# Climate Change Projections

## Applied Weather Associates (AWA)

Dam Safety 2020-Virtual Conference

# Climate Model Background

- Several Global Climate Models, each try to solve atmospheric dynamics to replicate future climate conditions
  - Very course resolution in space and time
  - Gross assumptions
  - Many unknowns
- Global Models are downscaled using Regional Climate Models to better replicate local climate/topography
- Two types of downscaling
  - Statistical
  - Dynamic

# Climate Model Background

- Each model (global/regional) has issues/unknowns/errors/uncertainty
  - Incorrect replication of atmospheric processes
  - Inability to numerically quantify certain processes
  - Unknown positive/negative feedbacks
  - Inaccurate observational/gridded data
  - Future GHG concentrations
  - Downscaling techniques
  - Natural variability of climate system

# Climate Model Background

- No one climate model produces an ideal simulation
- Each represents one of many possible realizations
  - Utilize an ensemble approach
  - One model-multiple initial conditions
  - One GHG scenario but multiple models
- Range/distribution of ensemble projections are indicative of uncertainty
- Precipitation, especially extreme precip, shows the greatest range of variability
- Do provide useful projections and “what if” scenarios

# Climate Model Projections Used


The North American CORDEX Program

- 1) CanESM2 CanRCM4
  - Canadian Earth System Model (CanESM)
  - Canadian Regional Climate Model (CanRCM)
    - Historic 1950-2005 (Ppt, Ta, SH, Press)
    - RCP45 2006-2100 (Ppt, Ta, SH, Press)
    - RCP85 2006-2100 (Ppt, Ta, SH, Press)
- 2) CanESM2 CRCM5
  - Canadian Earth System Model (CanESM)
  - Canadian Regional Climate Model (CRCM)
    - Historic 1951-2005 (Ppt, Ta, SH, Press)
    - RCP45 2006-2100 (Ppt, Ta, SH, Press)
    - RCP85 2006-2100 (Ppt, Ta, SH, Press)
- 3) MPI ESM LR CRCM5
  - Max-Planck-Institute Earth System Model running on Low Resolution grid (MPI ESM LR)
  - Canadian Regional Climate Model (CRCM)
    - Historic 1951-2005 (Ppt, Ta, SH, Press)
    - RCP45 2006-2100 (Ppt, Ta, SH, Press)
    - RCP85 2006-2100 (Ppt, Ta, SH, Press)

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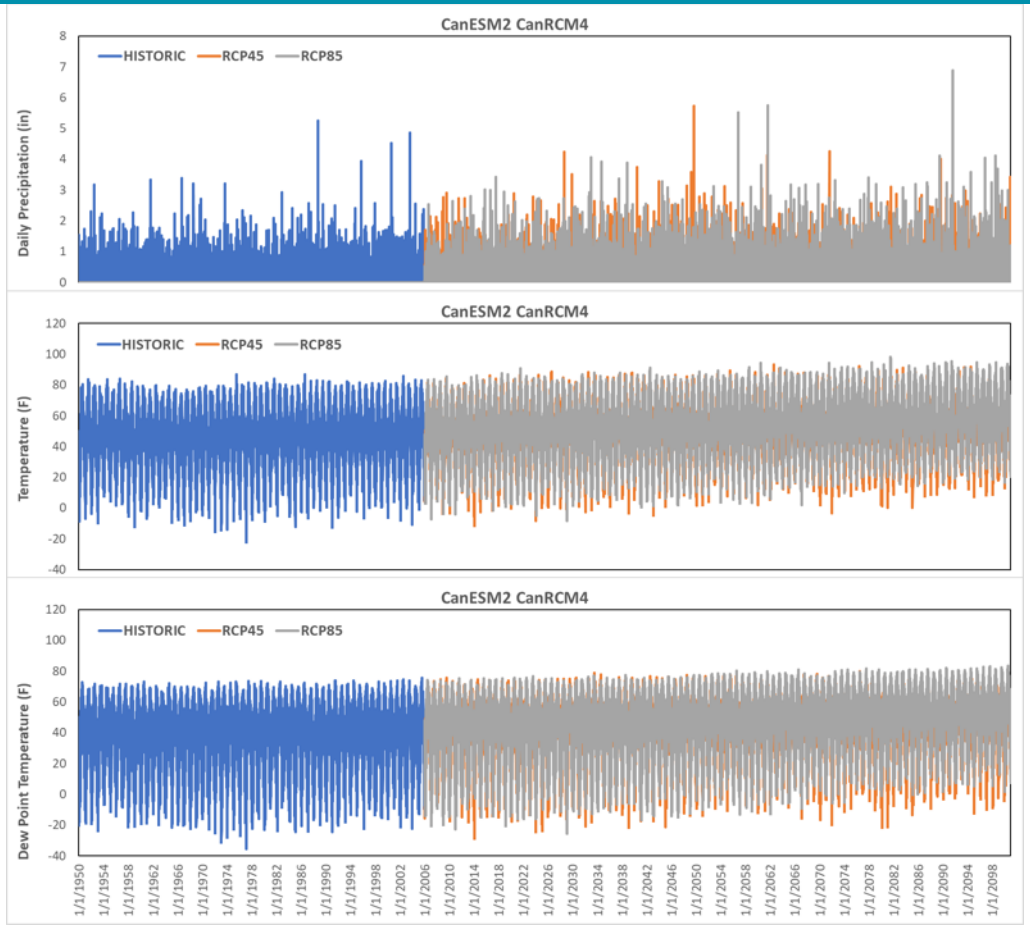
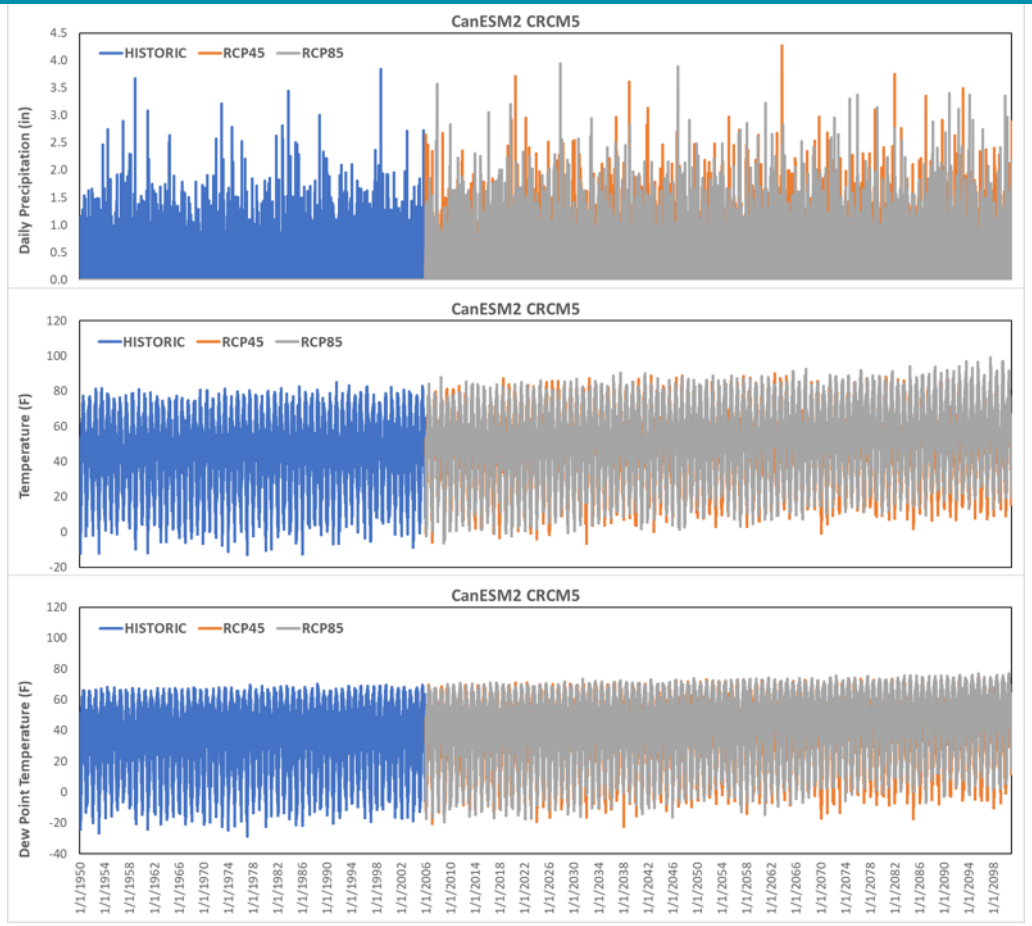
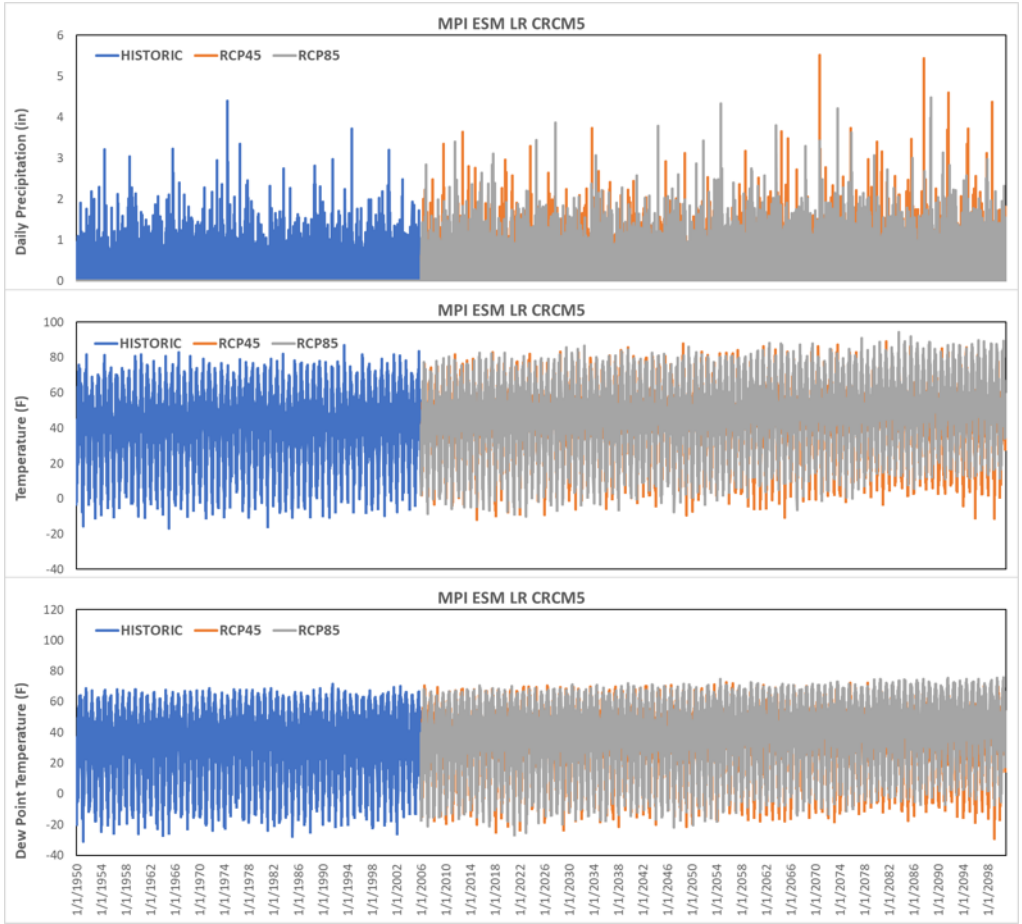
# Climate Model (CanESM2 CanRCM4)



# Climate Model (CanESM2 CRCM5)



# Climate Model (MPI ESM LR CRCM5)



# Climate Change Analysis Methods

- **1) Trend Analysis** for 1-day, 90-day, and Annual
  - Station Data
  - Model projections (Historic, RCP45, RCP85)

- 2**) Precipitation Frequency Analysis** for 1-day (Ppt, Summer, Winter), 90-day, and Annual
  - Model projections (Historic, RCP45, RCP85)
  - Estimate PF for 1-year through 10000-year
  - Quantify changes

- **3) $Ppt_{max}$ Analysis** for 1-day and 3-day
  - Derive model projection monthly Td climatologies  (Historic, RCP45, RCP85)
  - Perform storm maximization of top 30 Ppt events (Historic, RCP45, RCP85)
  - Estimate $Ppt_{adj}$ values through storm maximization process
  - Quantify changes

# 1. Station Trend Analysis (1-day & Annual)

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

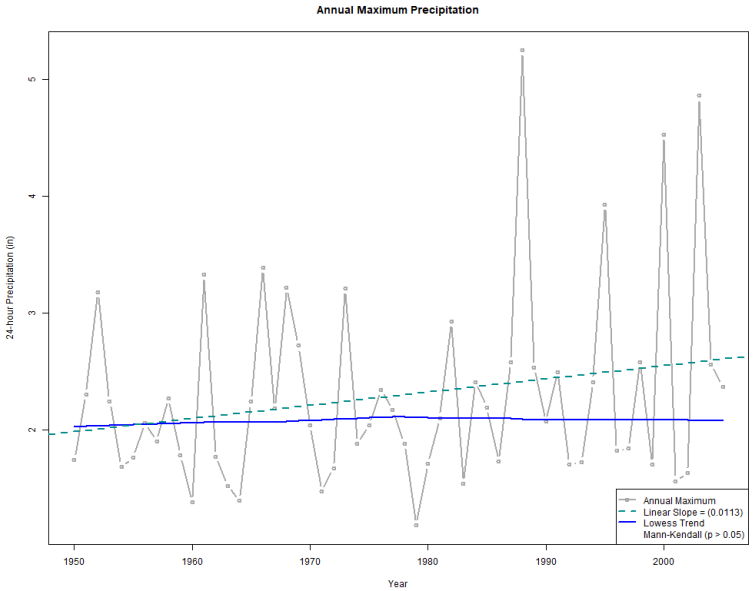
| STID_Short | STATION_ID | STATION | LATITUDE | LONGITUDE | ELEVATION | N | Trend |
|---|---|---|---|---|---|---|---|
| 102 | USC00190190 | ASHBURNHAM, MA | 42.6178 | -71.9159 | 1108 | 78 | None |
| 104 | USC00270690 | BERLIN, NH | 44.4535 | -71.1855 | 920 | 102 | None |
| 105 | USC00272999 | FIRST CONNECTICUT LAKE, NH | 45.0899 | -71.2906 | 1650 | 90 | None |
| 108 | USC00274399 | KEENE, NH | 42.9390 | -72.3247 | 511 | 120 | None |
| 109 | USC00274556 | LANCASTER, NH | 44.4958 | -71.5767 | 860 | 72 | Increase |
| 111 | USC00431243 | CAVENDISH, VT | 43.3847 | -72.5988 | 842 | 111 | None |
| 112 | USC00431360 | CHELSEA, VT | 43.9833 | -72.4500 | 800 | 100 | None |
| 113 | USC00431433 | CHITTENDEN, VT | 43.7063 | -72.9618 | 1163 | 71 | Increase |
| 114 | USC00431580 | CORNWALL, VT | 43.9573 | -73.2106 | 345 | 119 | Increase |
| 116 | USC00437054 | SAINT JOHNSBURY, VT | 44.4200 | -72.0194 | 700 | 120 | None |
| 118 | USC00193549 | HEATH, MA | 42.6667 | -72.8167 | 1590 | 77 | None |

- Annual AMS Trend Analysis (Mann-Kendall)

| STID_Short | STATION_ID | STATION | LATITUDE | LONGITUDE | ELEVATION | N | Trend |
|---|---|---|---|---|---|---|---|
| 102 | USC00190190 | ASHBURNHAM, MA | 42.6178 | -71.9159 | 1108 | 76 | None |
| 104 | USC00270690 | BERLIN, NH | 44.4535 | -71.1855 | 920 | 101 | Increase |
| 105 | USC00272999 | FIRST CONNECTICUT LAKE, NH | 45.0899 | -71.2906 | 1650 | 89 | None |
| 108 | USC00274399 | KEENE, NH | 42.9390 | -72.3247 | 511 | 70 | Increase |
| 109 | USC00274556 | LANCASTER, NH | 44.4958 | -71.5767 | 860 | 61 | Increase |
| 111 | USC00431243 | CAVENDISH, VT | 43.3847 | -72.5988 | 842 | 96 | Increase |
| 112 | USC00431360 | CHELSEA, VT | 43.9833 | -72.4500 | 800 | 69 | None |
| 113 | USC00431433 | CHITTENDEN, VT | 43.7063 | -72.9618 | 1163 | 70 | Increase |
| 114 | USC00431580 | CORNWALL, VT | 43.9573 | -73.2106 | 345 | 67 | Increase |
| 116 | USC00437054 | SAINT JOHNSBURY, VT | 44.4200 | -72.0194 | 700 | 107 | Increase |
| 118 | USC00193549 | HEATH, MA | 42.6667 | -72.8167 | 1590 | 63 | None |

# 1. Trend Analysis (1-day)

- 1-day AMS Trend Analysis (Mann-Kendall)
  - Stations ~ No Trend



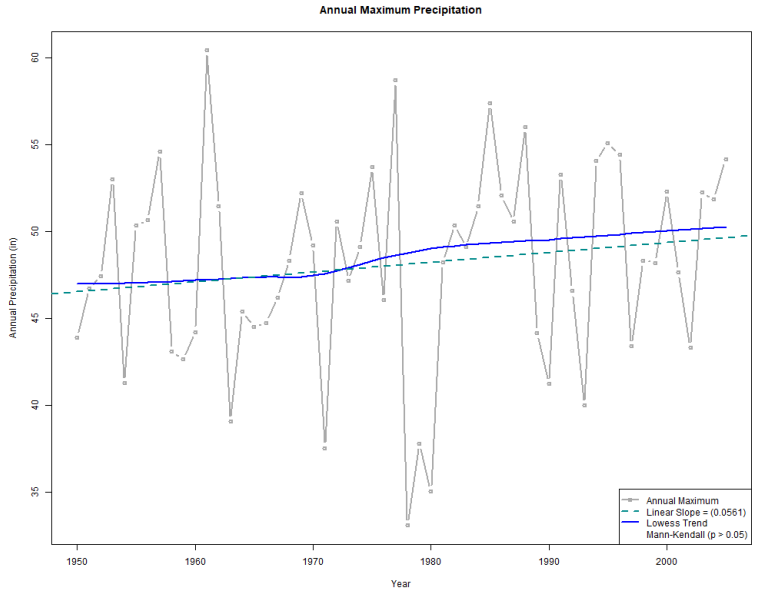

- 1) CanESM2 CanRCM4 1-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **increasing trend**

- 2) CanESM2 CRCM5 1-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **no trend**

- 3) MPI ESM LR CRCM5 1-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **no trend**

# 1. Trend Analysis (365-day)

- 365-day AMS Trend Analysis (Mann-Kendall)
  - Stations ~ 50/50 mix of No Trend and Increase Trend

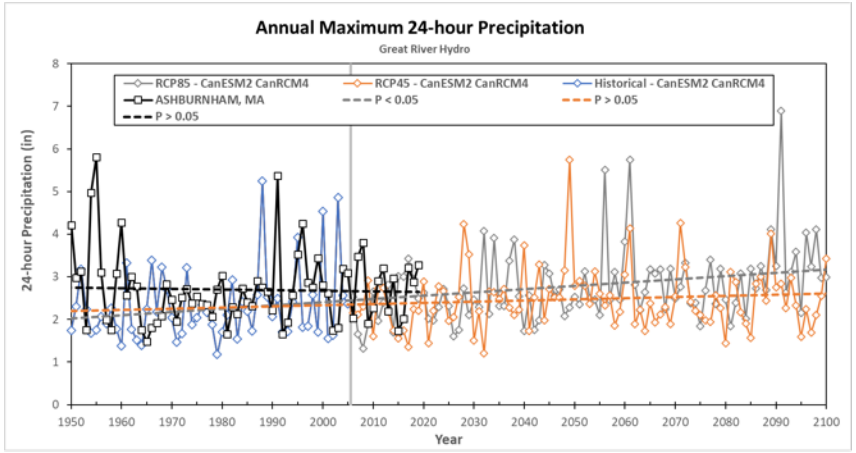


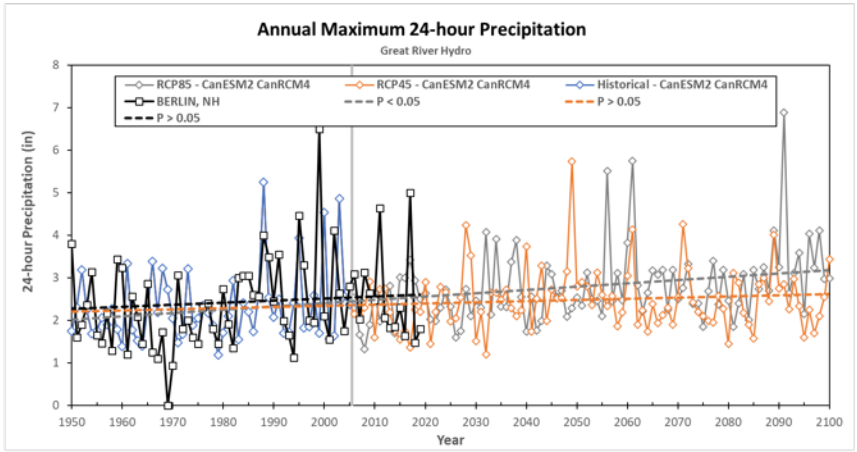

- 1) CanESM2 CanRCM4 365-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **increasing trend**

