	***2.1***	***3.2***
October	13.1	14.0	15.3	16.3	16.4	17.1	***2.1***	***3.2***	***2.3***	***3.2***
November	7.5	8.1	9.4	10.0	10.3	10.9	***2.0***	***2.8***	***1.9***	***2.9***
December	2.8	2.9	4.8	5.1	5.5	5.8	***2.0***	***2.7***	***2.2***	***3.0***

Climate Change Projections from 2015 through 2100

Region 4 - Application of Climate Change Results

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	82.1	82.6	92.0	92.9	96.0	95.5	***1.12***	***1.13***	***1.13***	***1.16***
February	71.4	71.8	82.9	81.8	84.9	84.1	***1.16***	***1.14***	***1.14***	***1.17***
March	94.1	94.1	103.7	104.1	109.9	110.5	***1.10***	***1.11***	***1.11***	***1.17***
April	85.5	85.9	93.4	93.6	94.5	92.7	***1.09***	***1.09***	***1.09***	***1.08***
May	87.7	85.9	92.2	92.8	91.5	90.7	***1.05***	***1.08***	***1.08***	***1.06***
June	93.3	94.3	98.8	97.5	98.2	97.8	***1.06***	***1.03***	***1.03***	***1.04***
July	116.1	118.0	124.0	123.0	125.0	124.8	***1.07***	***1.04***	***1.04***	***1.06***
August	108.2	108.7	115.3	116.7	117.0	117.2	***1.07***	***1.07***	***1.07***	***1.08***
September	86.3	88.3	91.4	90.8	90.7	91.0	***1.06***	***1.03***	***1.03***	***1.03***
October	82.6	82.7	84.4	84.6	86.4	85.3	***1.02***	***1.02***	***1.02***	***1.03***
November	87.6	87.2	92.0	91.7	94.9	94.7	***1.05***	***1.05***	***1.05***	***1.09***
December	95.6	96.0	107.2	104.2	111.8	111.8	***1.12***	***1.09***	***1.09***	***1.17***

Climate Change Projections from 2015 through 2100

Region 4 - Conclusion

TREND

- **Increase** in Ta and Td
- SSP45 Ppt – most show No Trend/Change
- SSP85 Ppt - most show increase trend

FREQUENCY

- 1-day – SSP45 and SSP85 confidence for **no change** in summer or winter season Ppt magnitude by 2100
  - greatest change most likely in winter seasons
- 3-day – SSP45 and SSP85 confidence for **no change** in summer or winter season in Ppt magnitude by 2100
  - greatest change most likely in winter season
- Annual – SSP45 and SSP85 confidence for **no change** of Ppt magnitude by 2100 and **increase** Temp by 2100

CLIMATOLOGY

- Monthly Climatology – slight **increase** (<20%) in Ppt and **increase** Temp by 2100
- Annual Climatology – slight **increase** (<20%) in annual Ppt and **increase** in annual Temp by 2100

All Regions - Climate Change Results

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models
- 9 models did not have all data
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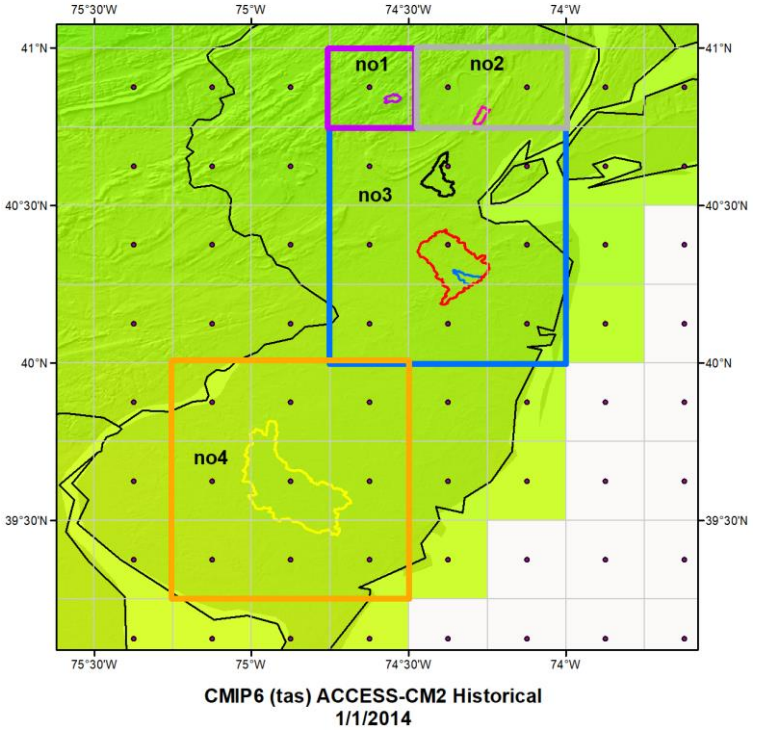
  - (3) 30-days per month
- Used 26 models on daily time step
  - Temperature
  - Relative humidity
  - Precipitation



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NJ_Region_4	Lenape	40.0, -75.25, 39.25, -74.5

Climate Change Analysis Methods (6)

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Model projections (Historic, SSP45, SSP85)
  - All Season, Summer, Winter

- **2) Monthly Analysis**
  - Model projections (Historic, SSP45, SSP85)
  - Precipitation and temperature