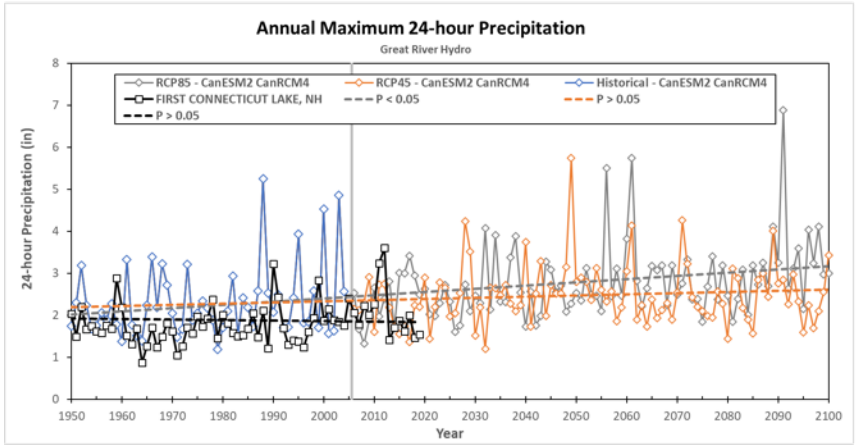
- 2) CanESM2 CRCM5 365-day AMS
  - trend depends on period investigated
    - Historical: **increasing trend**
    - RCP45: **no trend**
    - RCP85: **no trend**

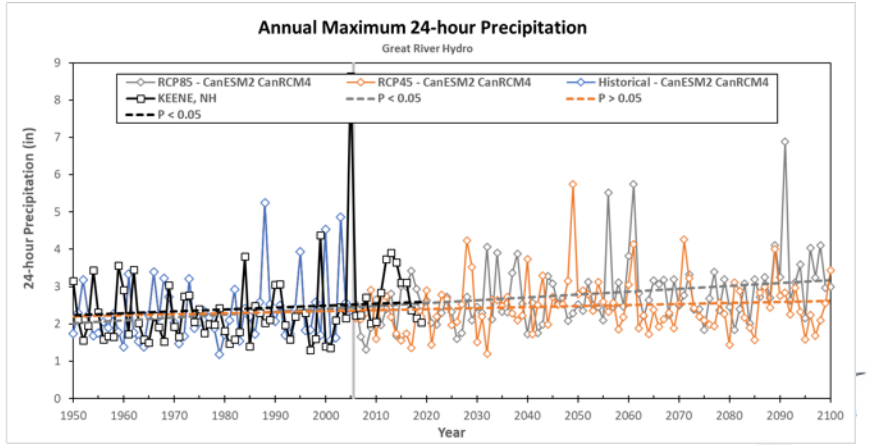
- 3) MPI ESM LR CRCM5 365-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **increasing trend**

# 1. Station/Projection Trend (1-day) – Model 1



# 2. Frequency Analysis (L-moments)

- 1-day, 90-day, 365-day L-moment Frequency Analysis (Historic, RCP45, RCP85)
  - 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-, 1000-, and 10000-year AEPs

# 2. Frequency Analysis (CanESM2 CanRCM4)

- 1-day, 90-day, 365-day L-moment Frequency Analysis
  - 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
  - Compared 10-, 50-, 100-, 1000-, and 10000-year AEPs

*** 1-Day

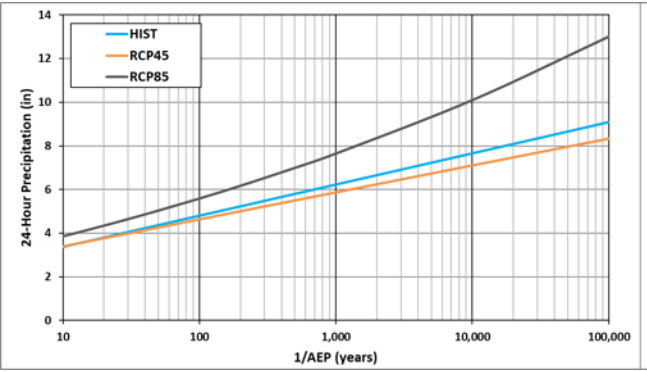
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.3 | 4.4 | 4.8 | 6.2 | 7.7 | - | - | - | - | - | |
| RCP-45 | 3.4 | 4.3 | 4.6 | 5.9 | 7.6 | 101% | 98% | 97% | 94% | 100% | 98% |
| RCP-85 | 3.8 | 5.0 | 5.6 | 7.6 | 10.1 | 114% | 115% | 116% | 123% | 132% | 120% |

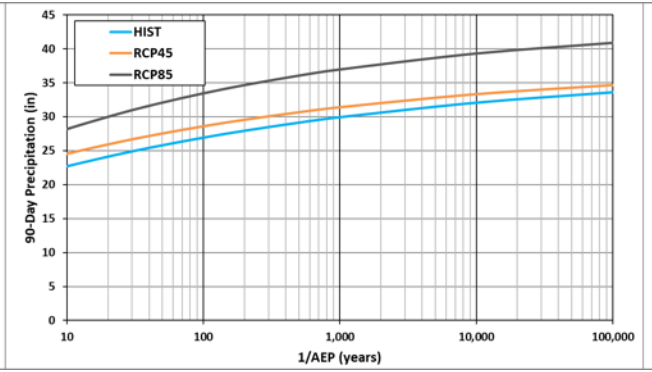
*** 90-Day

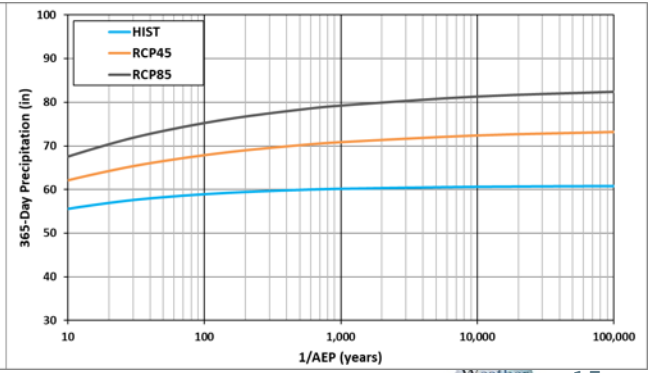
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 23 | 26 | 27 | 30 | 32 | - | - | - | - | - | |
| RCP-45 | 24 | 28 | 29 | 31 | 33 | 108% | 107% | 106% | 105% | 104% | 106% |
| RCP-85 | 28 | 32 | 33 | 37 | 39 | 124% | 124% | 124% | 123% | 123% | 124% |

*** 365-Day

| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 55 | 58 | 59 | 60 | 61 | - | - | - | - | - | |
| RCP-45 | 62 | 67 | 68 | 71 | 72 | 112% | 114% | 115% | 118% | 119% | 116% |
| RCP-85 | 67 | 73 | 75 | 79 | 81 | 121% | 126% | 128% | 132% | 134% | 128% |




**24-hour Basin Avg 100-yr = XX mm**

+++ values represent 1-day not 24-hour

# 2. Frequency Analysis (CanESM2 CRCM5)

- 1-day, 90-day, 365-day L-moment Frequency Analysis
  - 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
  - Compared 10-, 50-, 100-, 1000-, and 10000-year AEPs

*** 1-Day

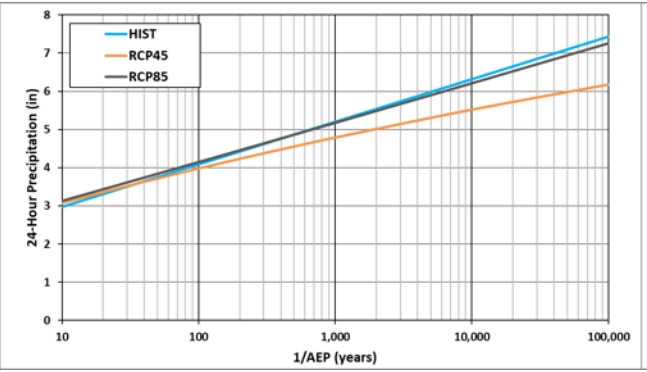
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.0 | 3.8 | 4.1 | 5.2 | 6.3 | - | - | - | - | - | |
| RCP-45 | 3.1 | 3.7 | 4.0 | 4.8 | 5.2 | 103% | 99% | 97% | 92% | 82% | 95% |
| RCP-85 | 3.1 | 3.8 | 4.1 | 5.2 | 6.2 | 105% | 102% | 101% | 99% | 98% | 101% |

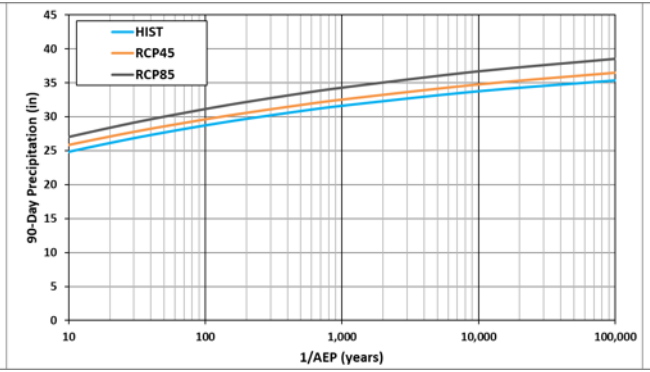
*** 90-Day

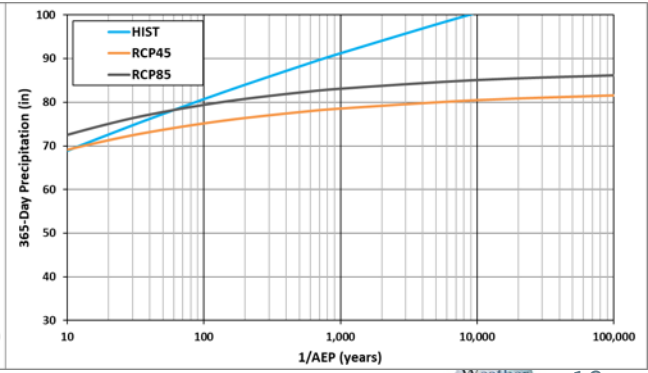
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 25 | 28 | 29 | 32 | 34 | - | - | - | - | - | |
| RCP-45 | 26 | 29 | 30 | 33 | 35 | 104% | 103% | 103% | 103% | 103% | 103% |
| RCP-85 | 27 | 30 | 31 | 34 | 37 | 109% | 108% | 108% | 108% | 109% | 109% |

*** 365-Day

| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 69 | 77 | 81 | 91 | 101 | - | - | - | - | - | |
| RCP-45 | 69 | 74 | 75 | 79 | 80 | 100% | 95% | 93% | 86% | 80% | 91% |
| RCP-85 | 72 | 78 | 79 | 83 | 85 | 105% | 101% | 98% | 91% | 85% | 96% |




**24-hour Basin Avg 100-yr = XX mm**

+++ values represent 1-day not 24-hour

# 2. Frequency Analysis (MPI ESM LR CRCM5)

- 1-day, 90-day, 365-day L-moment Frequency Analysis
  - 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
  - Compared 10-, 50-, 100-, 1000-, and 10000-year AEPs

*** 1-Day

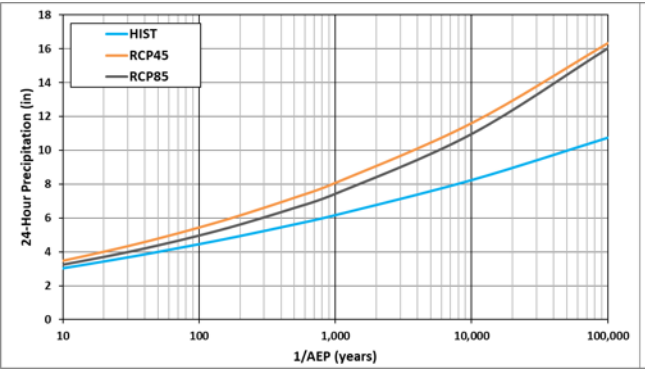
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.0 | 4.0 | 4.5 | 6.2 | 8.2 | - | - | - | - | - | |
| RCP-45 | 3.4 | 4.8 | 5.4 | 8.1 | 7.4 | 114% | 120% | 122% | 131% | 90% | 115% |
| RCP-85 | 3.2 | 4.4 | 5.0 | 7.4 | 11.0 | 107% | 110% | 112% | 120% | 133% | 116% |

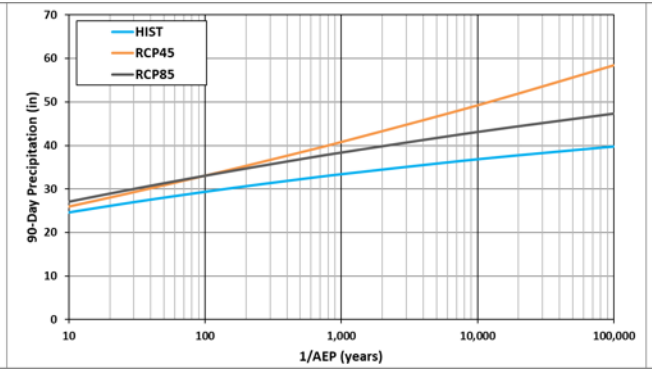
*** 90-Day

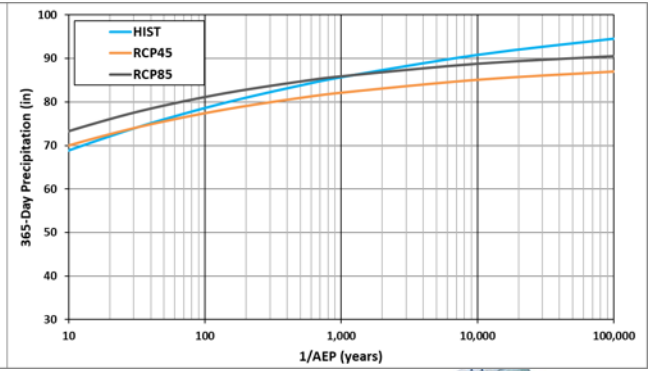
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 25 | 28 | 29 | 33 | 37 | - | - | - | - | - | |
| RCP-45 | 26 | 31 | 33 | 41 | 49 | 105% | 110% | 113% | 122% | 133% | 117% |
| RCP-85 | 27 | 31 | 33 | 38 | 43 | 110% | 112% | 112% | 115% | 117% | 113% |

*** 365-Day

| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 69 | 76 | 79 | 86 | 91 | - | - | - | - | - | |
| RCP-45 | 70 | 76 | 77 | 82 | 85 | 102% | 99% | 98% | 96% | 94% | 98% |
| RCP-85 | 73 | 79 | 81 | 86 | 89 | 107% | 104% | 103% | 100% | 98% | 102% |



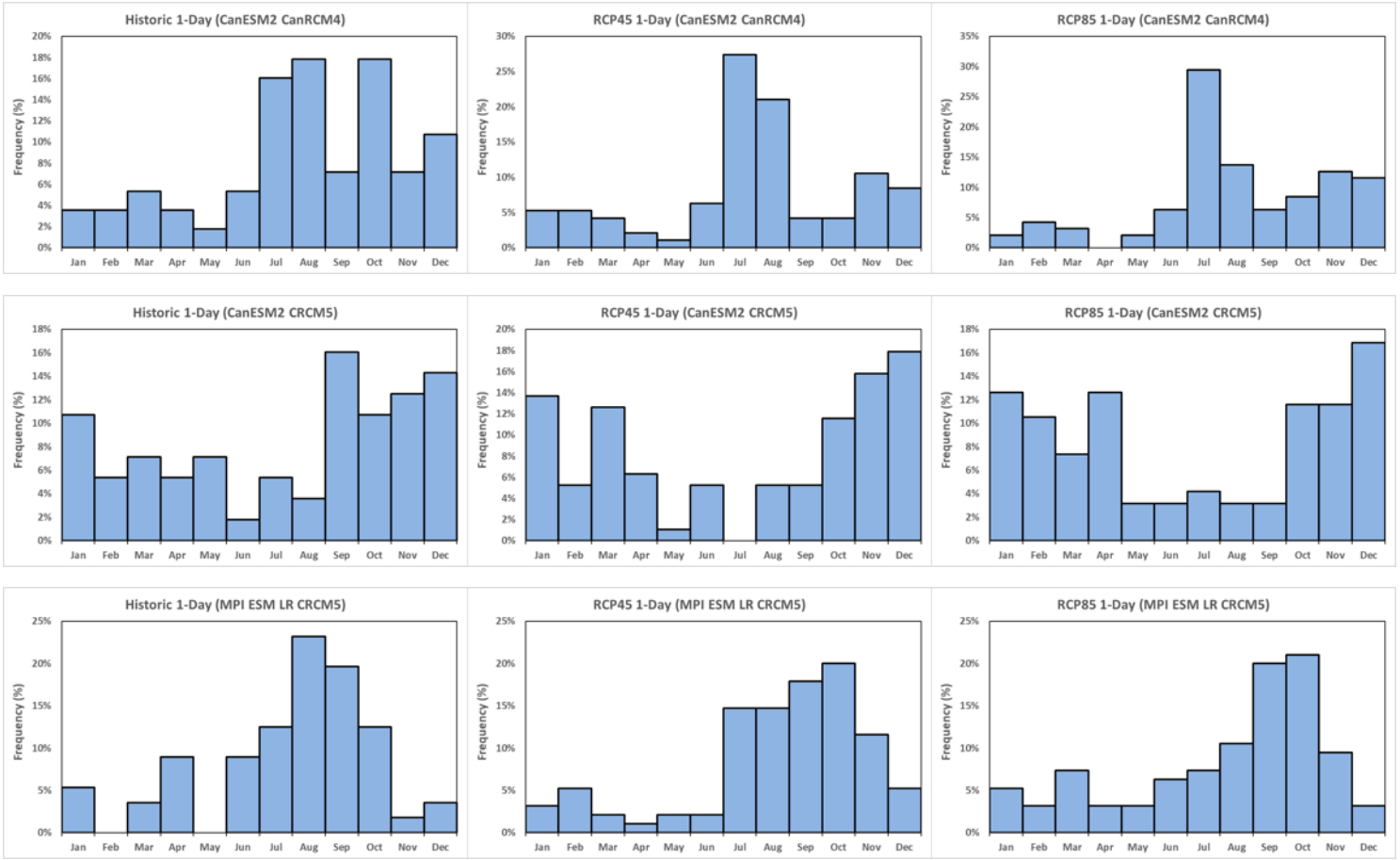




**24-hour Basin Avg 100-yr = XX mm**

+++ values represent 1-day not 24-hour

# 2. Frequency Analysis (1-day AMS Seasonality)



# 2. Frequency Analysis (CanESM2 CanRCM4)

- 1-day L-moment Frequency Analysis (**Precip, 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
  - Compared 10-, 50-, 100-, 1000-, and 10000-year AEPs

*** 1-Day Precipitation

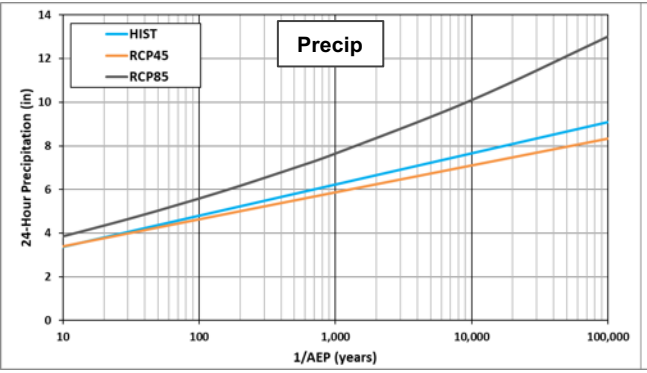
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.3 | 4.4 | 4.8 | 6.2 | 7.7 | - | - | - | - | - | |
| RCP-45 | 3.4 | 4.3 | 4.6 | 5.9 | 7.6 | 101% | 98% | 97% | 94% | 100% | 98% |
| RCP-85 | 3.8 | 5.0 | 5.6 | 7.6 | 10.1 | 114% | 115% | 116% | 123% | 132% | 120% |

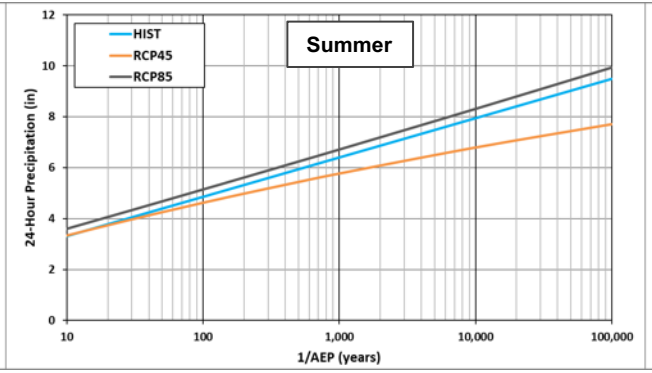
*** 1-Day Summer

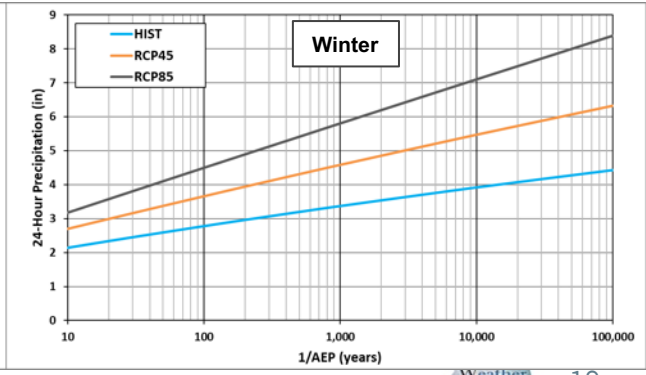
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.3 | 4.4 | 4.9 | 6.4 | 7.9 | - | - | - | - | - | |
| RCP-45 | 3.3 | 4.2 | 4.6 | 5.8 | 6.8 | 101% | 97% | 95% | 90% | 86% | 94% |
| RCP-85 | 3.6 | 4.7 | 5.1 | 6.7 | 8.3 | 109% | 106% | 106% | 105% | 105% | 106% |