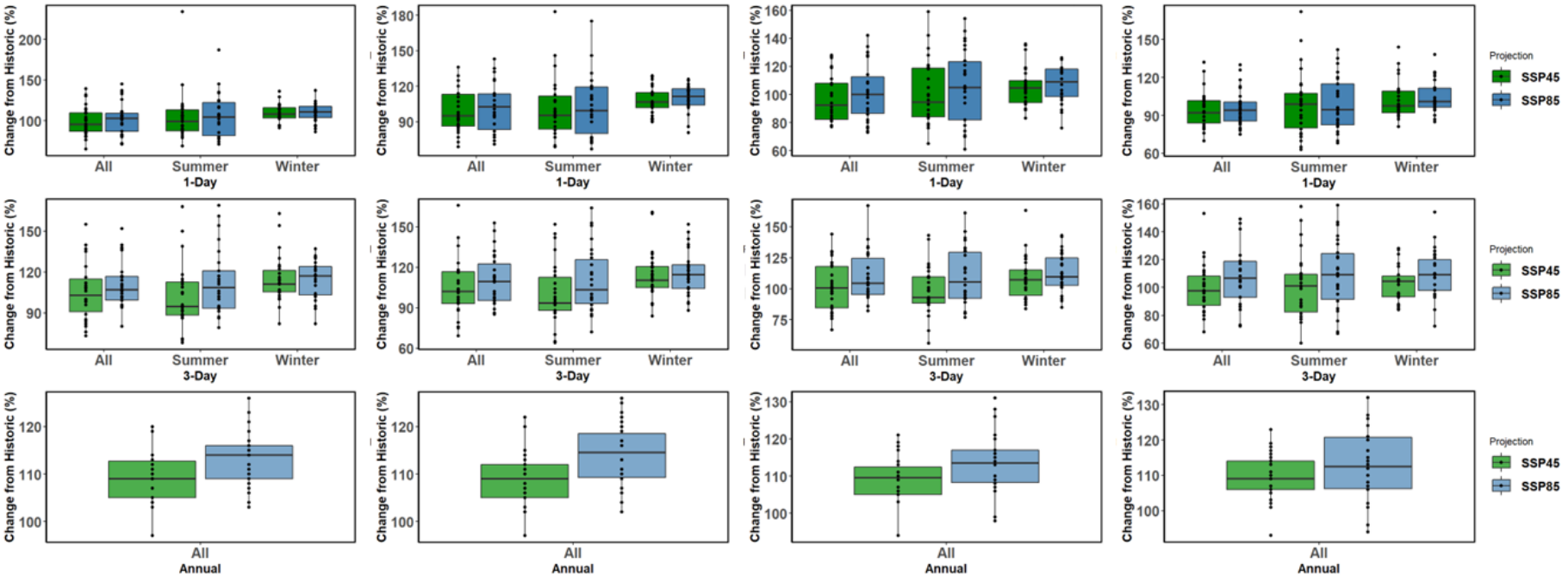
- 3**) Precipitation Frequency Analysis** for 1-day, 3-day, and Annual
  - All Season, Summer, and Winter
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes

All Regions - Trend Results

	Precipitation			Temperature
	1-day	3-day	Annual	1-day
Historic	92% – no trend 5% – increase 3% – decrease	98% – no trend 1% – increase 1% – decrease	100% – no trend 0% – increase 0% – decrease	25% – no trend 75% – increase 0% – decrease
SSP45	71% – no trend 29% – increase 0% – decrease	75% – no trend 21% – increase 0% – decrease	67% – no trend 33% – increase 0% – decrease	4% – no trend 96% – increase 0% – decrease
SSP85	38% – no trend 63% – increase 0% – decrease	51% – no trend 59% – increase 0% – decrease	20% – no trend 80% – increase 0% – decrease	0% – no trend 100% – increase 0% – decrease

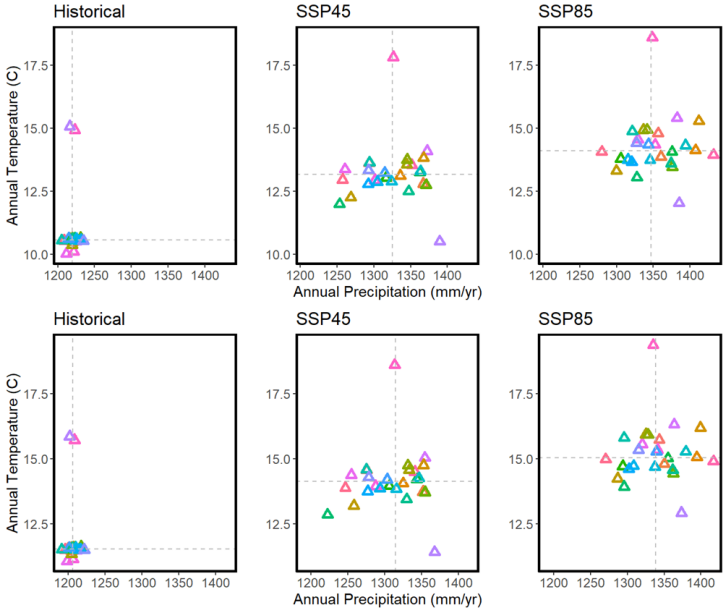
All Regions - Climate Change Results (2)

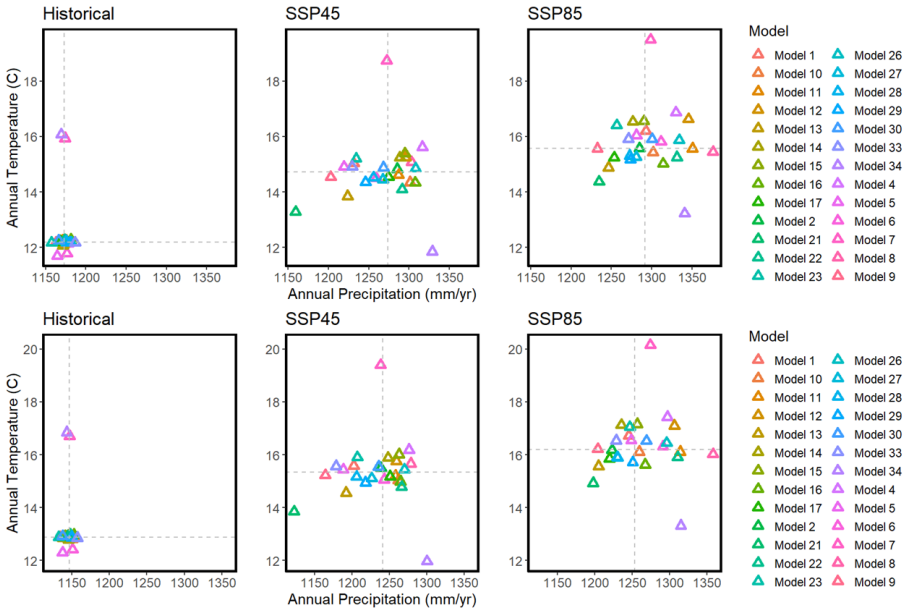
- **1-day (ssp45; ssp85)**
  - All = -6%; 0%
  - Summer = -3%; 1%
  - Winter = 4%; 8%
- **3-day**
  - All = 1%; 7%
  - Summer = -4%; 7%
  - Winter = 8%; 13%
- **Annual**
  - All = 9%; 14%