*** 1-Day Winter

| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 2.1 | 2.6 | 2.8 | 3.4 | 3.9 | - | - | - | - | - | |
| RCP-45 | 2.7 | 3.4 | 3.7 | 4.6 | 5.5 | 126% | 130% | 132% | 136% | 140% | 133% |
| RCP-85 | 3.1 | 4.1 | 4.5 | 5.8 | 7.1 | 148% | 158% | 162% | 172% | 181% | 164% |




+++ values represent 1-day not 24-hour

# 2. Frequency Analysis (CanESM2 CRCM5)

- 1-day L-moment Frequency Analysis (**Precip, 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
  - Compared 10-, 50-, 100-, 1000-, and 10000-year AEPs

*** 1-Day Precipitation

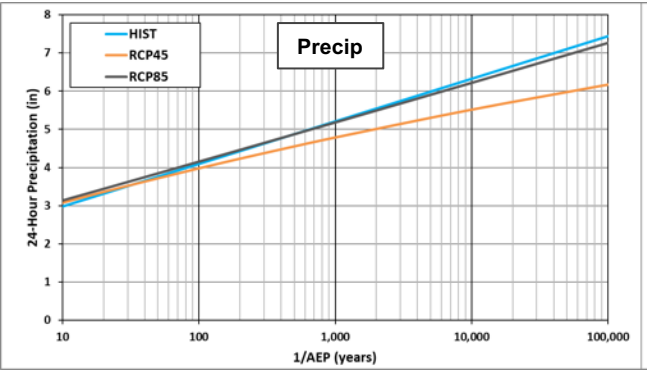
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.0 | 3.8 | 4.1 | 5.2 | 6.3 | - | - | - | - | - | |
| RCP-45 | 3.1 | 3.7 | 4.0 | 4.8 | 5.2 | 103% | 99% | 97% | 92% | 82% | 95% |
| RCP-85 | 3.1 | 3.8 | 4.1 | 5.2 | 6.2 | 105% | 102% | 101% | 99% | 98% | 101% |

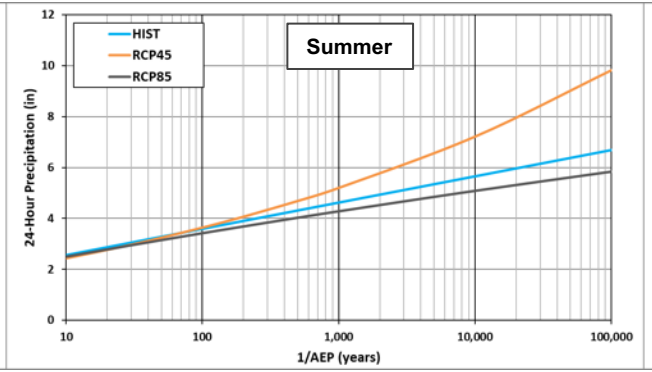
*** 1-Day Summer

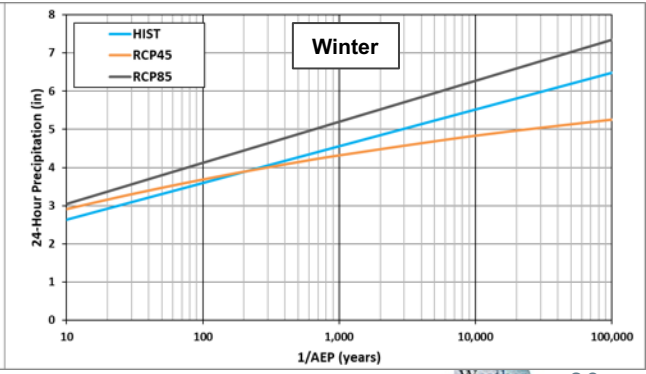
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 2.5 | 3.3 | 3.6 | 4.6 | 5.7 | - | - | - | - | - | |
| RCP-45 | 2.4 | 3.2 | 3.6 | 5.2 | 7.2 | 95% | 99% | 102% | 113% | 128% | 107% |
| RCP-85 | 2.5 | 3.1 | 3.4 | 4.3 | 5.1 | 98% | 96% | 95% | 93% | 90% | 94% |

*** 1-Day Winter

| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 2.6 | 3.3 | 3.6 | 4.6 | 5.5 | - | - | - | - | - | |
| RCP-45 | 2.9 | 3.5 | 3.7 | 4.3 | 4.8 | 111% | 105% | 103% | 95% | 88% | 100% |
| RCP-85 | 3.0 | 3.8 | 4.1 | 5.2 | 6.3 | 116% | 115% | 115% | 114% | 114% | 115% |




+++ values represent 1-day not 24-hour

# 2. Frequency Analysis (MPI ESM LR CRCM5)

- 1-day L-moment Frequency Analysis (**Precip, 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
  - Compared 10-, 50-, 100-, 1000-, and 10000-year AEPs

*** 1-Day Precipitation

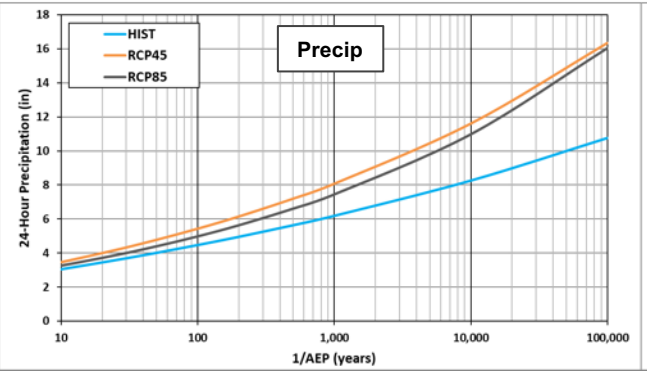
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.0 | 4.0 | 4.5 | 6.2 | 8.2 | - | - | - | - | - | |
| RCP-45 | 3.4 | 4.8 | 5.4 | 8.1 | 7.4 | 114% | 120% | 122% | 131% | 90% | 115% |
| RCP-85 | 3.2 | 4.4 | 5.0 | 7.4 | 11.0 | 107% | 110% | 112% | 120% | 133% | 116% |

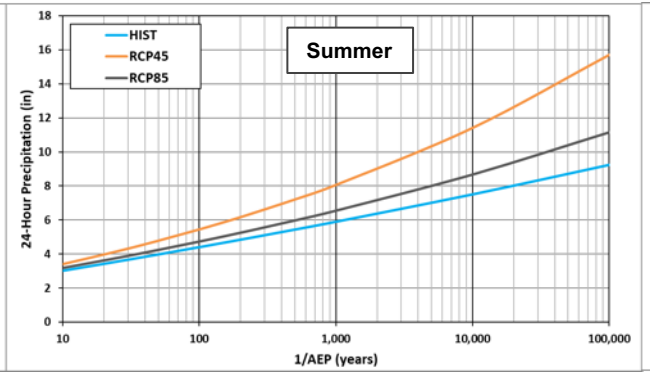
*** 1-Day Summer

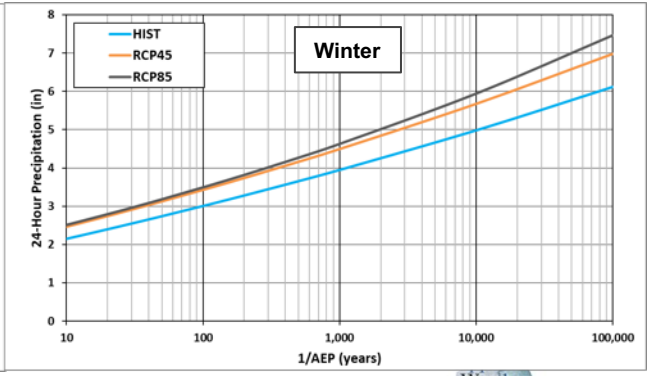
| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 3.0 | 4.0 | 4.4 | 5.9 | 7.5 | - | - | - | - | - | |
| RCP-45 | 3.4 | 4.8 | 5.5 | 8.1 | 11.4 | 113% | 120% | 124% | 137% | 152% | 129% |
| RCP-85 | 3.2 | 4.2 | 4.7 | 6.6 | 8.7 | 106% | 107% | 108% | 111% | 115% | 109% |

*** 1-Day Winter

| | 10yr | 50yr | 100yr | 1000yr | 10000yr | Pct Change | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical | 2.1 | 2.7 | 3.0 | 4.0 | 5.0 | - | - | - | - | - | |
| RCP-45 | 2.4 | 3.1 | 3.4 | 4.5 | 5.7 | 115% | 114% | 114% | 114% | 114% | 114% |
| RCP-85 | 2.5 | 3.2 | 3.5 | 4.6 | 5.9 | 117% | 116% | 116% | 117% | 119% | 117% |



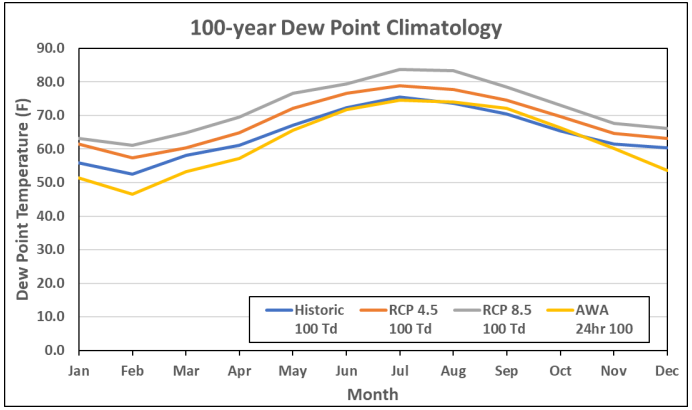

+++ values represent 1-day not 24-hour

# 3. PMP Ratio Analysis

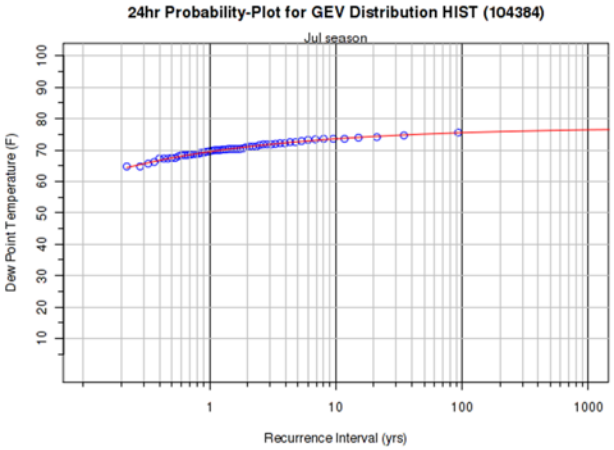
- Estimate 1-day and 3-day **$Ppt_{adj}$** for top 30 1-day and 3-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Deive monthly dew point (td) climatologies (Historic, RCP45, RCP85)
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor
    - (**r = PW_100 / PW_obs**)
  - Estimated **$Ppt_{adj}$** (~PMP) value for each event (**P * r**)

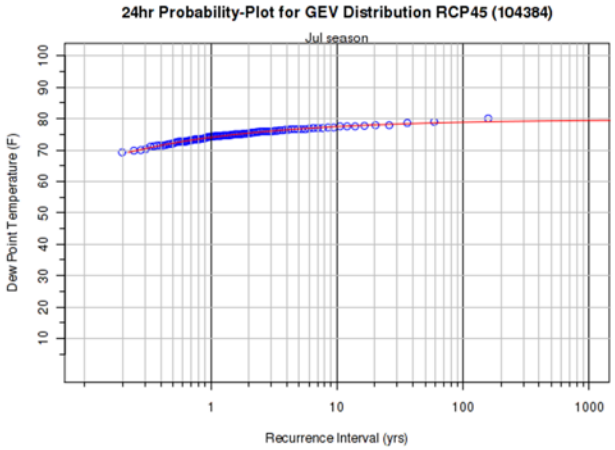
# 3a. Td Analysis (CanESM2 CanRCM4)

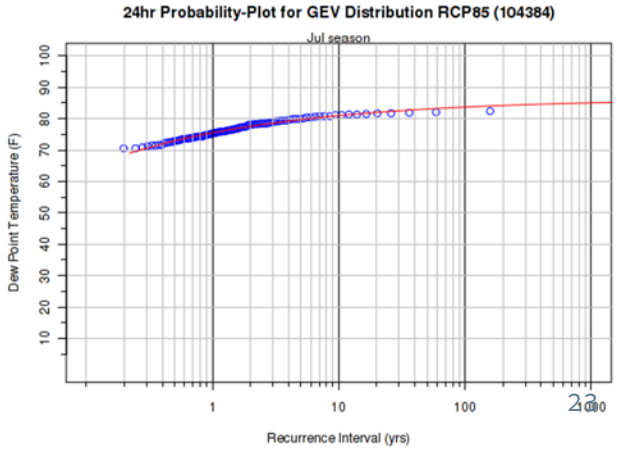
- Calculate monthly dew point temperature (Td) 100-year climatology
  - all months have similar shape/seasonality
    - the **Historic** has largest range
  - Historic Average – 64.5 F
  - RCP45 Average – 68.5 F
  - RCP85 Average – 72.2 F




*** AWA 24-hour 100-year Td Climatology (gold), is similar in summer and lower in winter than historic projection

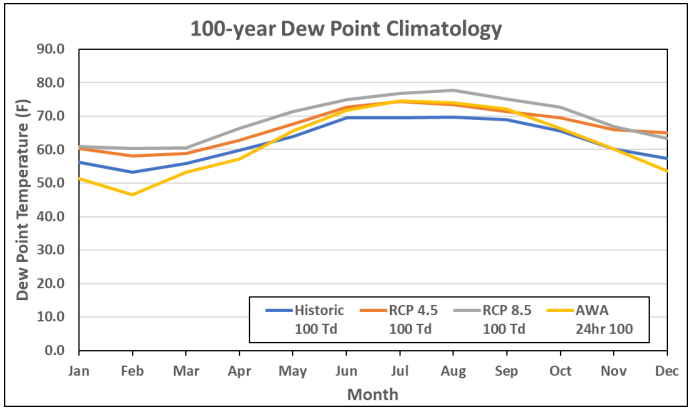


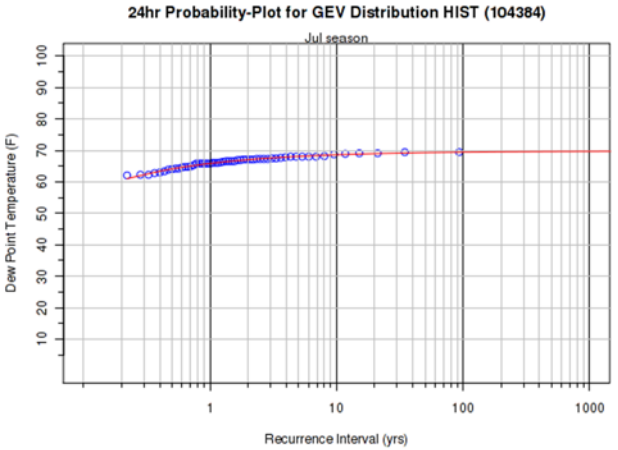



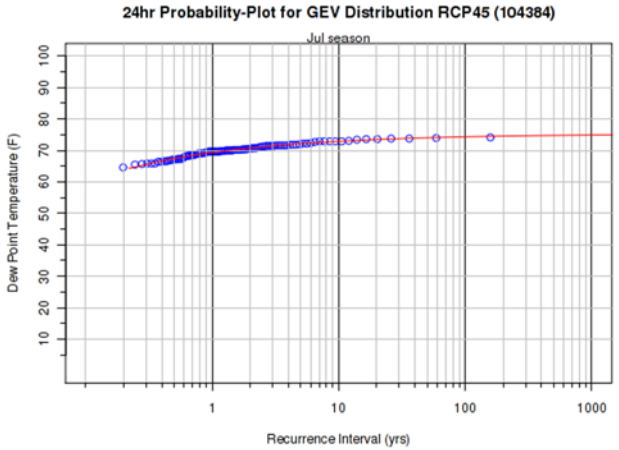
# 3a. Td Analysis (CanESM2 CRCM5)

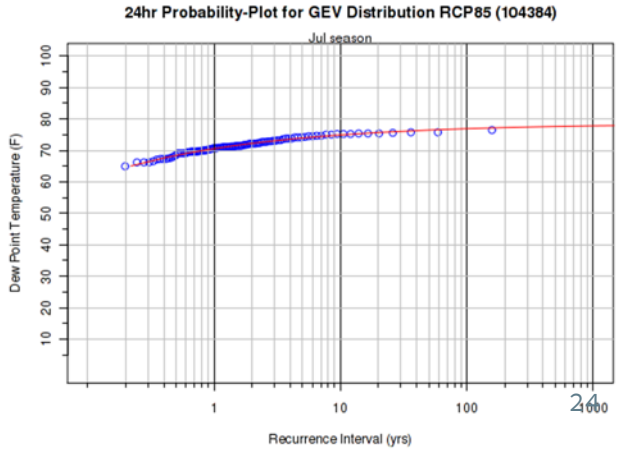
- Calculate monthly dew point temperature (Td) 100-year climatology
  - all months have similar shape/seasonality
    - the **RCP85** has largest range
  - Historic Average – 62.5 F
  - RCP45 Average – 66.7 F
  - RCP85 Average – 68.9 F




*** AWA 24-hour 100-year Td Climatology (gold), is greater in summer and lower in winter than historic projection

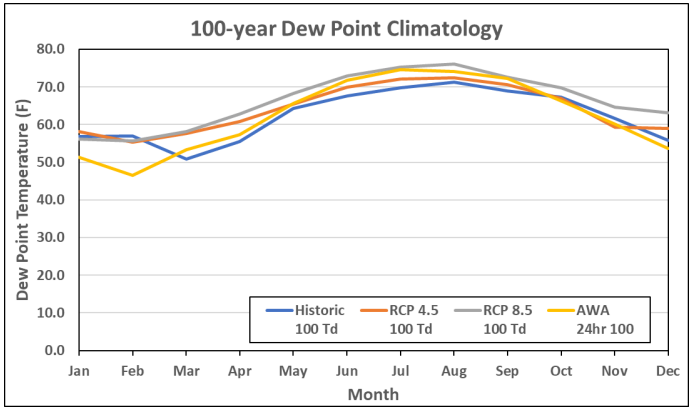


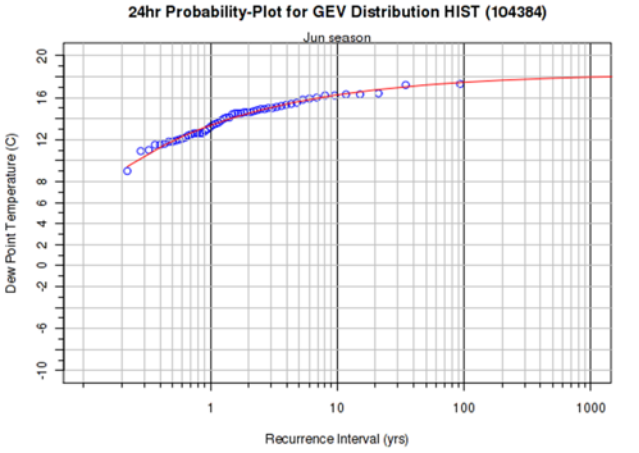



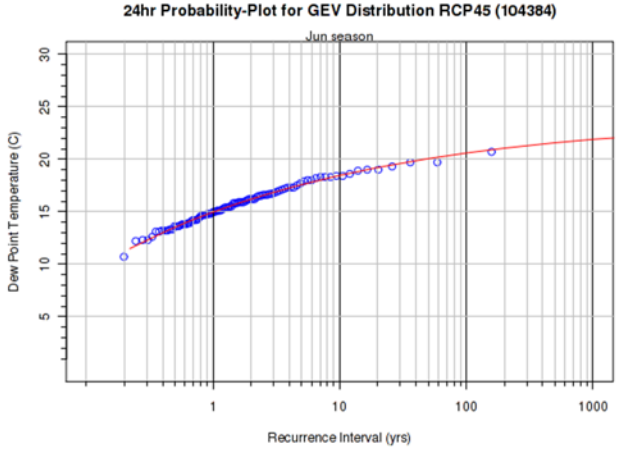
# 3a. Td Analysis (MPI ESM LR CRCM5)