All Regions - Summary Annual Ta and Ppt

- **Annual Climatology (temp, ppt)**
  - Historical = 11.8 C; 1186 mm
  - SSP45 = 14.3 C; 1289 mm (2.6 C; 109%)
  - SSP85 = 15.2 C; 1308 mm (3.4 C; 110%)





All Regions - Climate Change Results (3)

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Temperature 1-Day; C	**2.4**	**2.3**	0.6	6.7	**5.5**	**4.9**	3.3	11.9
Temperature 1-Day Summer; C	**2.4**	**2.3**	0.6	6.7	**5.5**	**4.9**	3.3	11.9
Temperature 1-Day Winter PF; C	**2.4**	**2.4**	1.1	4.0	**5.3**	**5.5**	3.0	8.1
Precipitation 1-Day PF; %	**-2**	**-6**	-30	34	**1**	**0**	-27	40
Precipitation 1-Day Summer PF; %	**1**	**-3**	-34	87	**4**	**1**	-33	65
Precipitation 1-Day Winter PF; %	**6**	**4**	-14	36	**8**	**8**	-18	32
Precipitation 3-Day PF; %	**3**	**1**	-31	54	**10**	**7**	-20	55
Precipitation 3-Day Summer PF; %	**1**	**-4**	-38	55	**10**	**7**	-26	63
Precipitation 3-Day Winter PF; %	**10**	**8**	-17	54	**13**	**13**	-18	46
Precipitation Annual PF; %	**9**	**9**	-5	22	**14**	**14**	-1	29

Climate Change Projections from 2015 through 2100

All Regions – App. of Climate Change Results

- Results are presented as median values based on model ensemble
- Design Storm and Routing Applications
  - Recommend SSP45 climate scenario as “likely”, SSP85 as “unlikely”
- Results are through 2100 and can be scaled to other periods
  - Example, for 2050 adjustment scale 2100 results by 0.59.

	2050	2100
1-Day Summer PF; %	-2	-3
1-Day Winter PF; %	2	4
3-Day Summer PF; %	-3	-4
3-Day Winter PF; %	5	8

Climate Change Projections from 2015 through 2100

All Regions – App. of Climate Change Results (2)

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Mean Delta		Median Delta	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	-0.2	-0.6	2.4	2.3	3.2	2.9	***2.6***	***3.4***	***2.9***	***3.5***
February	1.9	1.4	4.5	3.7	5.4	4.7	***2.6***	***3.5***	***2.3***	***3.3***
March	6.2	5.7	8.8	7.8	9.7	9.0	***2.6***	***3.5***	***2.1***	***3.4***
April	12.2	11.8	14.8	13.9	15.6	14.8	***2.6***	***3.3***	***2.1***	***3.0***
May	17.6	17.3	20.0	19.2	20.9	20.4	***2.4***	***3.3***	***1.9***	***3.1***
June	22.1	21.6	24.5	24.0	25.4	25.2	***2.4***	***3.4***	***2.4***	***3.6***
July	24.1	24.0	26.4	26.4	27.4	27.4	***2.2***	***3.3***	***2.4***	***3.4***
August	22.7	23.0	24.8	25.4	26.0	26.4	***2.1***	***3.2***	***2.4***	***3.4***
September	18.5	19.3	20.5	21.4	21.7	22.6	***2.0***	***3.3***	***2.2***	***3.3***
October	12.1	12.9	14.3	15.2	15.4	16.1	***2.1***	***3.2***	***2.3***	***3.2***
November	6.3	7.0	8.2	8.8	9.2	9.7	***1.9***	***2.8***	***1.8***	***2.7***
December	1.5	1.4	3.5	3.8	4.2	4.5	***2.0***	***2.7***	***2.3***	***3.1***

Climate Change Projections from 2015 through 2100

SSP45 Mean = 2.3 C
SSP85 Mean = 3.2 C

All Regions – App. of Climate Change Results (2)

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Median Delta		Median Pct.	
	Mean	Median	Mean	Median	Mean	Median	SSP45	SSP85	SSP45	SSP85
January	82.2	82.6	93.1	94.0	97.0	96.8	***10.9***	***14.8***	***1.14***	***1.17***
February	72.4	71.6	84.2	84.3	86.1	85.1	***11.8***	***13.6***	***1.18***	***1.19***
March	97.6	98.2	109.1	108.8	114.0	113.8	***11.4***	***16.4***	***1.11***	***1.16***
April	92.0	91.2	101.3	100.5	103.6	102.8	***9.3***	***11.6***	***1.10***	***1.13***
May	99.3	98.5	103.7	104.1	103.8	102.9	***4.4***	***4.6***	***1.06***	***1.04***
June	98.5	99.0	102.9	102.4	103.3	102.4	***4.4***	***4.8***	***1.03***	***1.03***
July	114.3	114.7	121.7	121.3	122.8	121.6	***7.4***	***8.5***	***1.06***	***1.06***
August	106.7	106.8	113.3	115.0	114.7	116.0	***6.6***	***8.1***	***1.08***	***1.09***
September	91.7	92.2	97.3	95.9	94.8	94.1	***5.6***	***3.2***	***1.04***	***1.02***
October	89.0	88.7	91.6	90.6	93.1	91.6	***2.6***	***4.1***	***1.02***	***1.03***
November	91.5	91.1	97.3	97.1	100.7	100.7	***5.8***	***9.1***	***1.07***	***1.11***
December	97.0	97.8	107.7	105.1	112.7	112.2	***10.7***	***15.7***	***1.07***	***1.15***

Climate Change Projections from 2015 through 2100

SSP45 Mean = 7.6 mm; 8%
SSP85 Mean = 9.5 mm; 10%

All Regions - Conclusion

TREND

- **Increase** in Ta and Td
- SSP45 Ppt – most show No Trend/Change
- SSP85 Ppt - most show increase trend