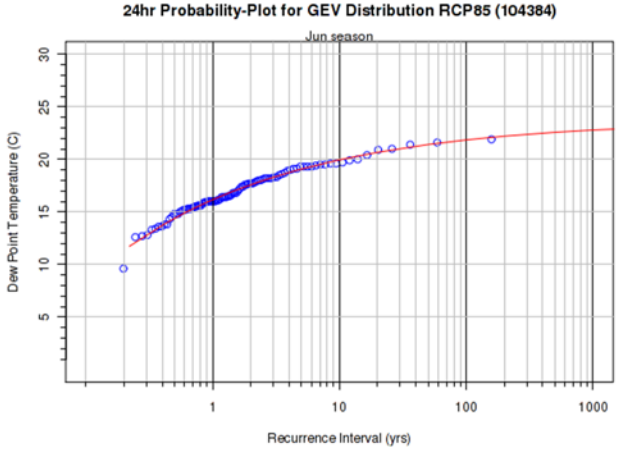
- Calculate monthly dew point temperature (Td) 100-year climatology
  - all months have similar shape/seasonality
    - the **RCP85** has largest range
  - Historic Average – 62.2 F
  - RCP45 Average – 64.0 F
  - RCP85 Average – 66.3 F




*** AWA 24-hour 100-year Td Climatology (gold), is greater in summer and lower in winter than historic projection



# 3b. $Ppt_{max}$ Analysis (CanESM2 CanRCM4)

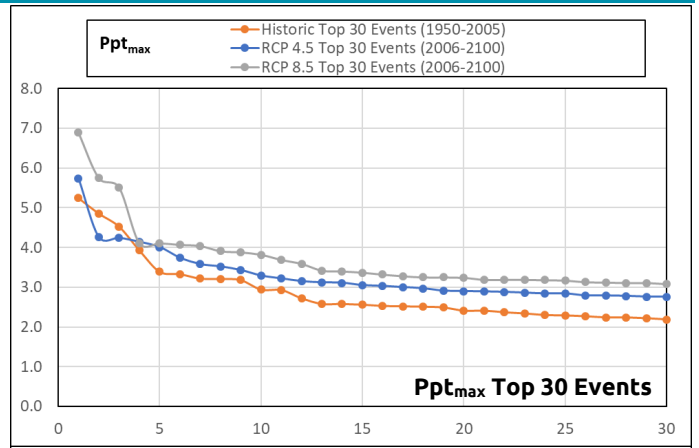
- Estimate **1-day** **$Ppt_{adj}$** for top 30 1-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated **$Ppt_{adj}$** value for each event (**P * r)**

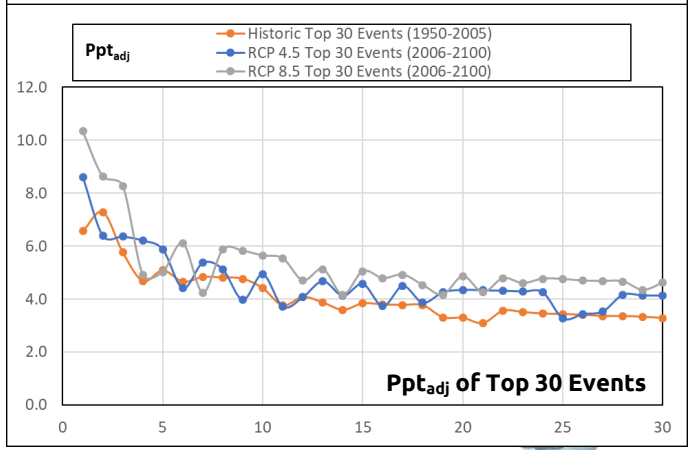
**CanESM2 CanRCM4**

| $Ppt_{max}$ | (in) | Pct Change |
|---|---|---|
| **Historical** | 5.3 | - |
| **RCP45** | 5.7 | 108% |
| **RCP85** | 6.9 | 130% |

| $Ppt_{adj}$ | (in) | rank | Pct Change |
|---|---|---|---|
| **Historical** | 7.3 | 2 | - |
| **RCP45** | 8.6 | 1 | 118% |
| **RCP85** | 10.3 | 1 | 141% |

+++ values represent 1-day not 24-hour



# 3b. $Ppt_{max}$ Analysis (CanESM2 CRCM5)

- Estimate **1-day** $Ppt_{adj}$ for top 30 1-day precipitation events
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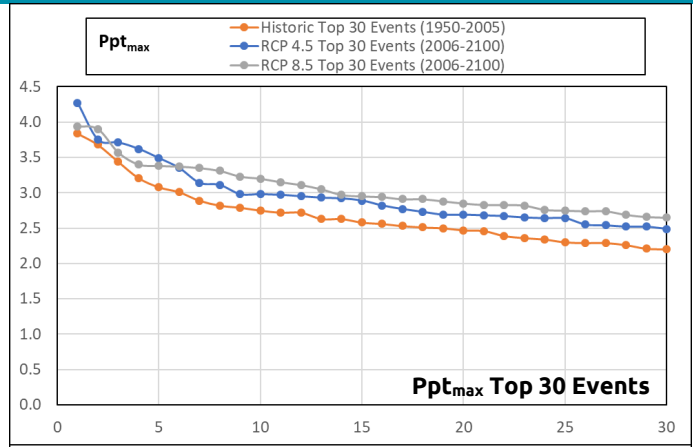
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated $Ppt_{adj}$ value for each event (**P * r)**

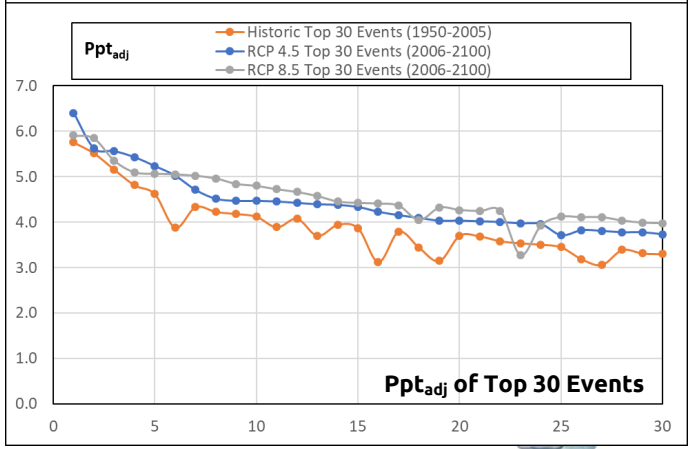
**CanESM2 CRCM5**

| $Ppt_{max}$ | (in) | Pct Change |
|---|---|---|
| **Historical** | 3.8 | - |
| **RCP45** | 4.3 | 113% |
| **RCP85** | 3.9 | 103% |

| $Ppt_{adj}$ | (in) | rank | Pct Change |
|---|---|---|---|
| **Historical** | 5.8 | 1 | - |
| **RCP45** | 6.4 | 1 | 110% |
| **RCP85** | 5.9 | 1 | 102% |

+++ values represent 1-day not 24-hour



# 3b. $Ppt_{max}$ Analysis (MPI ESM LR CRCM5)

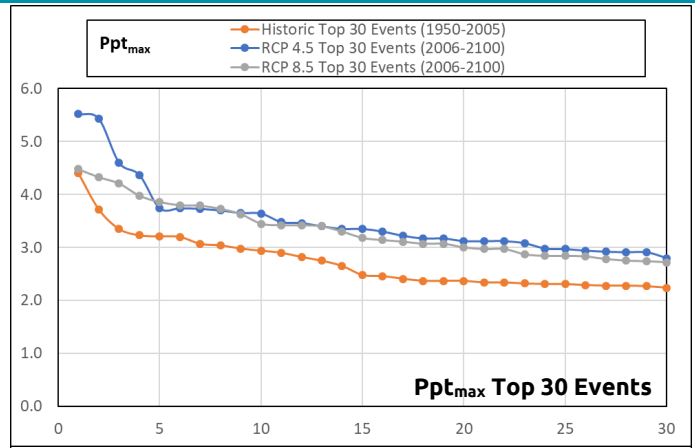
- Estimate **1-day** **$Ppt_{adj}$** for top 30 1-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated **$Ppt_{adj}$** value for each event (**P * r)**

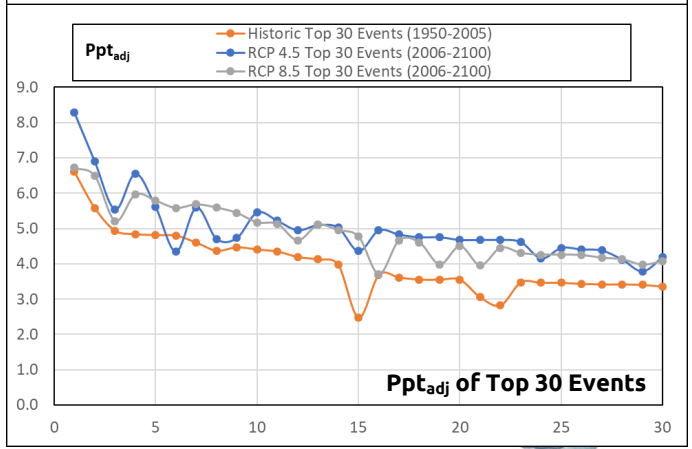
**MPI ESM LR CRCM5**

| $Ppt_{max}$ | (in) | Pct Change |
|---|---|---|
| **Historical** | 4.4 | - |
| **RCP45** | 5.5 | 125% |
| **RCP85** | 4.5 | 102% |

| $Ppt_{adj}$ | (in) | rank | Pct Change |
|---|---|---|---|
| **Historical** | 6.6 | 1 | - |
| **RCP45** | 8.3 | 1 | 126% |
| **RCP85** | 6.7 | 1 | 102% |

+++ values represent 1-day not 24-hour



# 4. Summary (Trend Analysis)

- **Station data (1 day) (Annual)**
  - 8 -**no trend**, 3 increasing (1-day)
  - 4 -**no trend**, 7 increasing (Annual)
- **1-day**
  - Historic – 3 **no trend**
  - RCP45 – 3 **no trend**
  - RCP85 - 2 **no trend** and 2 increasing trend
- **90-day**
  - Historic – 3 **no trend**
  - RCP45 – 3 **no trend**
  - RCP85 - 1 **no trend** and 2 increasing trend
- **Annual**
  - Historic – 2 **no trend** and 1 increasing trend
  - RCP45 – 3 **no trend**
  - RCP85 - 1 **no trend** and 2 increasing trend

# 4. Summary (Precipitation Frequency Analysis)

- **1-day (rcp45 to rcp85)**
  - Max = 115% to 120%
  - Min 95% to 101%
  - Range = 20% to 19%
  - Average = **103% to 112%**
- **90-day**
  - Max = 117% to 124%
  - Min 103% to 109%
  - Range = 14% to 15%
  - Average = **117% to 124%**
- **Annual**
  - Max = 116% to 128%
  - Min 91% to 96%
  - Range = 25% to 32%
  - Average = **102% to 109%**
- **1-day Summer (rcp45 to rcp85)**
  - Max = 129% to 109%
  - Min 94% to 94%
  - Range = 35% to 15%
  - Average = **110% to 103%**
- **1-day Winter (rcp45 to rcp85)**
  - Max = 133% to 164%
  - Min 100% to 115%
  - Range = 33% to 49%
  - Average = **116% to 132%**

# 4. Summary ($PPt_{adj}$)

- **Dew Point Climatologies**
  - All scenarios produce similar shape/season of monthly 100yr Td values
  - CanESM2 CanRCM4 has highest 100yr Td values
  - More of scaling adjustment of 2-3 F Historic to RCP45 and 2-3 F for RCP45 to RCP85

- **1day $Ppt_{max}$ (RCP45 to rcp85)**
  - Max = 125% to 130%
  - Min 108% to 102%
  - Range = 17% to 28%
  - Average = **115% to 112%**

- **1day $Ppt_{adj}$ (RCP45 to rcp85)**
  - Max = 126% to 141%
  - Min 110% to 102%
  - Range = 16% to 39%
  - Average = **110% to 102%**

- **3day $Ppt_{max}$ (RCP45 to rcp85)**
  - Max = 126% to 143%
  - Min 75% to 72%
  - Range = 51% to 71%
  - Average = **101% to 114%**

- **3day $Ppt_{adj}$ (RCP45 to rcp85)**
  - Max = 127% to 146%
  - Min 75% to 72%
  - Range = 52% to 74%
  - Average = **102% to 112%**

The largest observed Ppt is not always equal PMP based on in-place maximization

# 5. Conclusion

- Climate Models Project Temperature and Dew Point increases
- 1-day - **no significant change** of Precip magnitude by 2100 (still within uncertainty)

  *** higher confidence of **an increase** of Winter magnitude by 2100 (RCP85)
- 90-day – **no significant change** of Precip magnitude by 2100 (still within uncertainty); RCP85 higher confidence of an increase.
- Annual – **no significant change** of Precip magnitude by 2100 (still within uncertainty).

# 5. Global Summary based on Five Studies

- Indonesia
  - No change in short duration (<3-day), higher probability for increase for longer durations (>30-days)
- Peru
  - Significant change in short duration (<3-day), no significant change in longer durations (>30-days)
- Eastern United States
  - No significant change in durations 1-day through annual precipitation
  - Higher confidence of increase in winter precipitation
- Southern Canada
  - Significant change short duration (<3-day), no significant change longer durations 30-days through annual
- Northern United States/Southern Canada
  - No significant change in longer durations 1-day through annual precipitation
- All Temperature and Dew Point Temperature Increases

# Questions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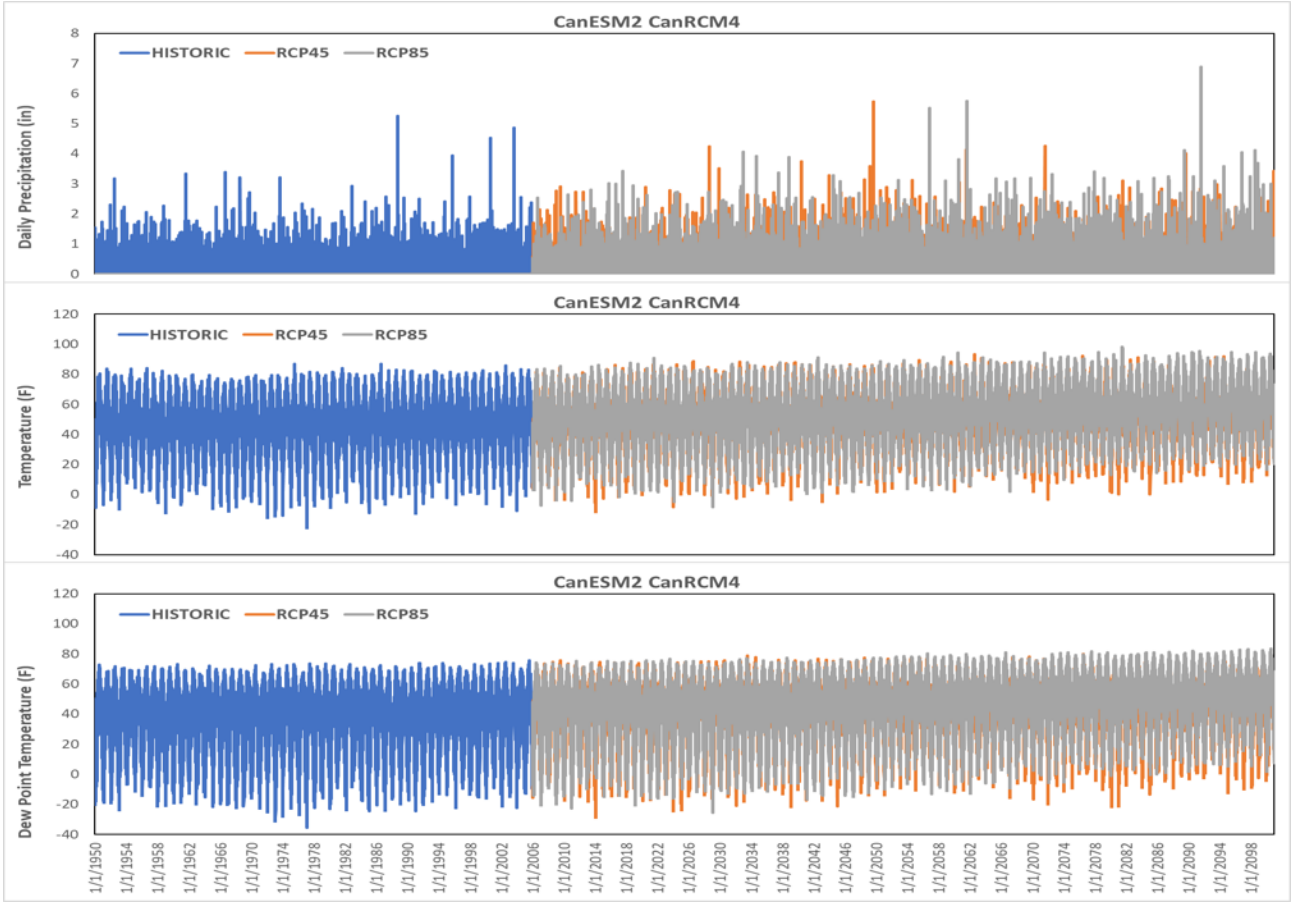


# Climate Model Background

- Various research groups conduct climate change modeling
  - Share data via CMIP5 group
  - Utilize same requirements to make each model comparable
  - 20 different groups in CMIP5
- Representative Concentration Pathway (RCP)
  - RCP account for unknown future GHG emissions
- RCP scenarios used as boundary conditions for CMIP5 GCMs
  - Commonly use RCP 4.5 and 8.5

# Climate Model Projections/Output

- Projections are relative to temperatures and sea levels in the late-20th to early-21st centuries (1986–2005 average). Temperature projections can be converted to a reference period of 1850–1900 or 1980–99 by adding 0.61 or 0.11 °C, respectively

- The **RCP 4.5** scenario is a stabilization scenario, which means the radiative forcing level stabilizes at 4.5 W/m2 before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions.

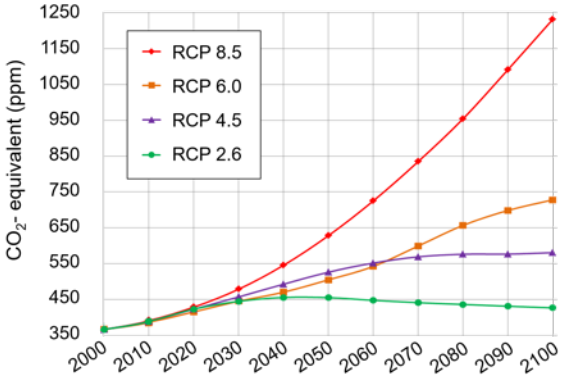
- The **RCP 8.5** emissions scenario the radiative forcing level reaches 8.5 W/m2 characterized by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels.

**AR5 global warming increase (°C) projections**[111]

| | 2046–2065 | 2081–2100 |
|---|---|---|
| Scenario | Mean and *likely* range | Mean and *likely* range |
| RCP2.6 | 1.0 (0.4 to 1.6) | 1.0 (0.3 to 1.7) |
| RCP4.5 | **1.4 (0.9 to 2.0)** | **1.8 (1.1 to 2.6)** |
| RCP6.0 | 1.3 (0.8 to 1.8) | 2.2 (1.4 to 3.1) |
| RCP8.5 | **2.0 (1.4 to 2.6)** | **3.7 (2.6 to 4.8)** |

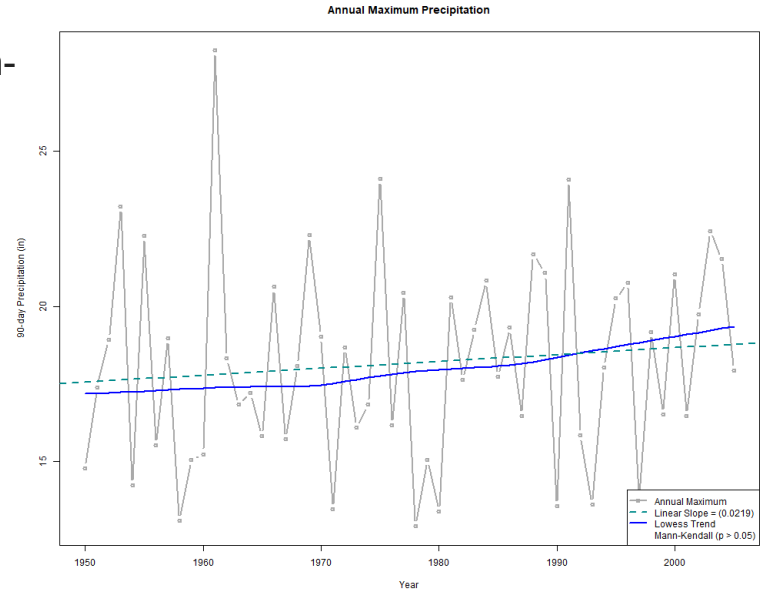
IPCC AR5 Greenhouse Gas Concentration Pathways

Representative Concentration Pathways (RCPs) from the fifth Assessment Report by the International Panel on Climate Change



# 1. Trend Analysis (90-day)

- Great River station 90-day AMS Trend Analysis (Mann-Kendall)

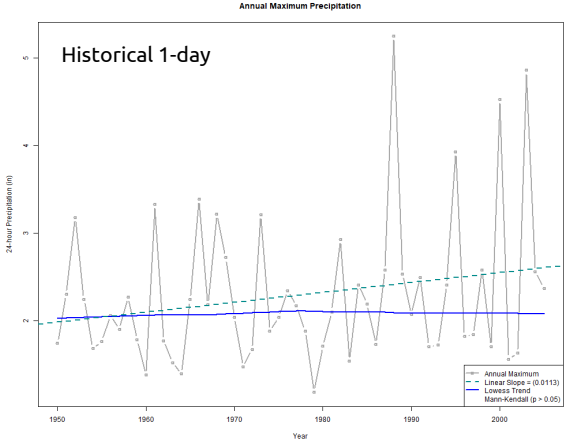


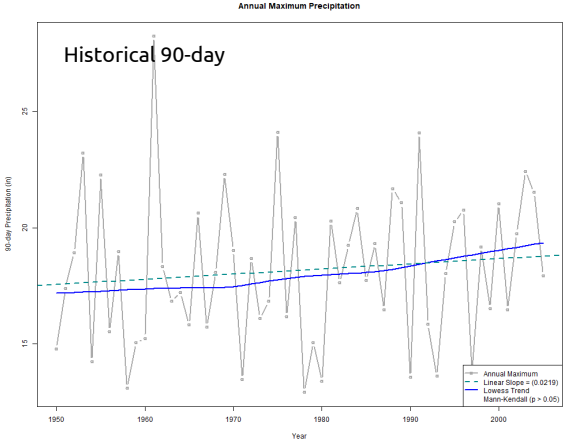

- 1) CanESM2 CanRCM4 90-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **increasing trend**

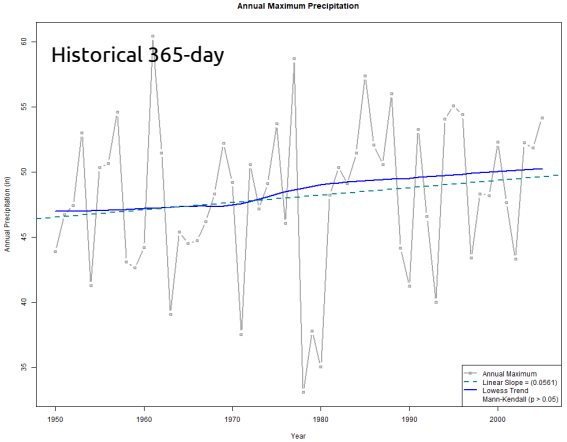
- 2) CanESM2 CRCM5 90-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **increasing trend**

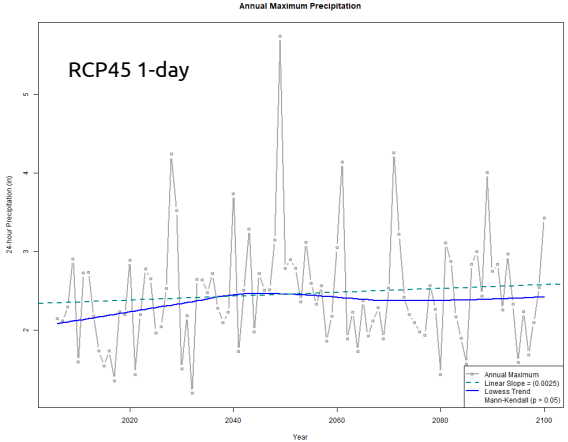
- 3) MPI ESM LR CRCM5 90-day AMS
  - trend depends on period investigated
    - Historical: **no trend**
    - RCP45: **no trend**
    - RCP85: **no trend**

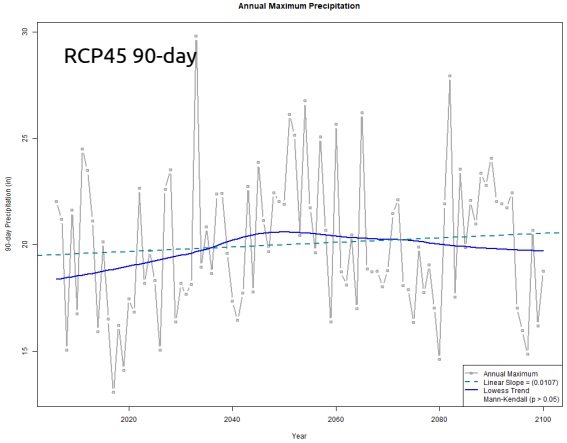
# 1. Trend Analysis (**CanESM2 CanRCM4**)

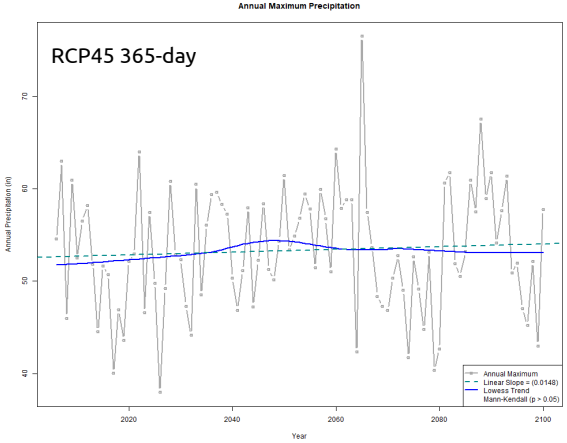


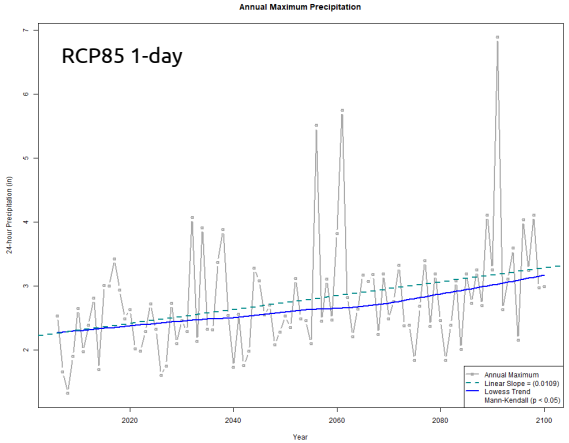



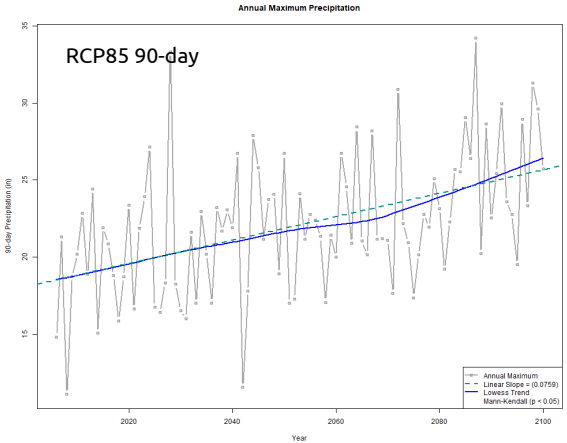



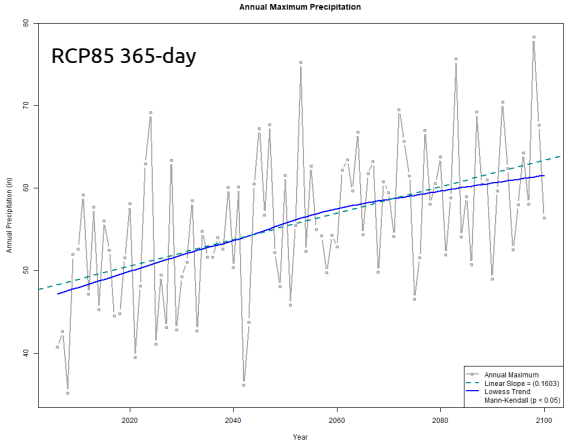



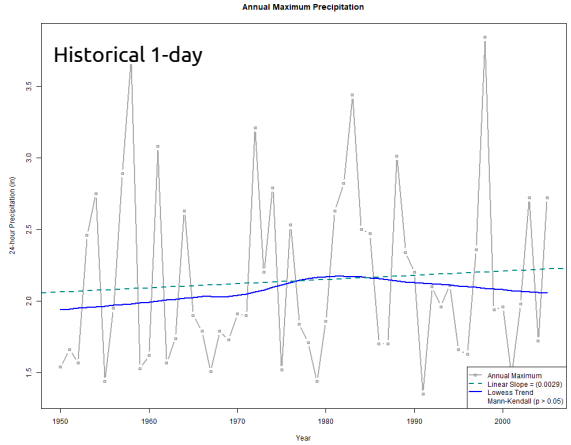
# 1. Trend Analysis (**CanESM2 CanRCM4**)

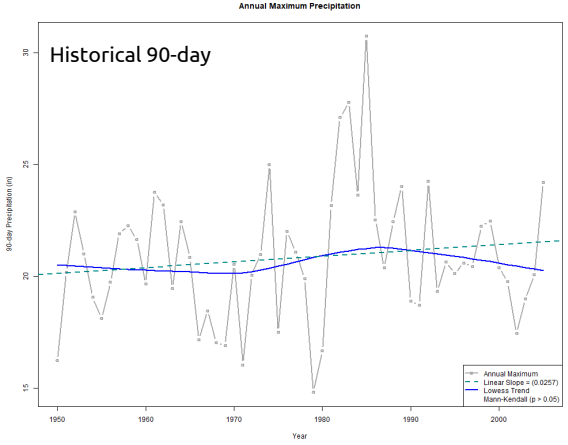


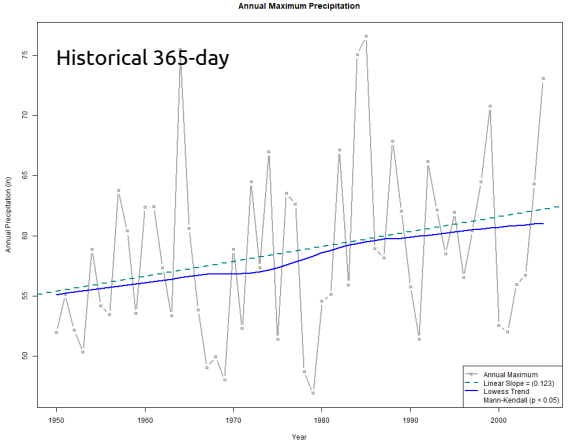



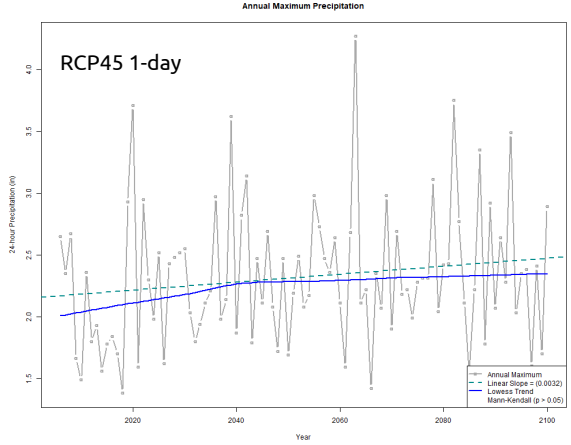



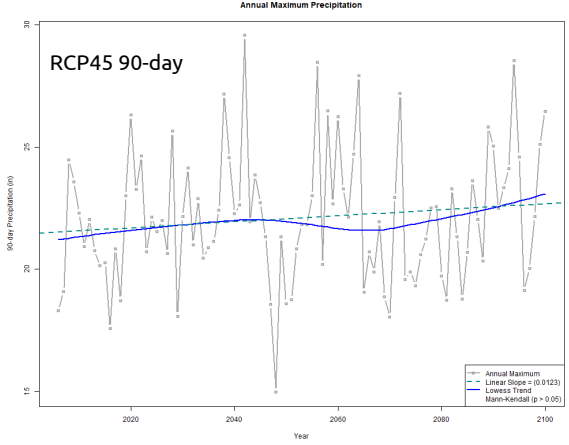
# 1. Trend Analysis (**CanESM2 CRCM5**)

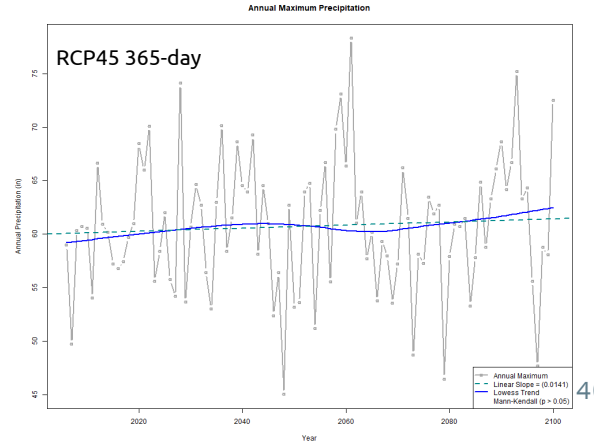


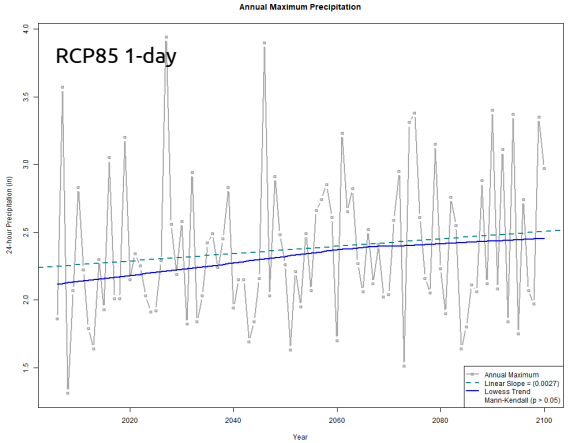



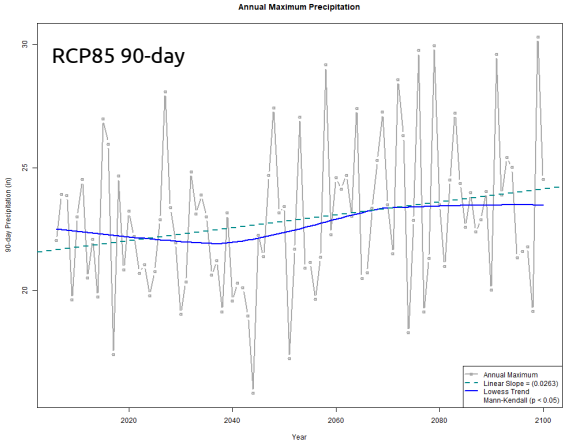



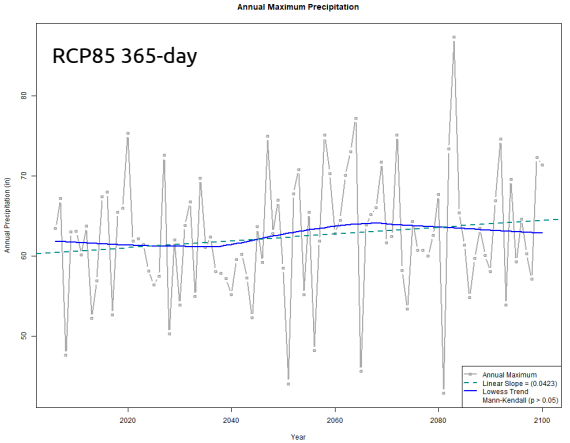



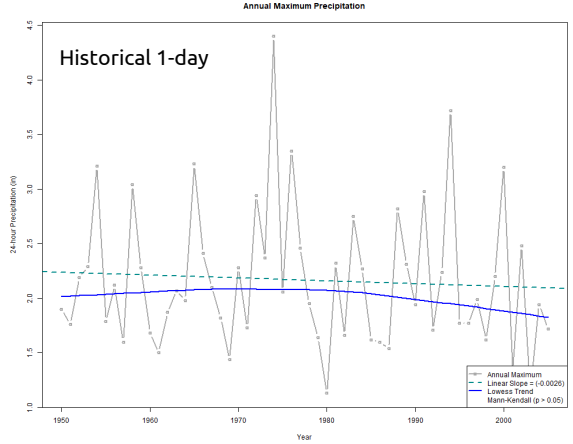
# 1. Trend Analysis (**CanESM2 CRCM5**)

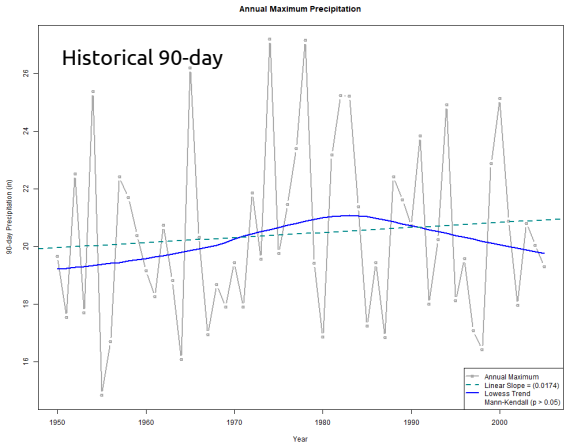


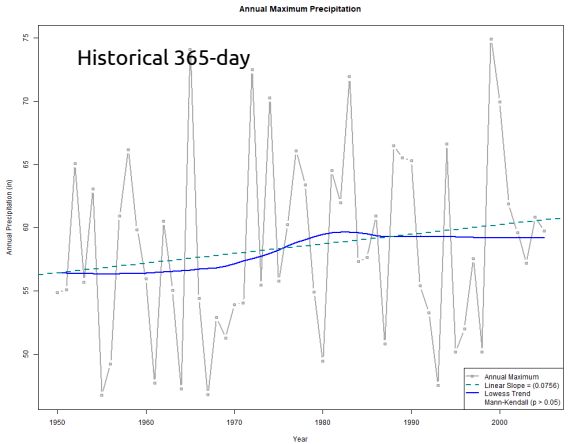



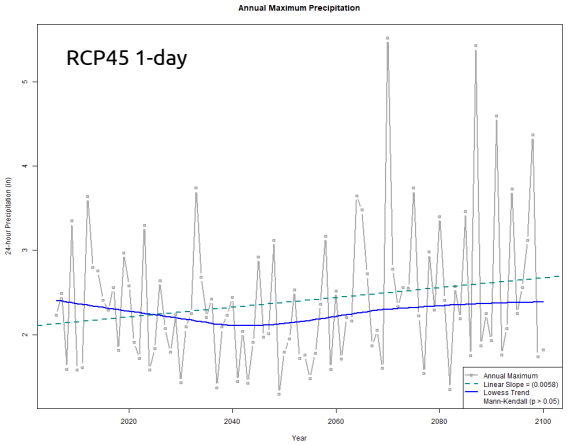



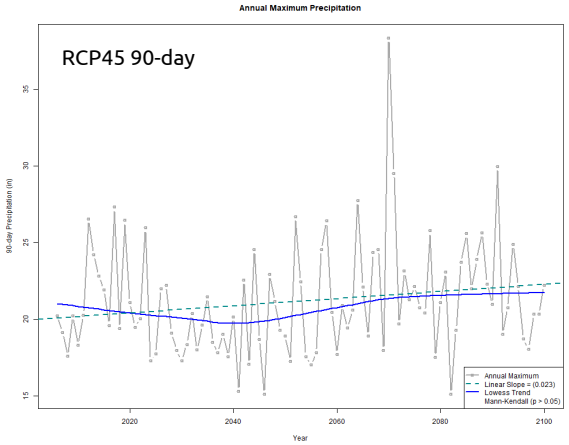
# 1. Trend Analysis (**MPI ESM LR CRCM5**)

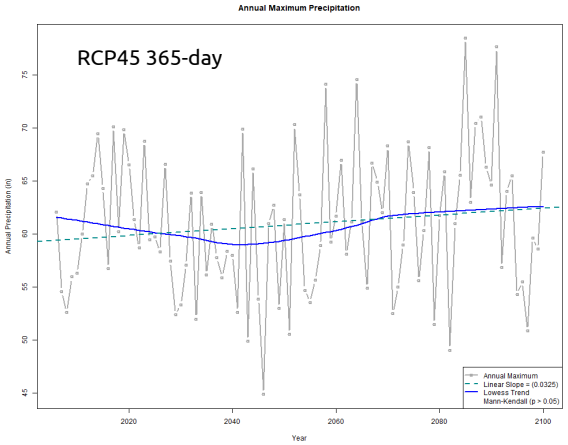


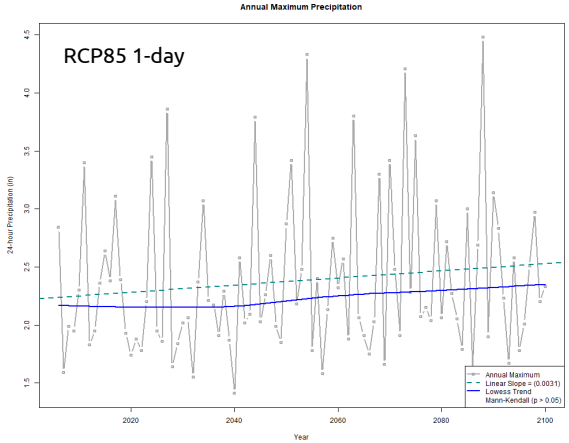



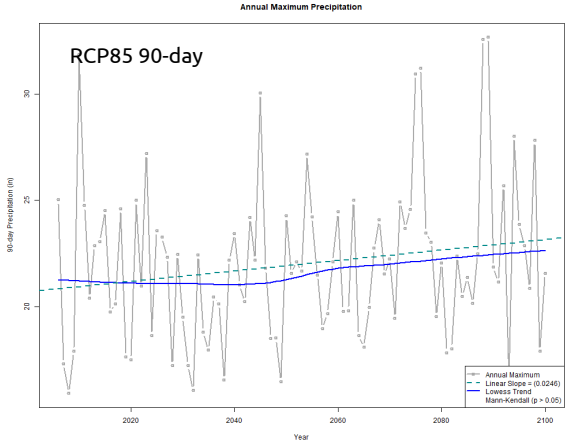



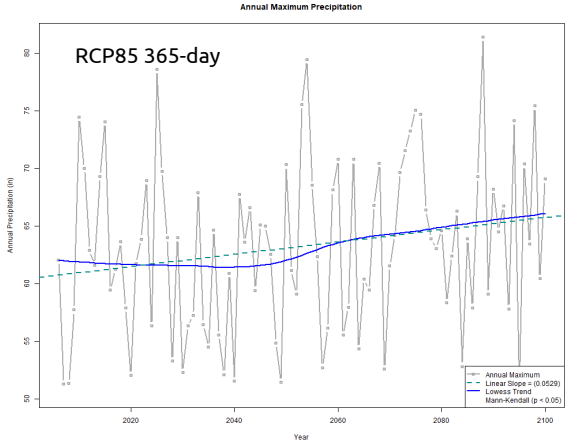



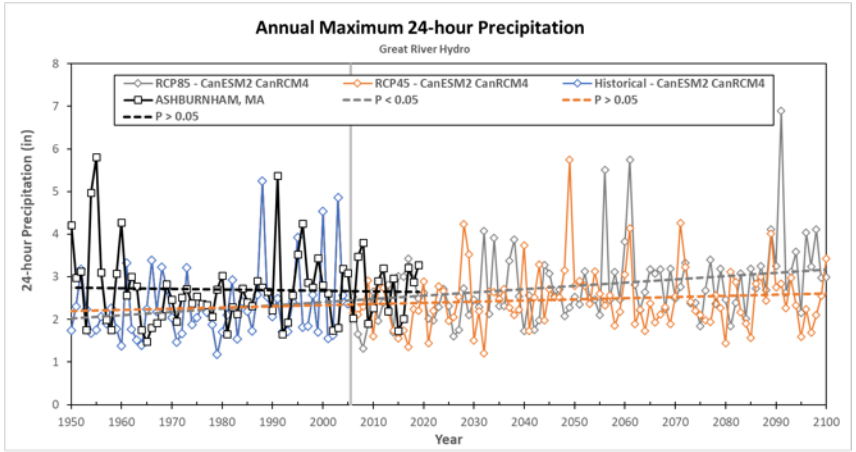
# 1. Trend Analysis (**MPI ESM LR CRCM5**)