FREQUENCY

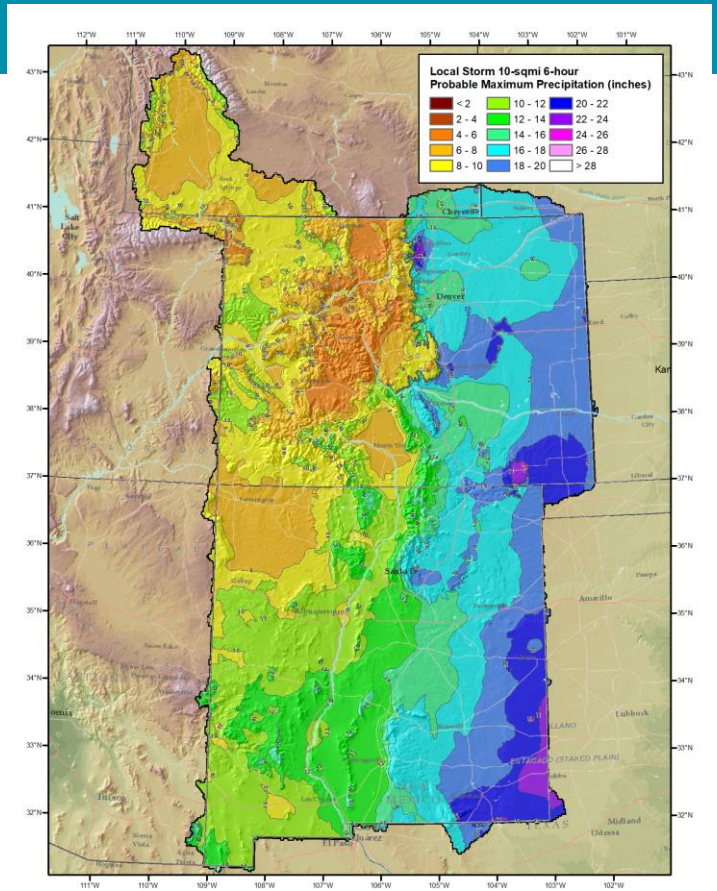
- 1-day – SSP45 and SSP85 confidence for **no change** in summer or winter season Ppt magnitude by 2100
  - greatest change most likely in winter seasons
- 3-day – SSP45 and SSP85 confidence for **no change** in summer or winter season in Ppt magnitude by 2100
  - greatest change most likely in winter season
- Annual – SSP45 and SSP85 confidence for **no change** of Ppt magnitude by 2100 and **increase** Temp by 2100

CLIMATOLOGY

- Monthly Climatology – slight **increase** (<20%) in Ppt and **increase** Temp by 2100