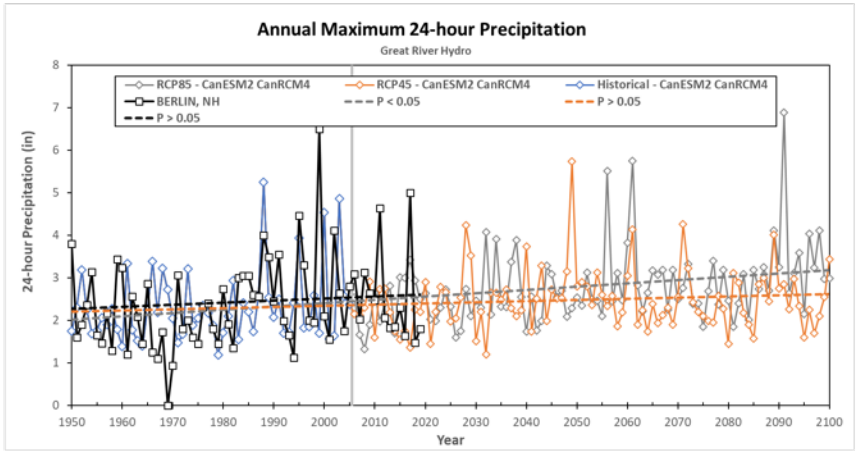


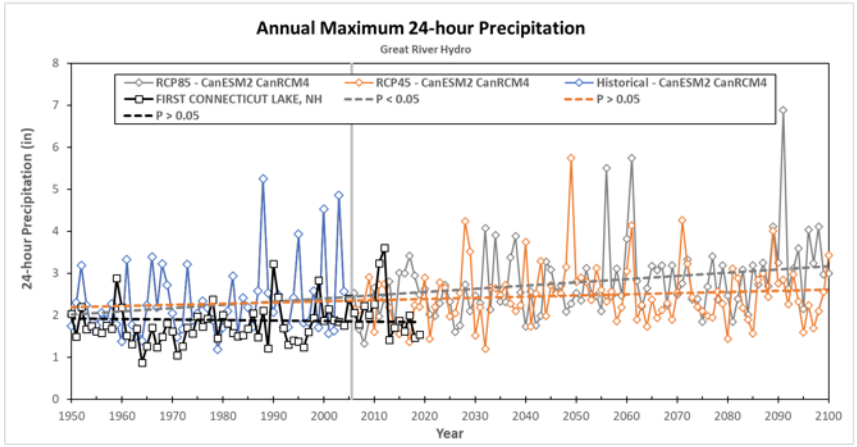



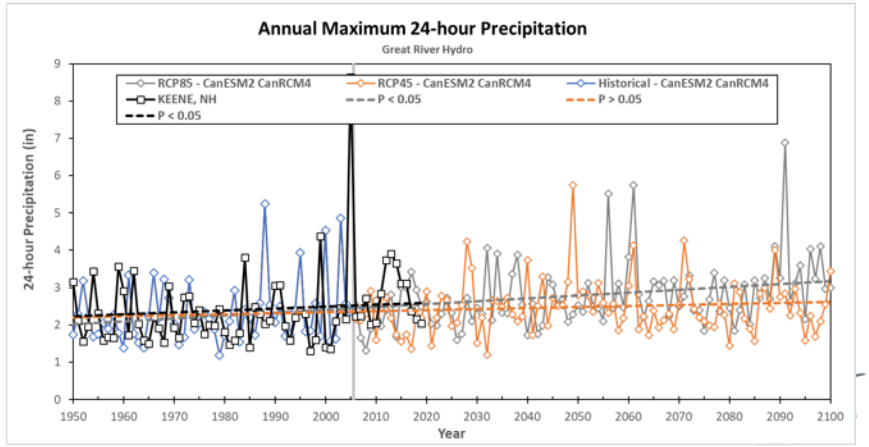



# 1. Station/Projection Trend (1-day) – Model 1

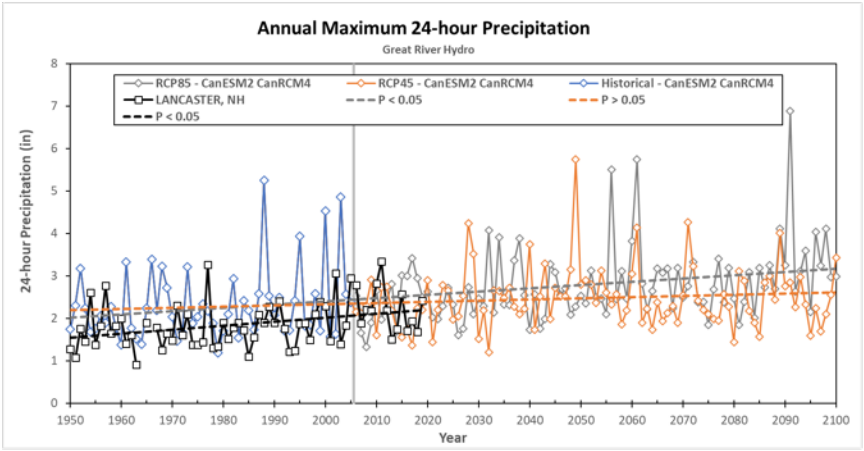


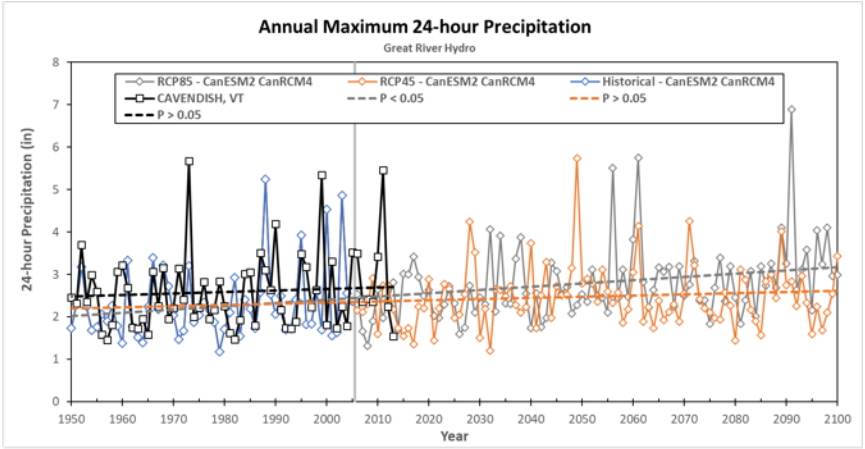



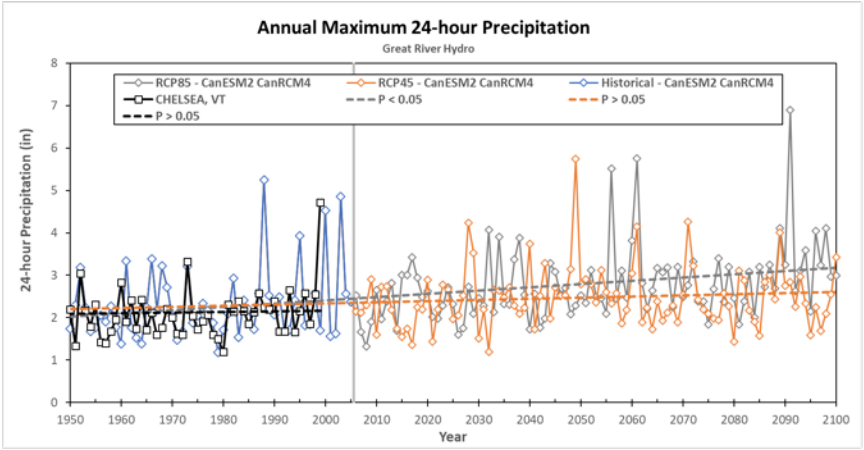



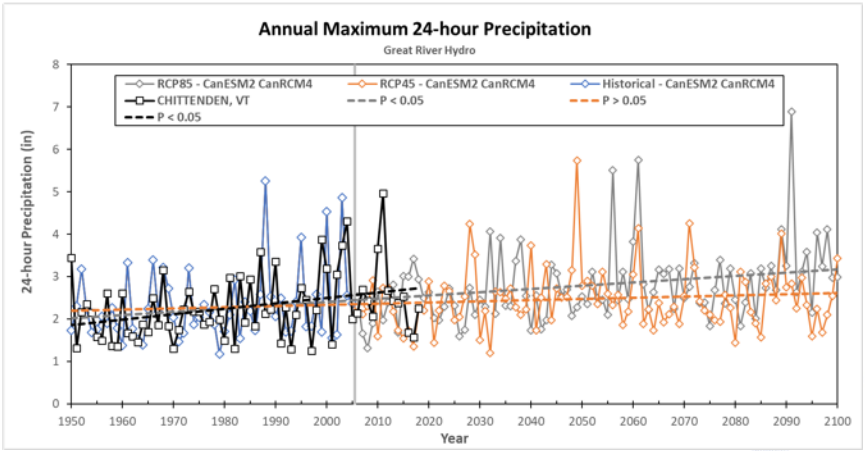



# 1. Station/Projection Trend (1-day) – Model 1

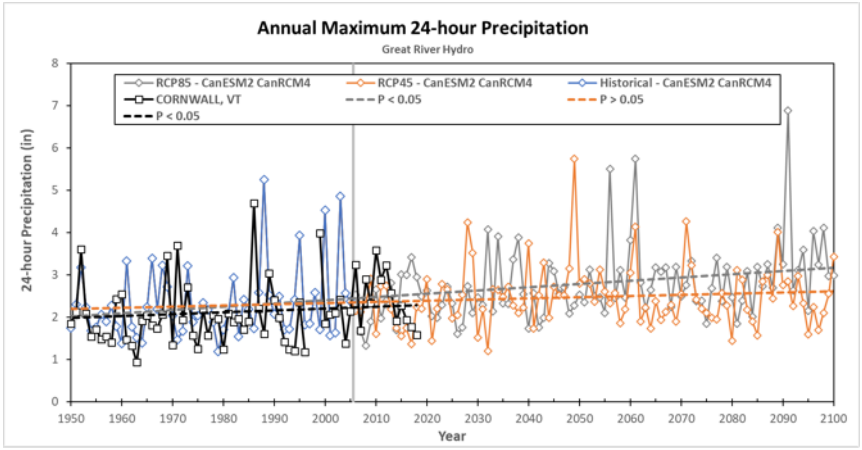


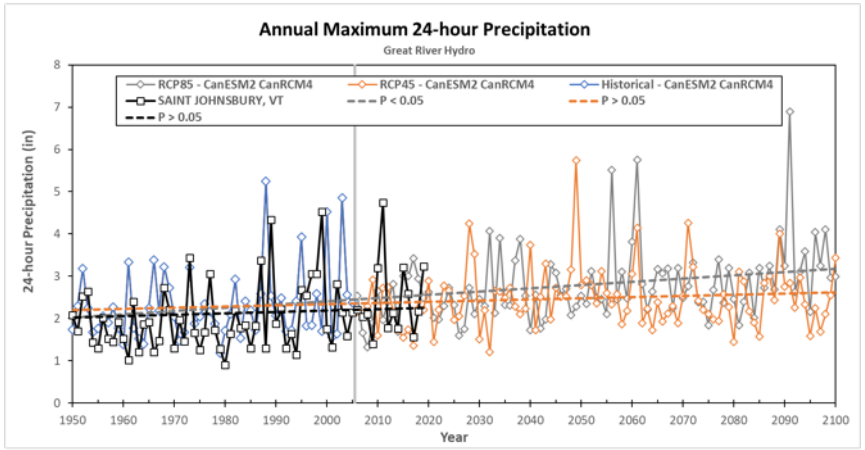



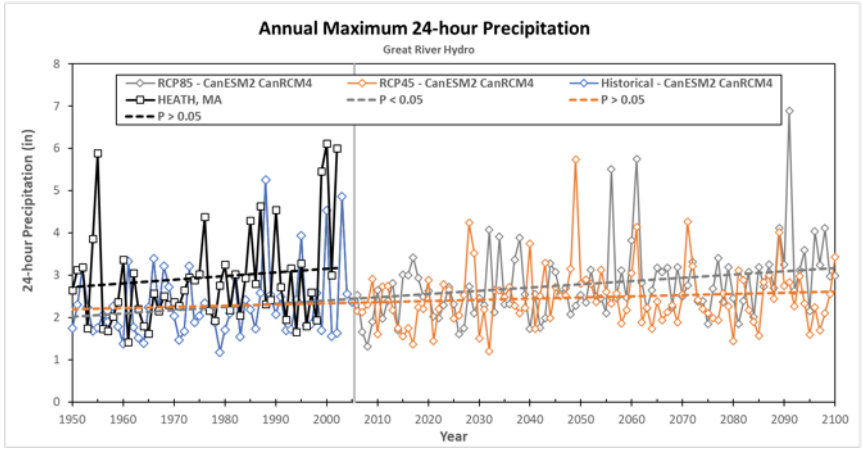



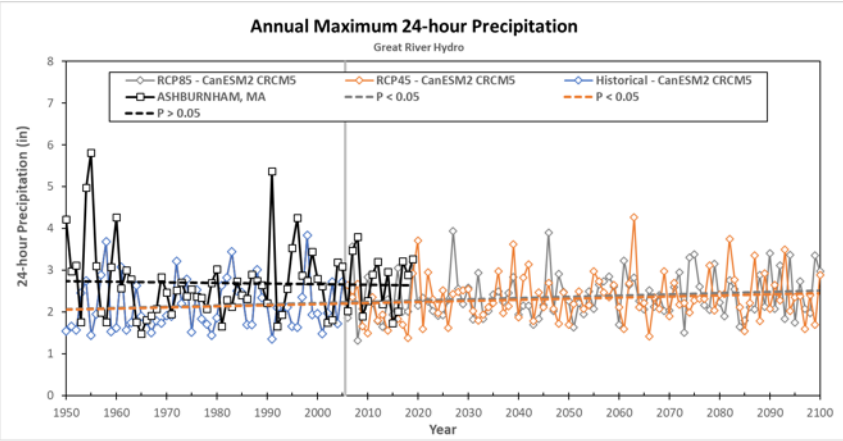
# 1. Station/Projection Trend (1-day) - Model 1