- Annual Climatology – slight **increase** (<20%) in annual Ppt and **increase** in annual Temp by 2100

What's Next

- Federal involvement?
  - What about the studies that have already been completed
  - Nationwide coverage
- Storage of database/updates
  - How to handoff to the next generation
- Numerical Modeling



Questions (2)

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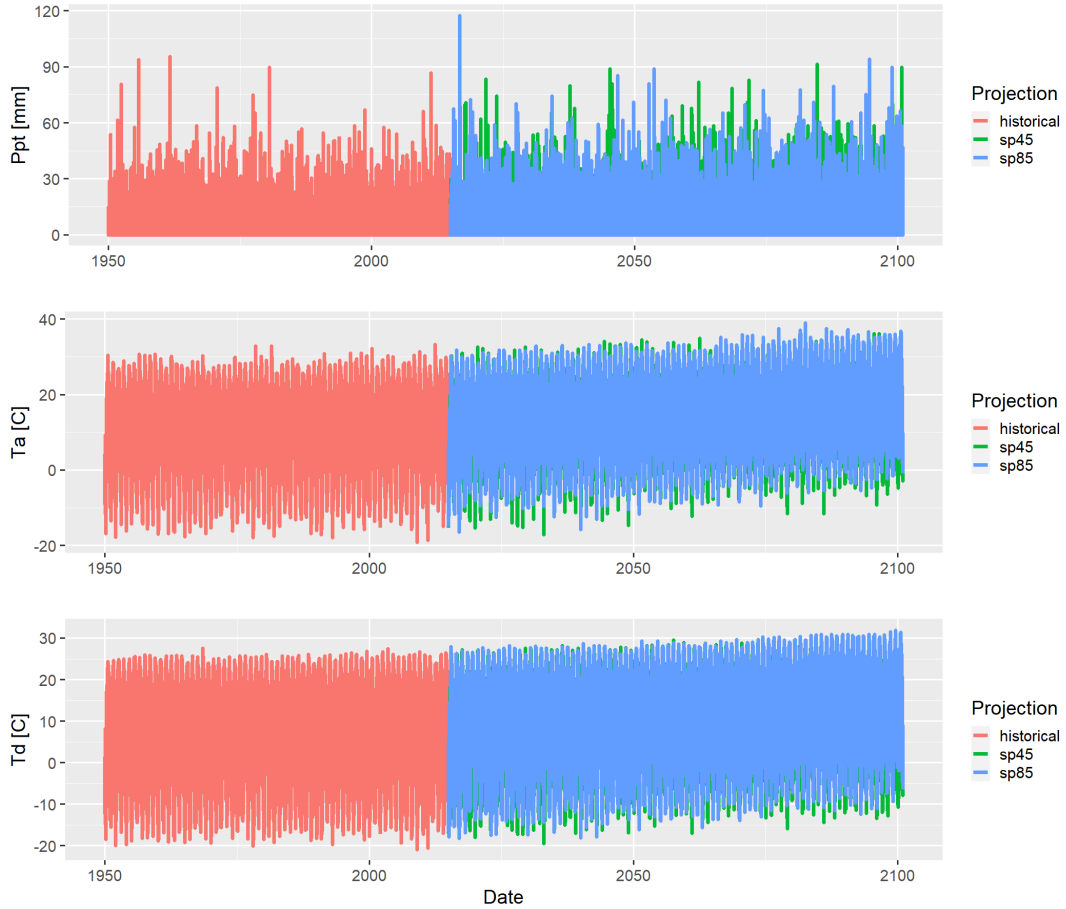
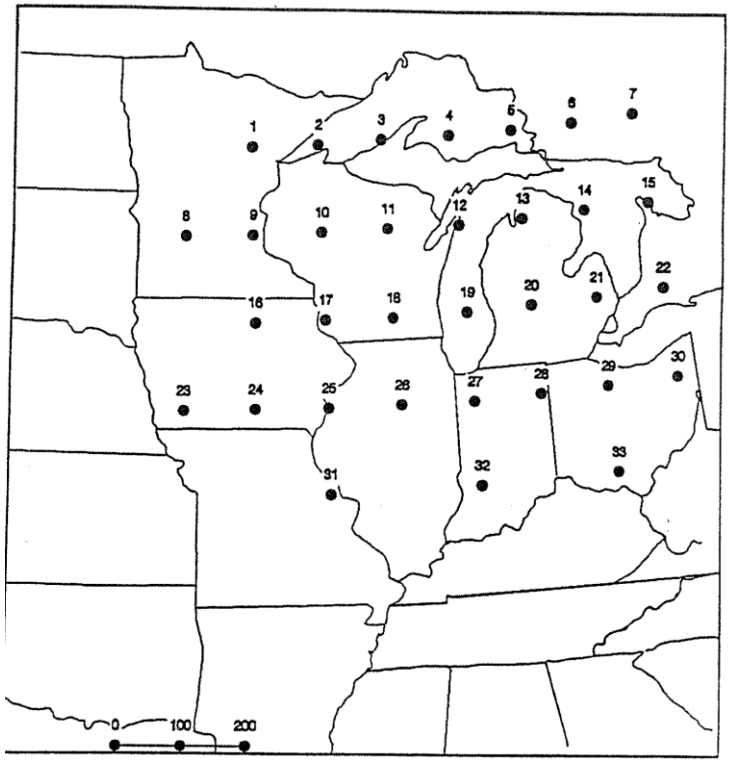
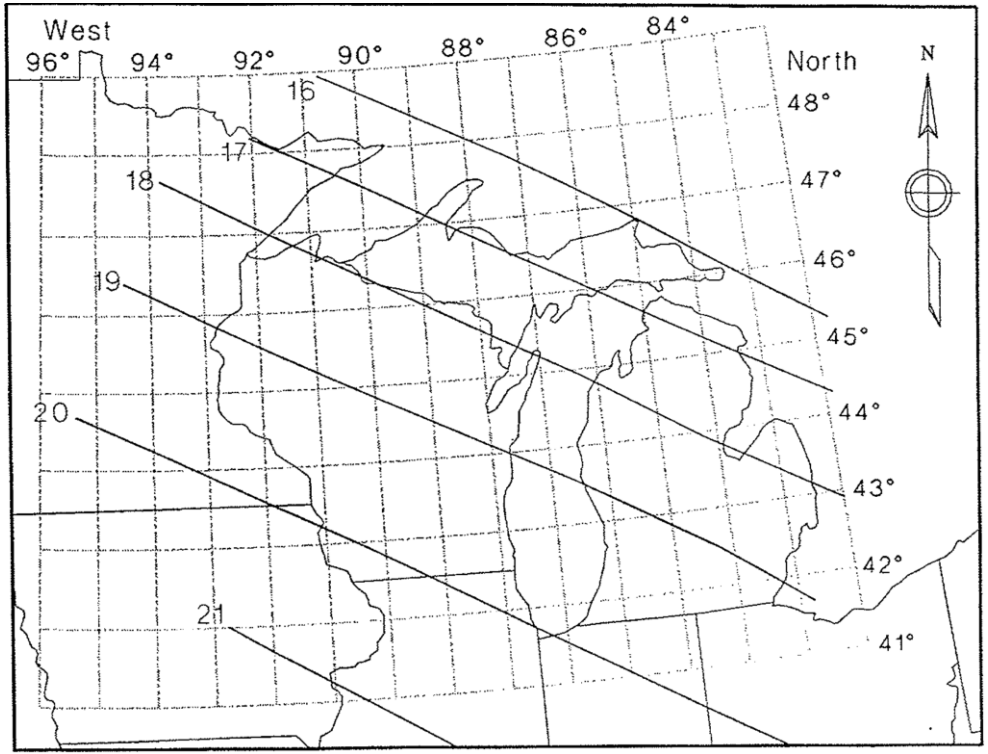


EPRI Michigan-Wisconsin-the First Step

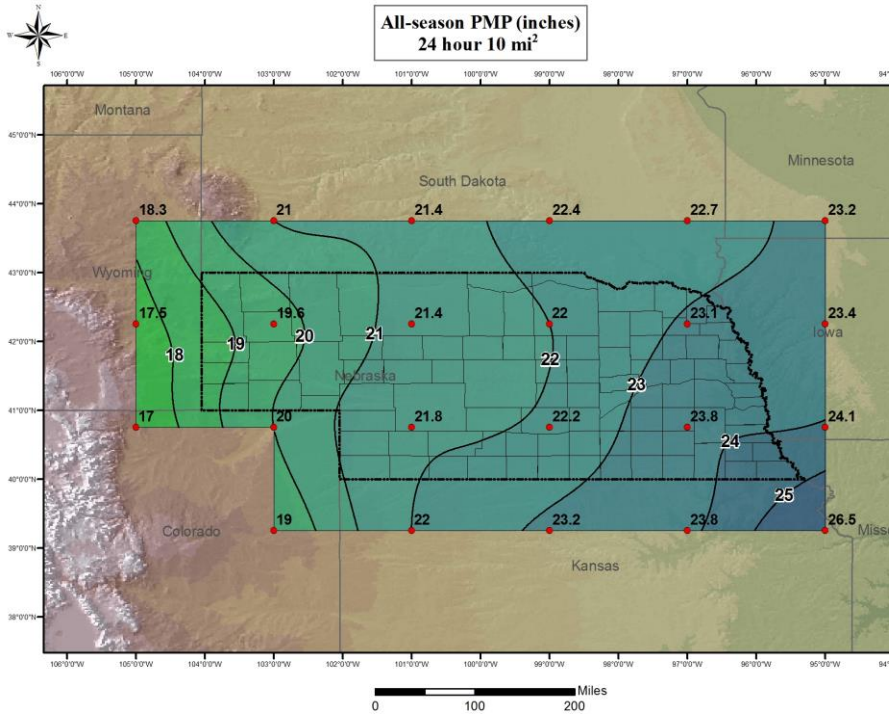


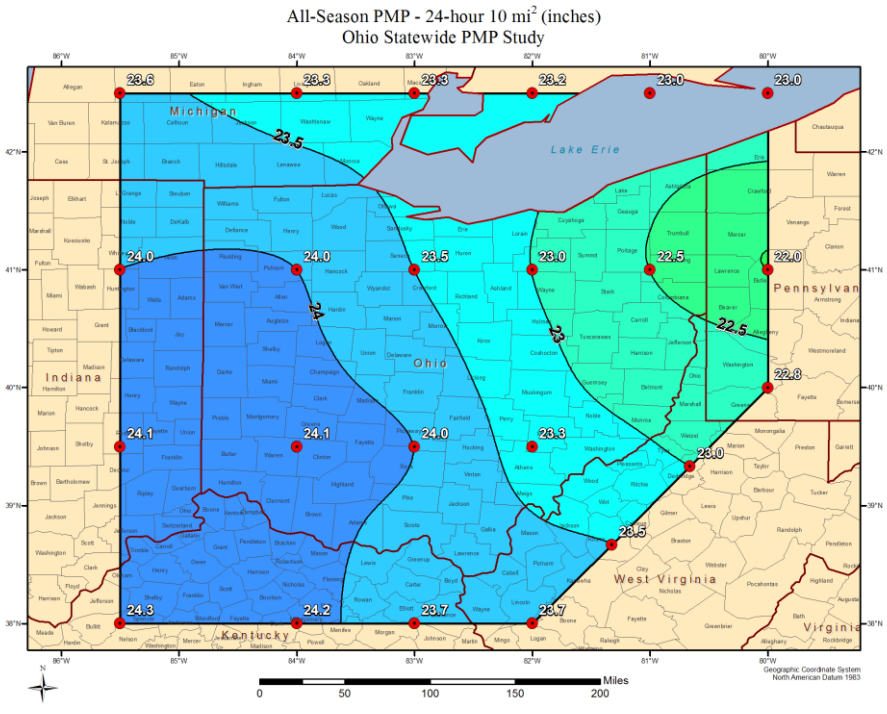
Transposition Grid



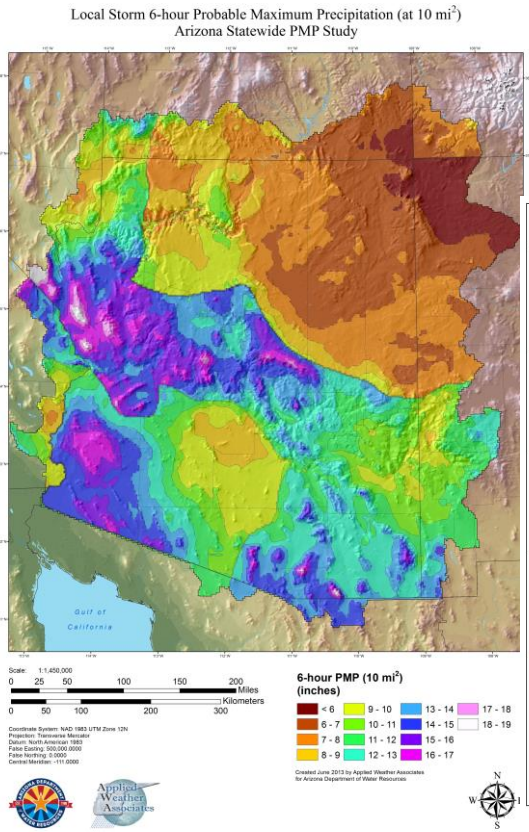
All-season PMP (in.) for 24 hr 100 mi^2

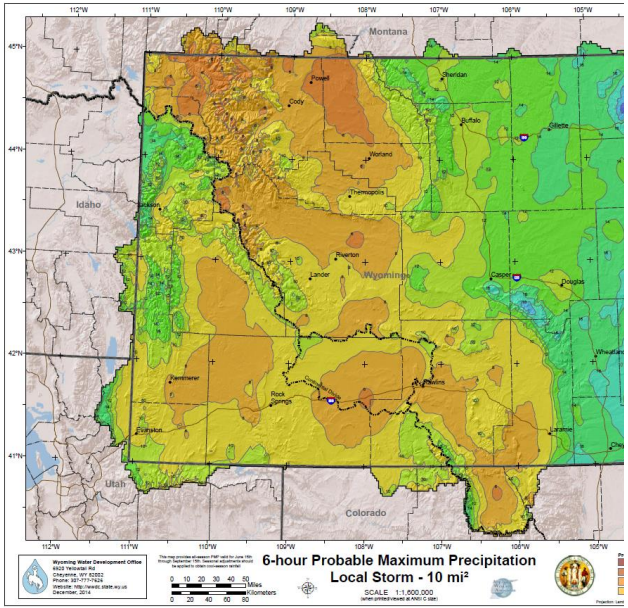
AWA Statewide Output Examples-old school