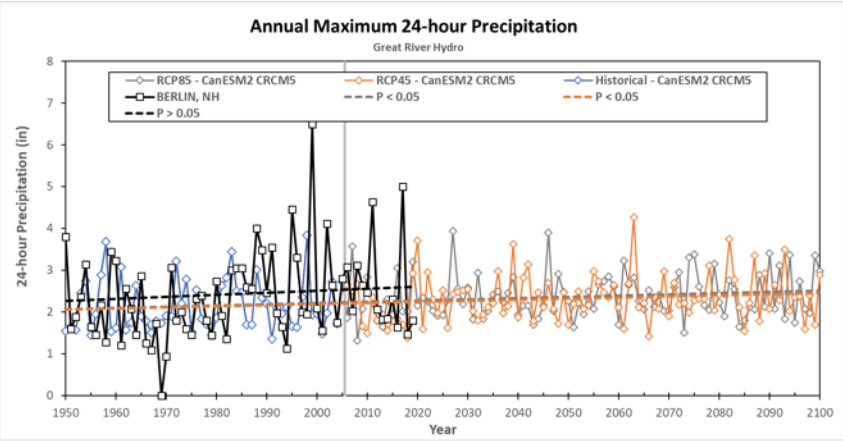


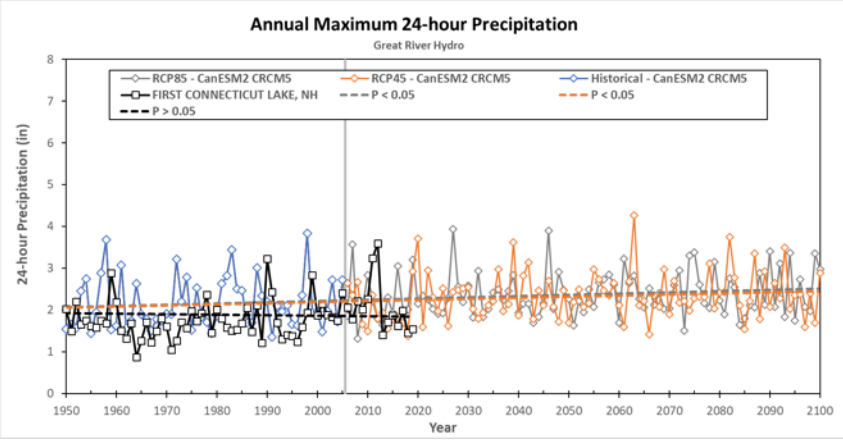



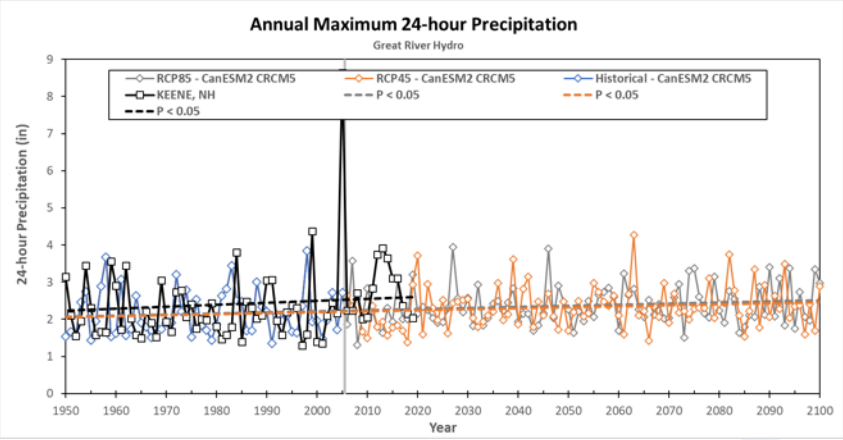



# 1. Station/Projection Trend (1-day) - Model 2

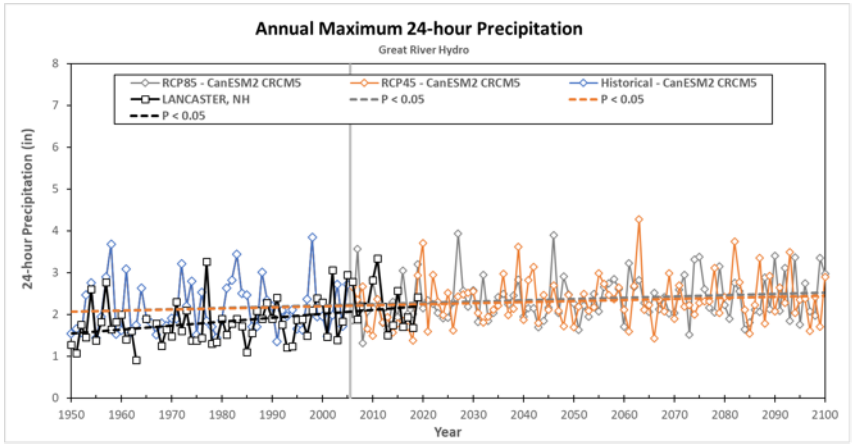


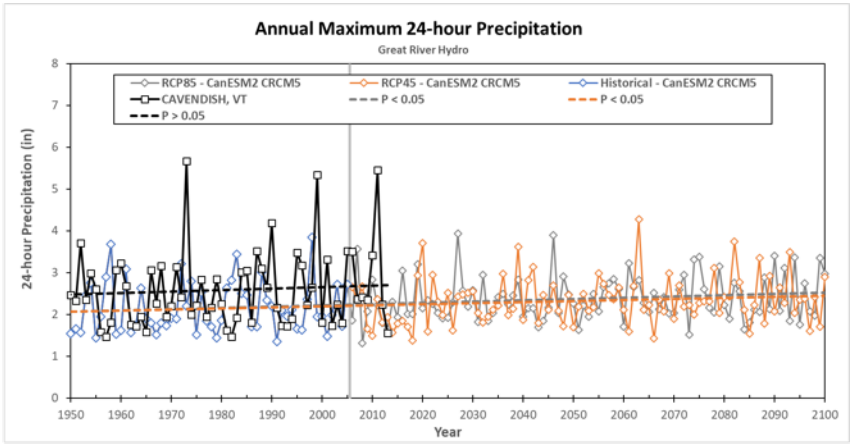



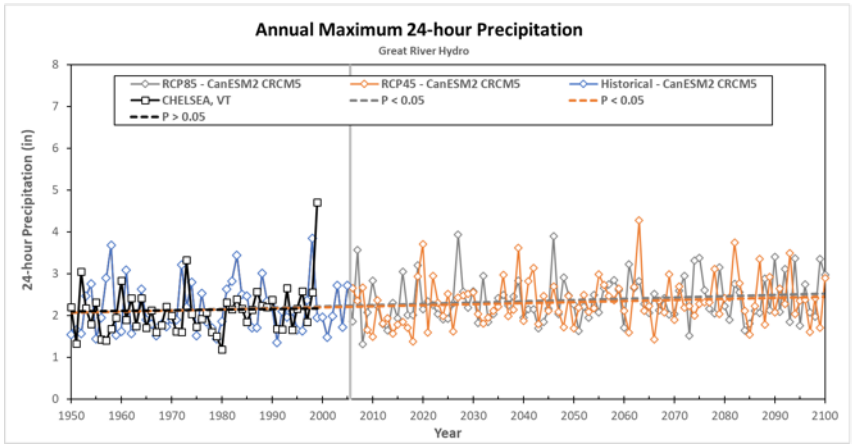



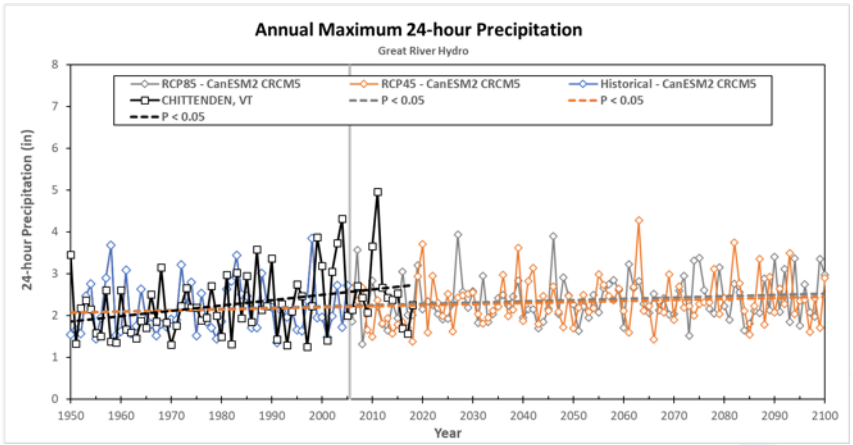



# 1. Station/Projection Trend (1-day) - Model 2

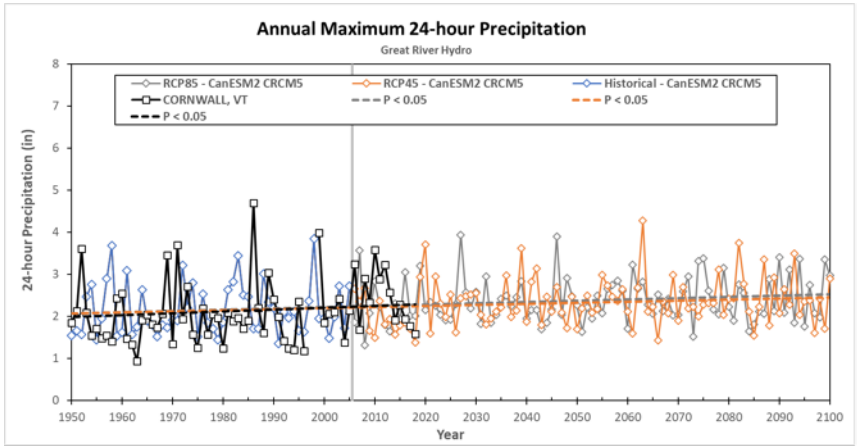


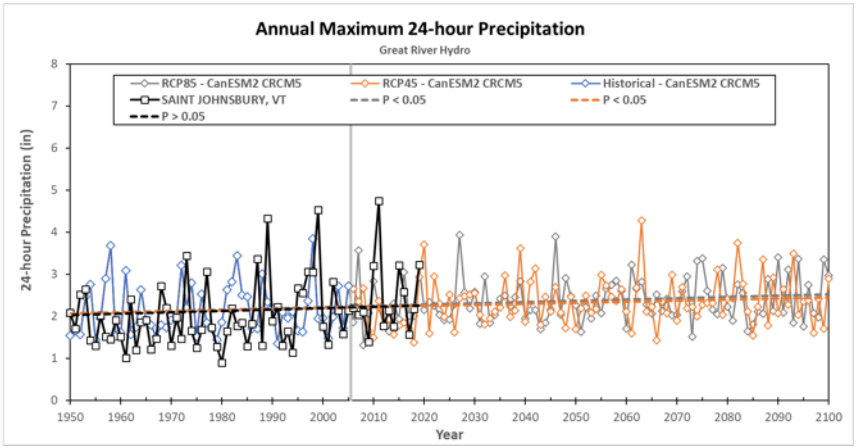



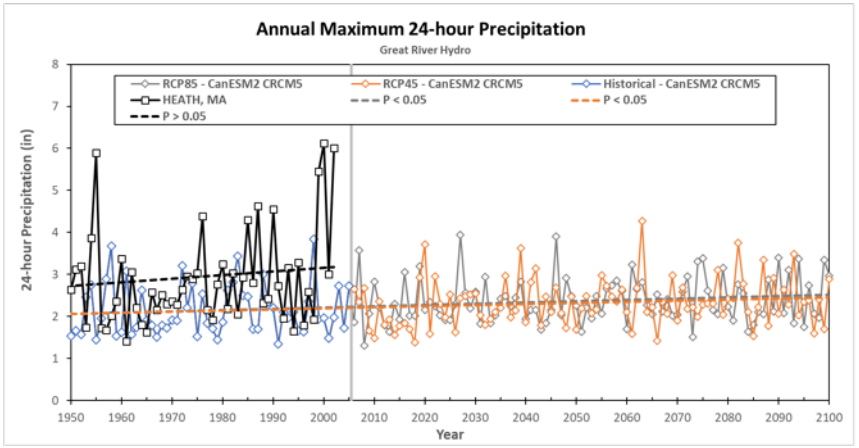



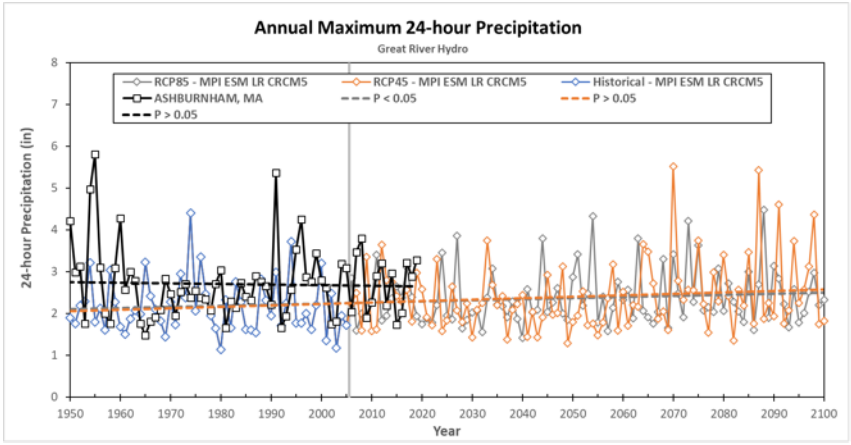
# 1. Station/Projection Trend (1-day) - Model 2

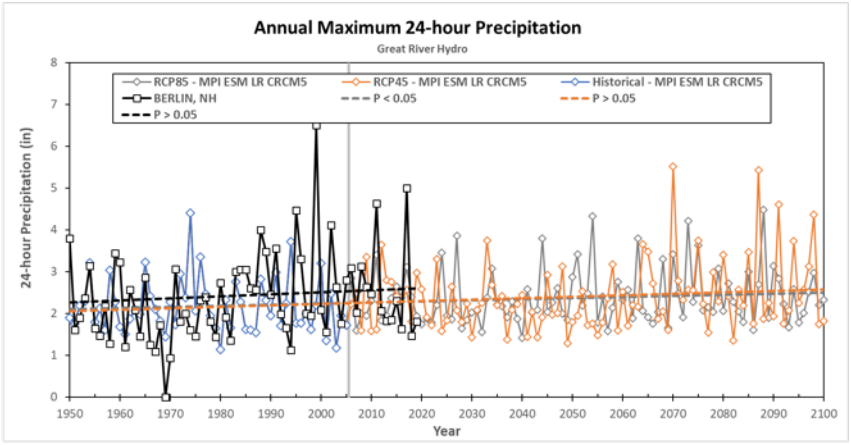


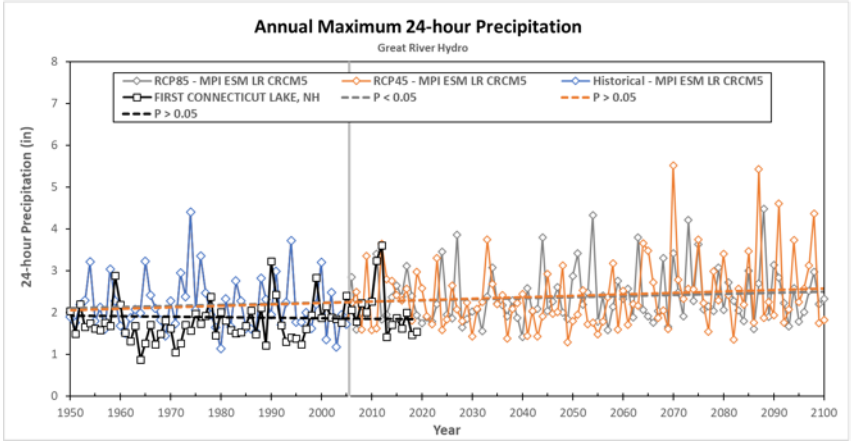



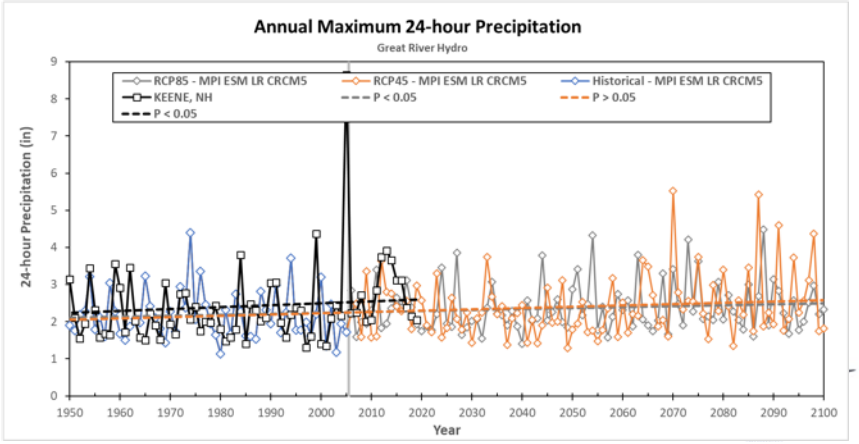



# 1. Station/Projection Trend (1-day) - Model 3

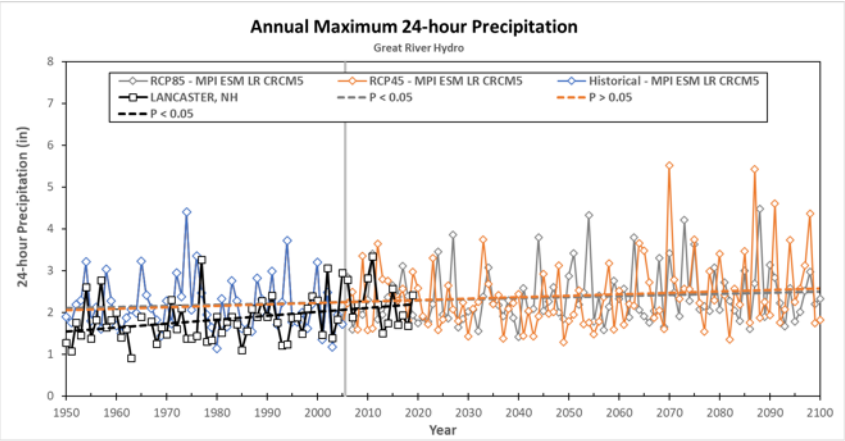


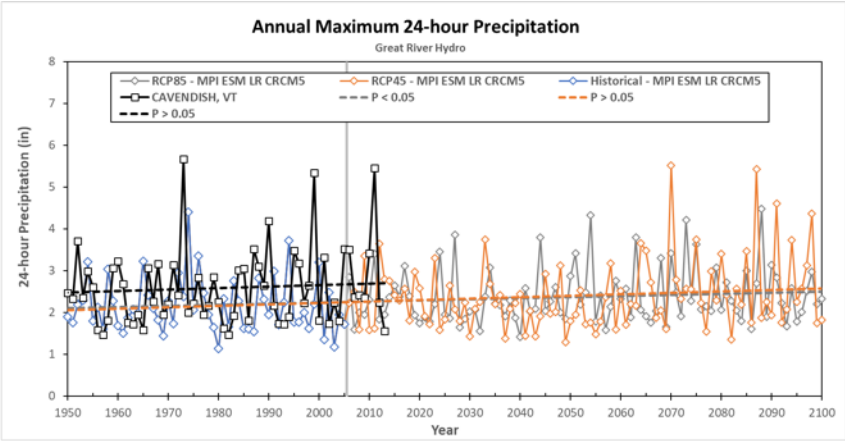



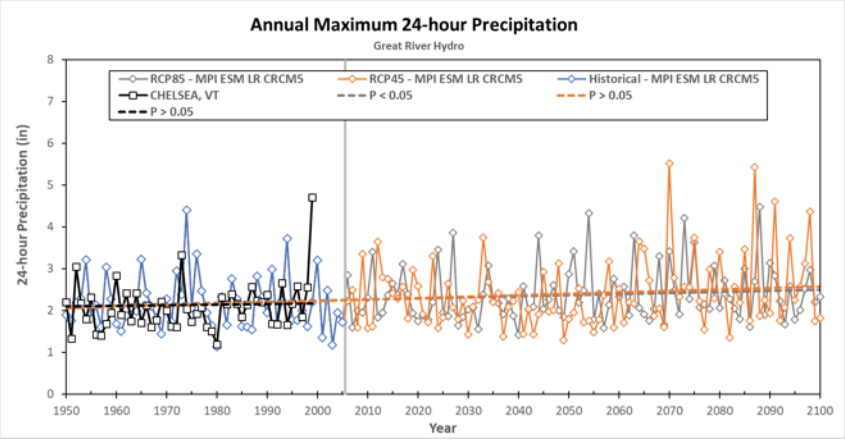



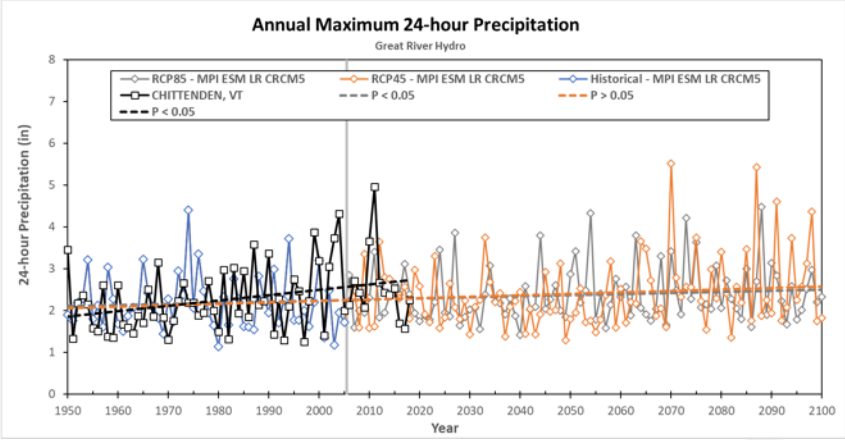



# 1. Station/Projection Trend (1-day) - Model 3

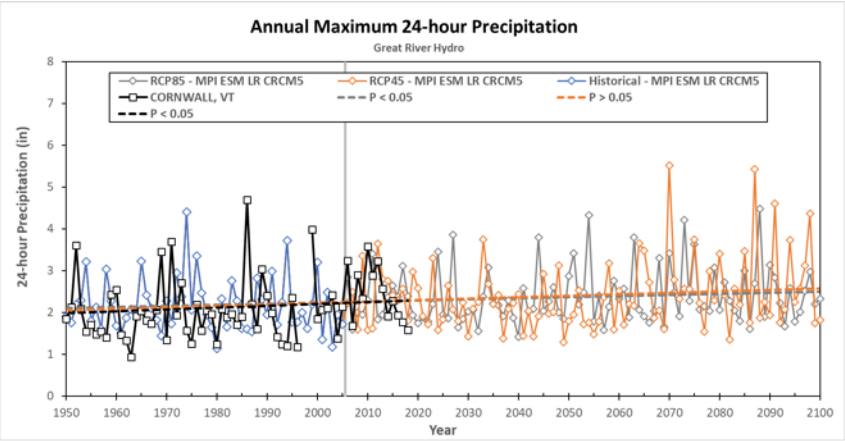


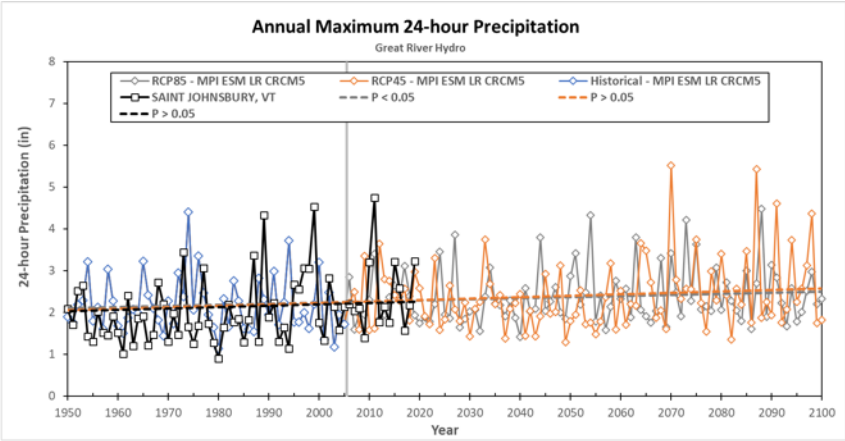



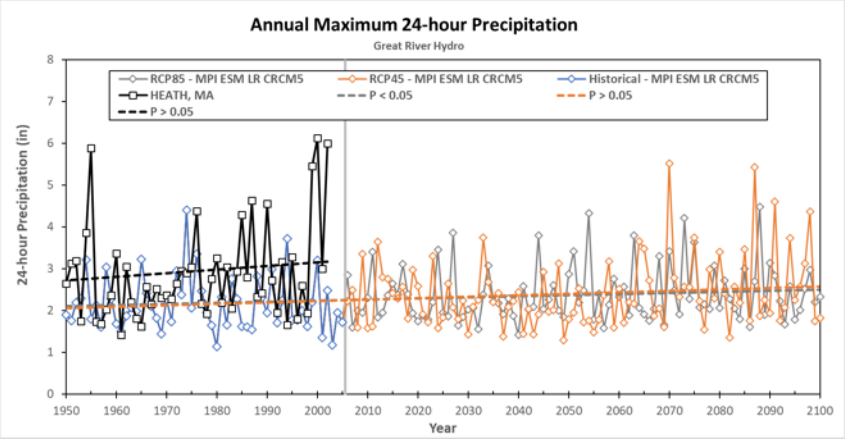



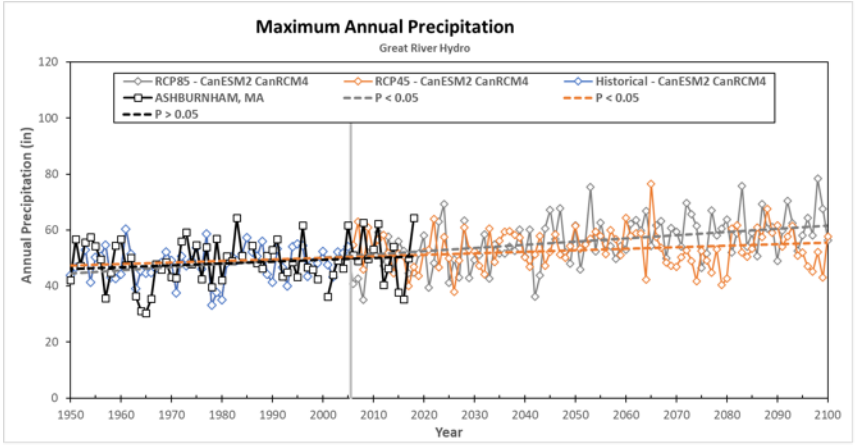
# 1. Station/Projection Trend (1-day) - Model 3