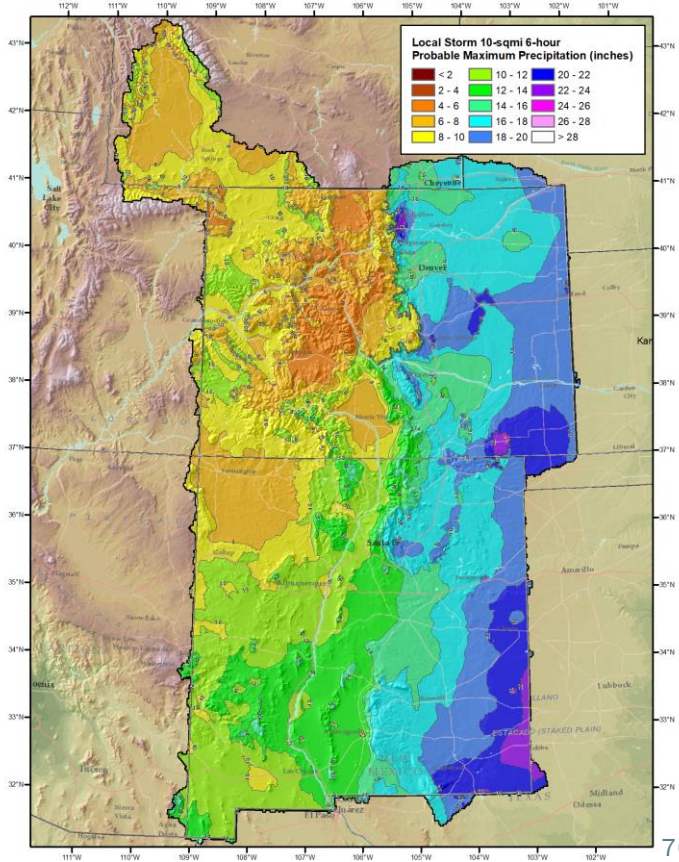




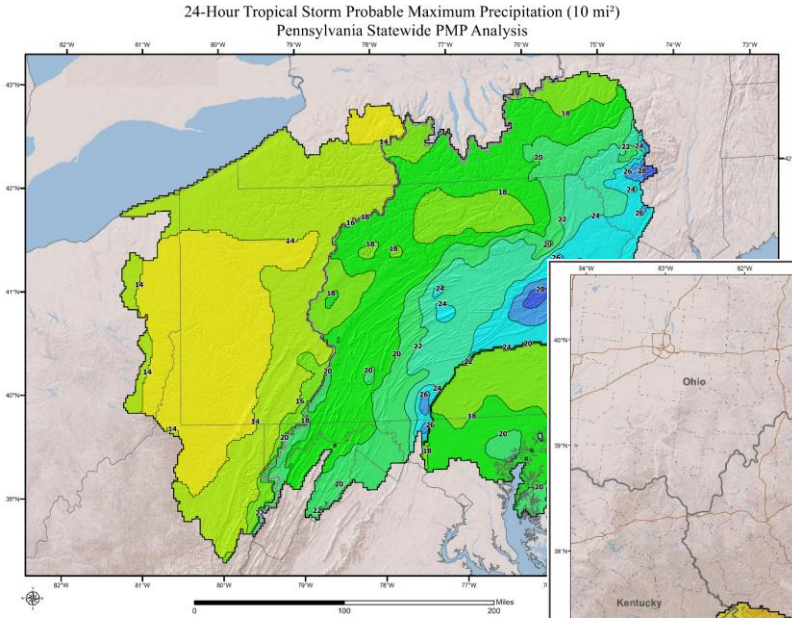
AWA Statewide Output Examples-Southwest-Rockies

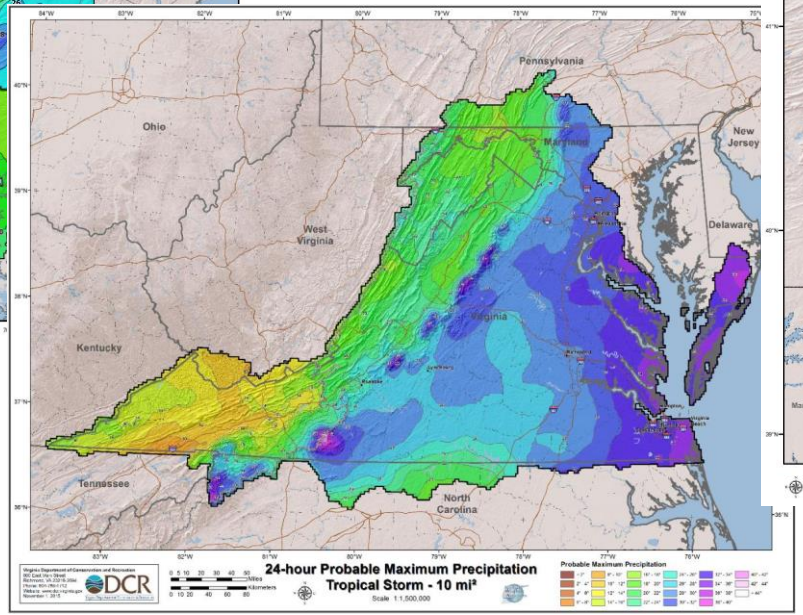


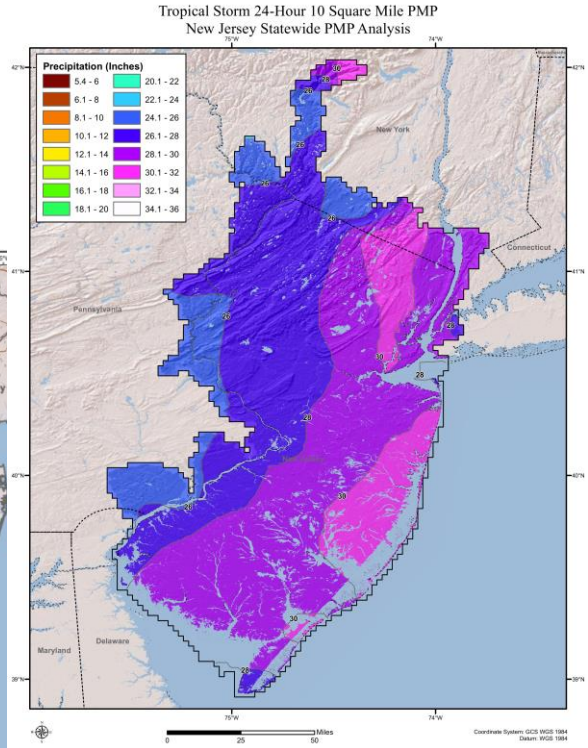




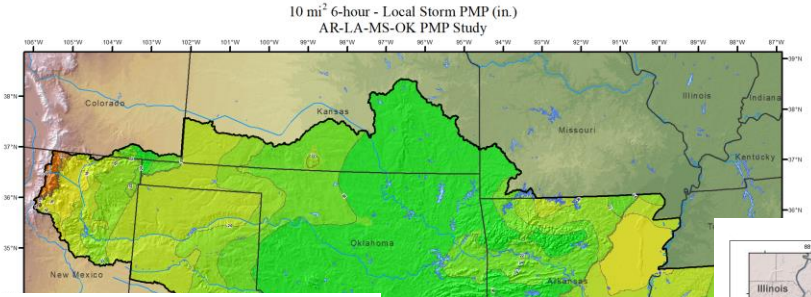
AWA Statewide Output Examples-East (3)

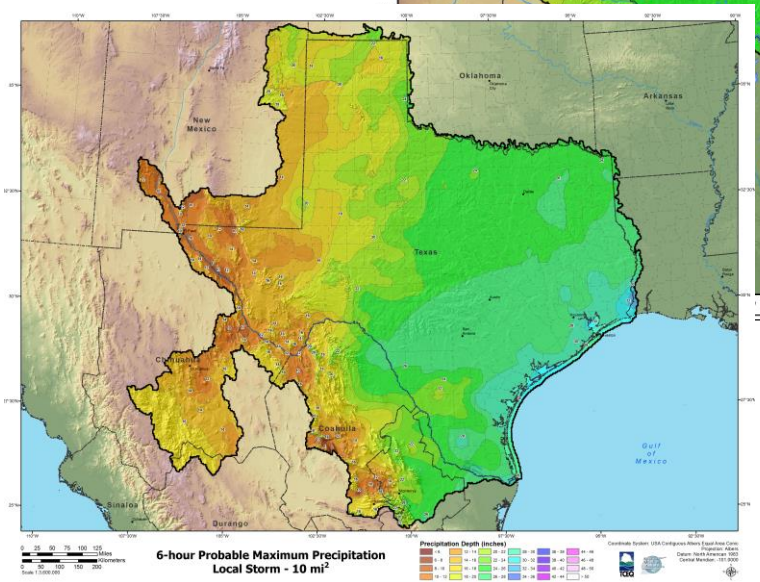


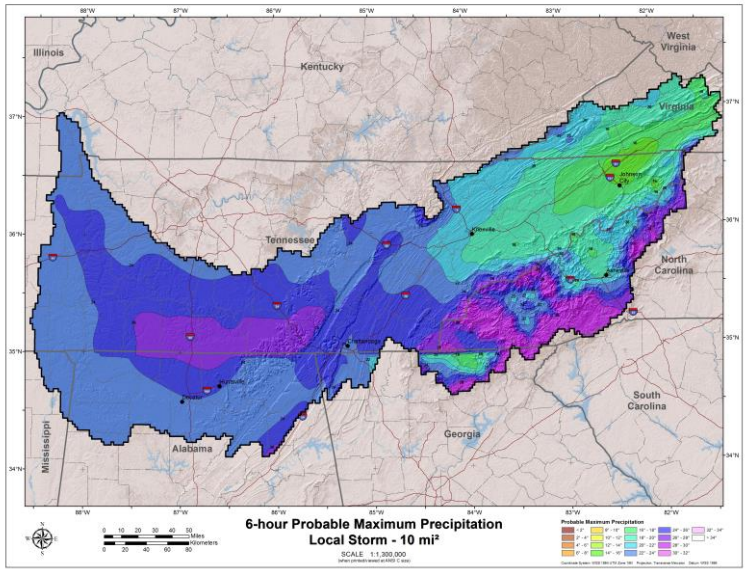




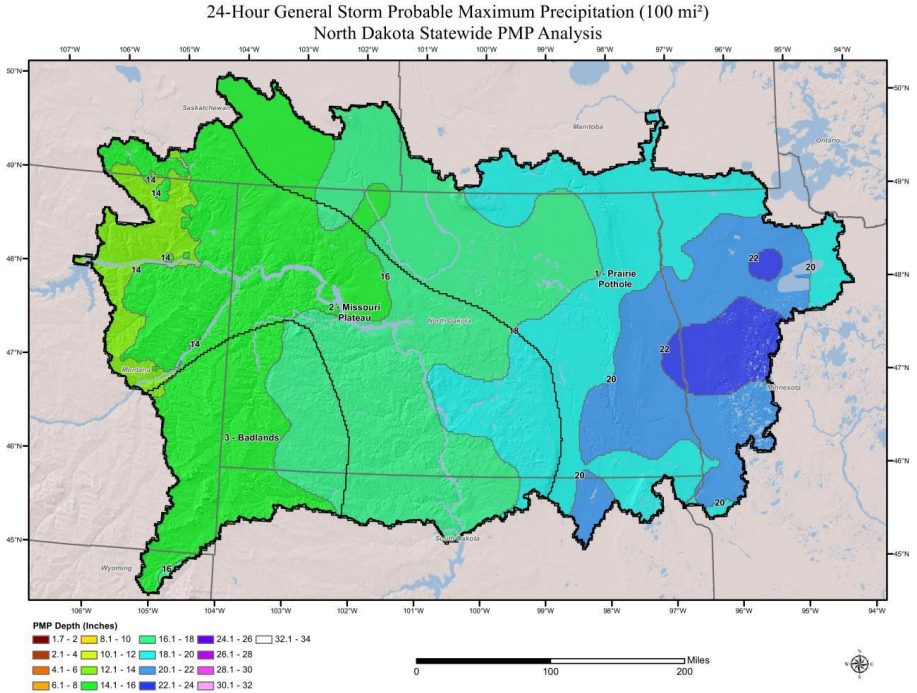
AWA Statewide Output Examples-South

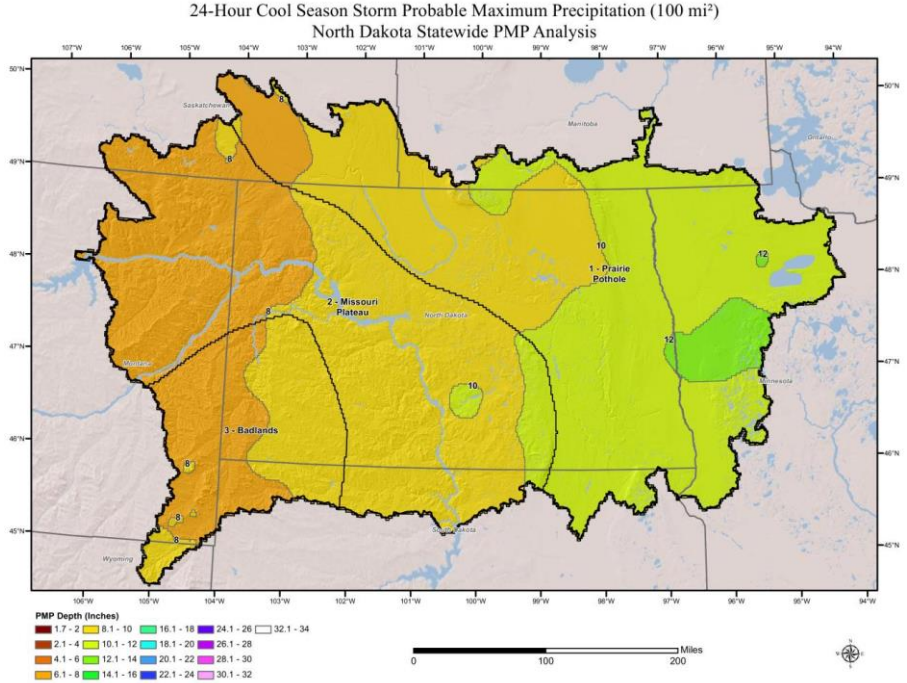






AWA Statewide Output Examples-North





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AWA Statewide Output Examples-Tropics