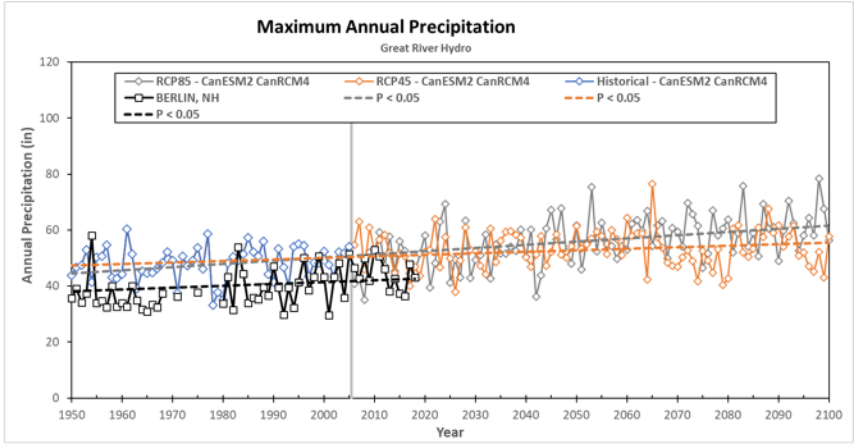


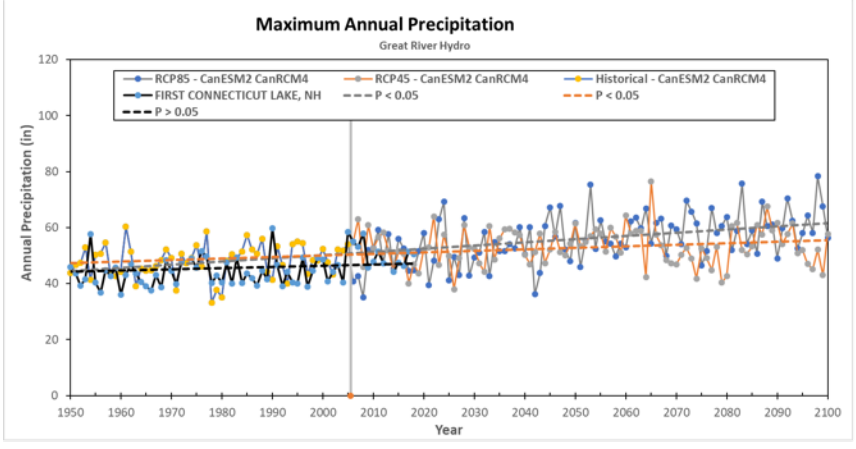



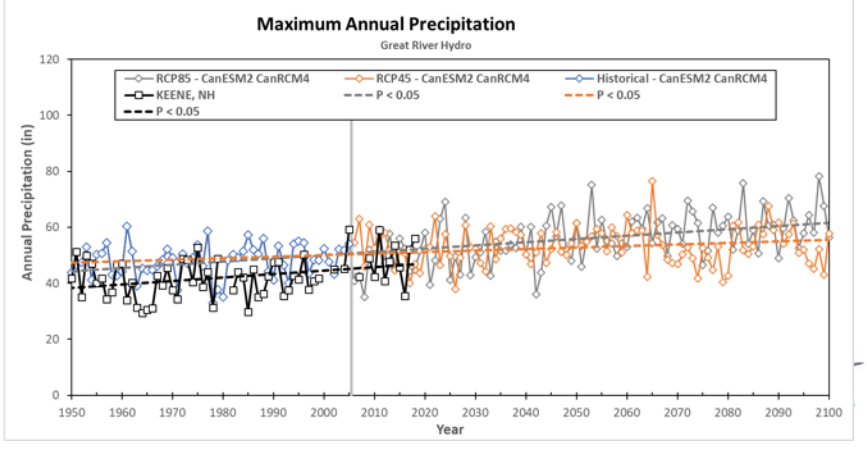



# 1. Station/Projection Trend (Annual) – Model 1

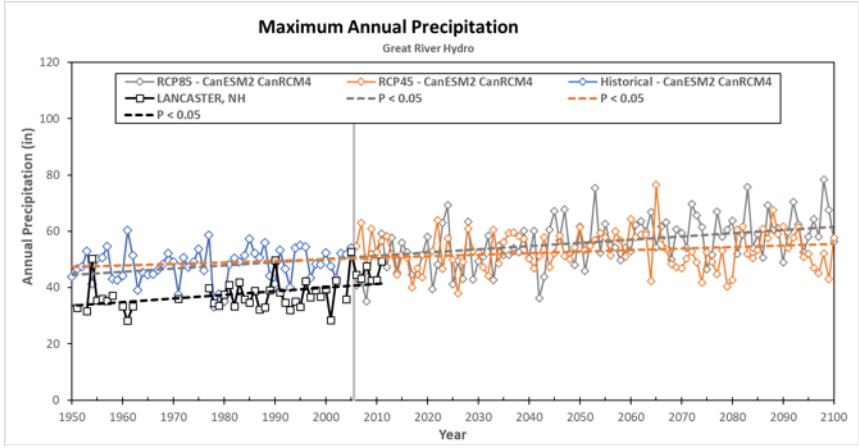


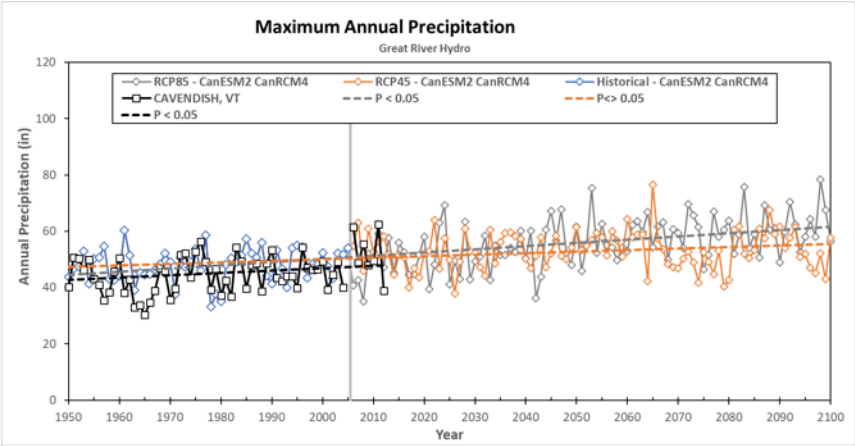



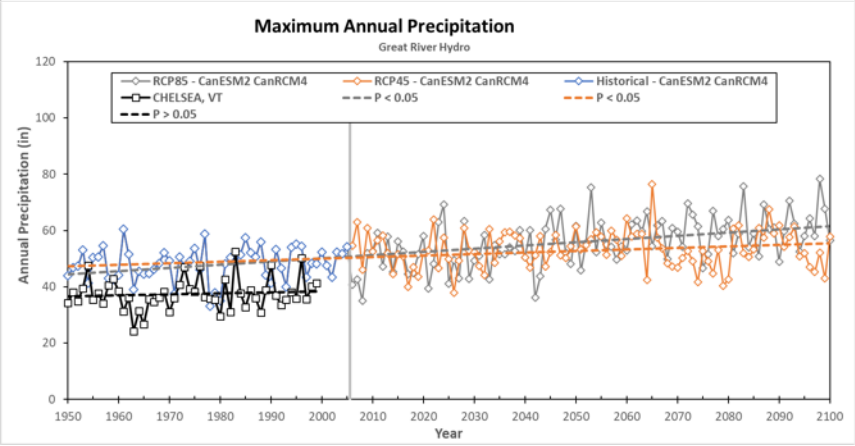



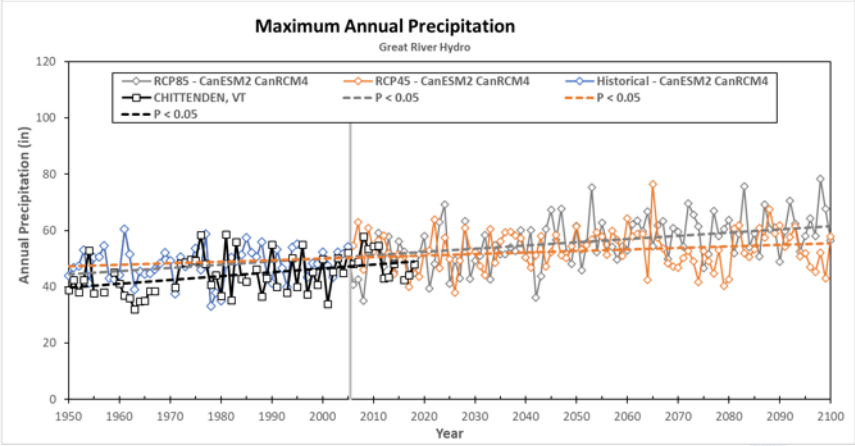



# 1. Station/Projection Trend (Annual) – Model 1

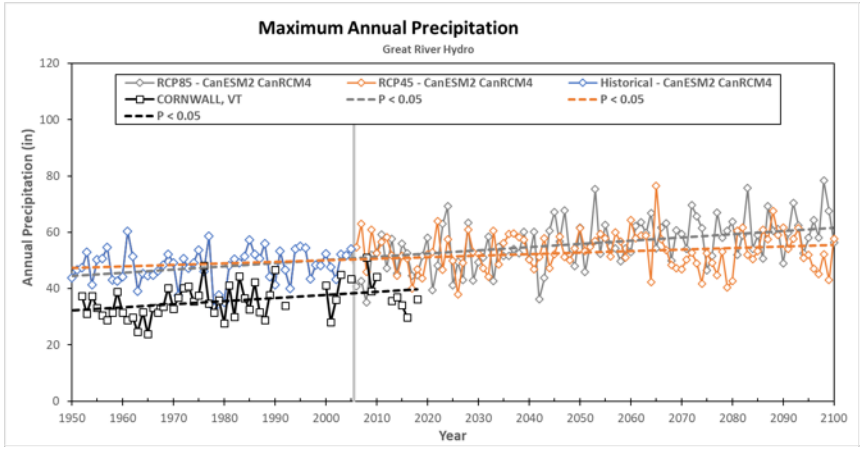


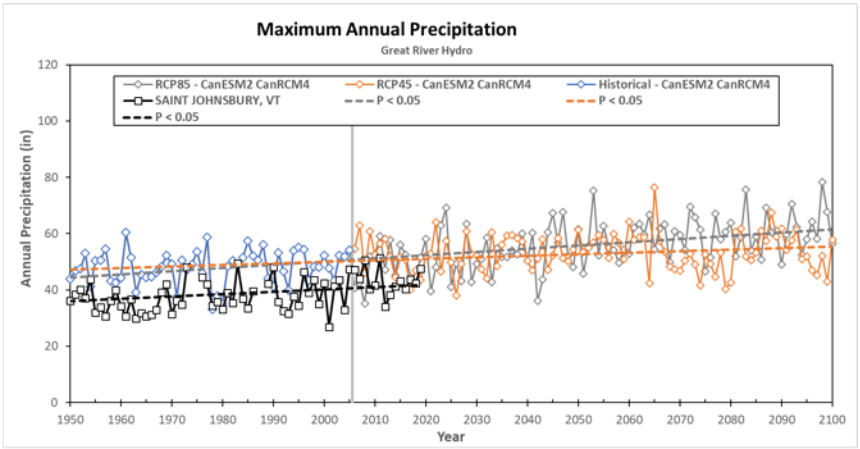



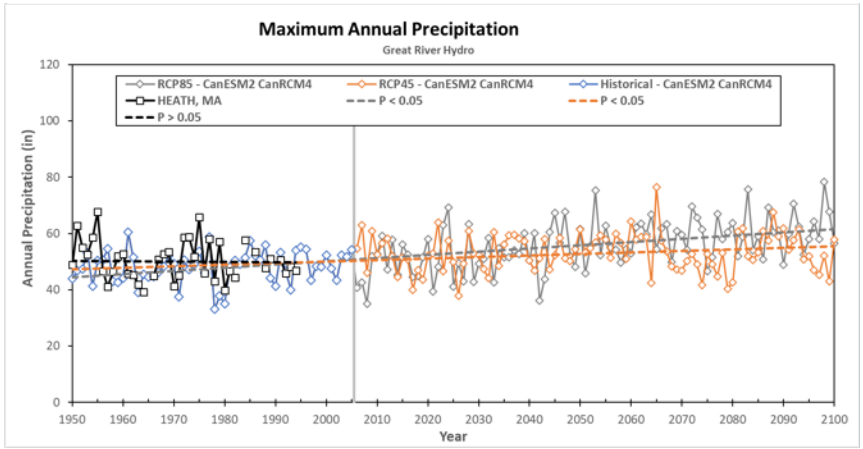



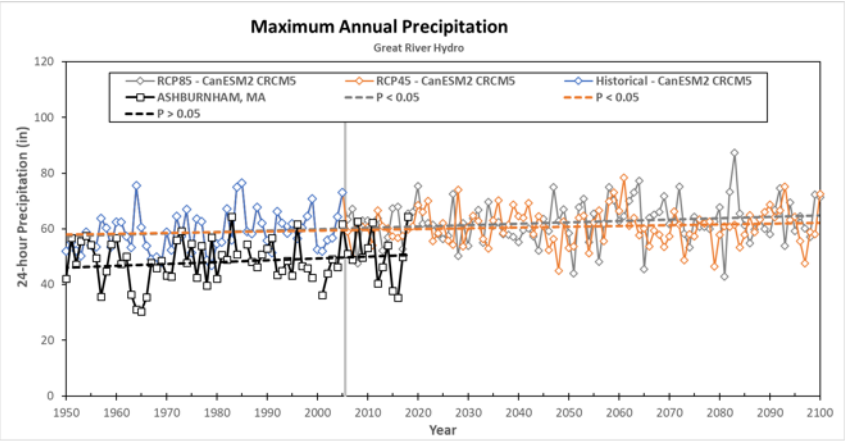
# 1. Station/Projection Trend (Annual) – Model 1

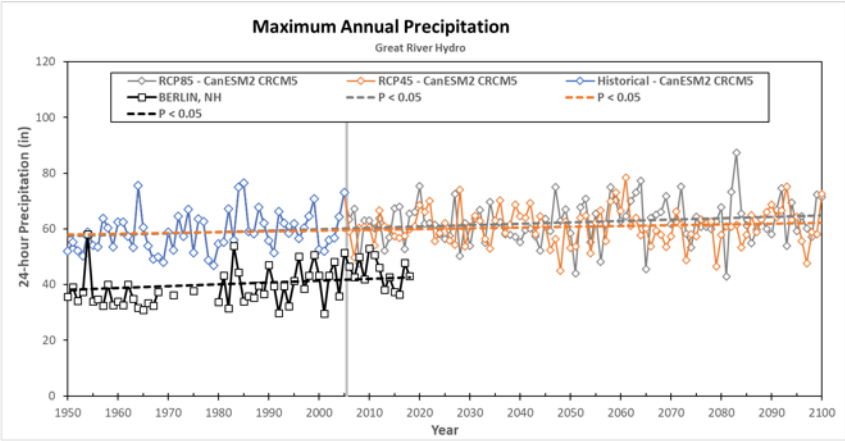


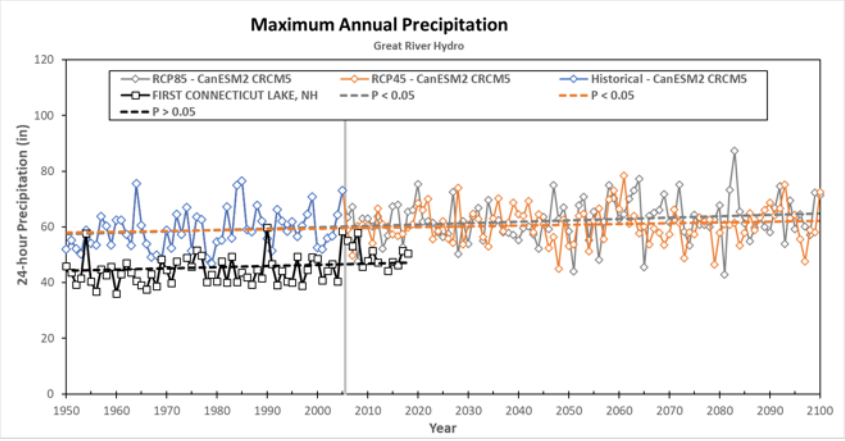



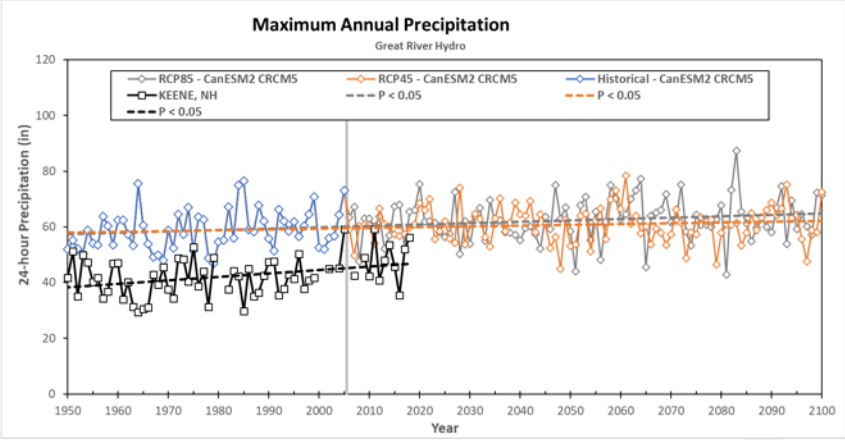



# 1. Station/Projection Trend (Annual) – Model 2

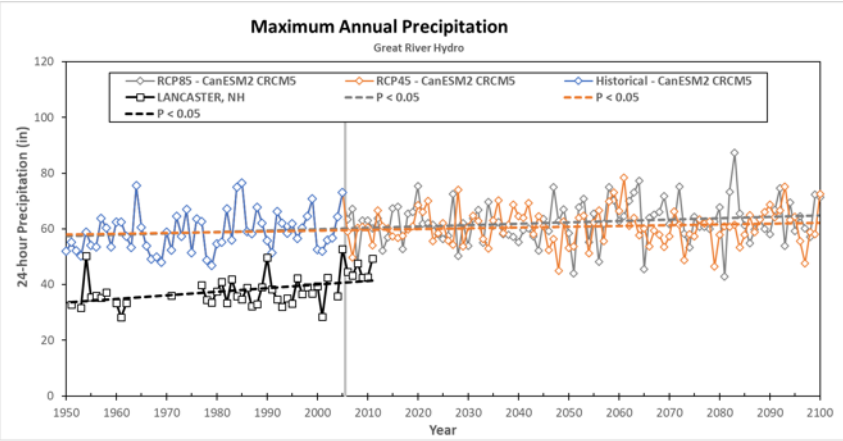


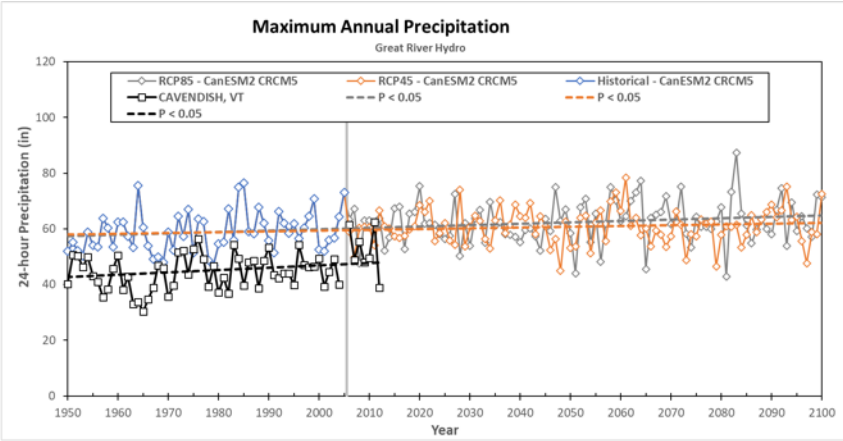



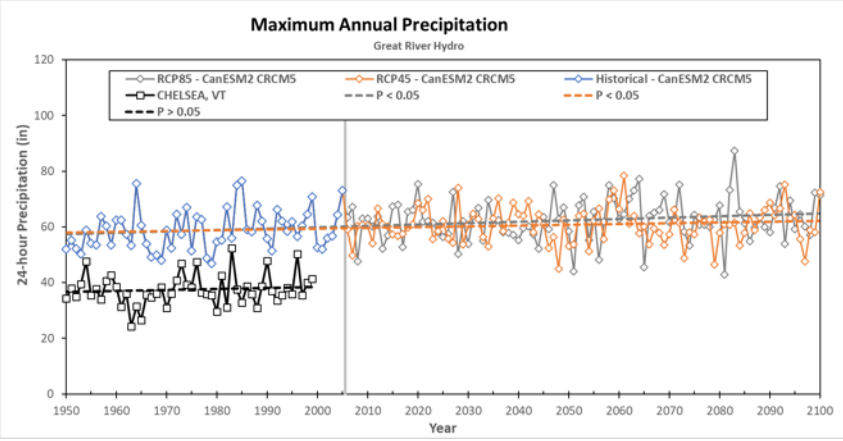



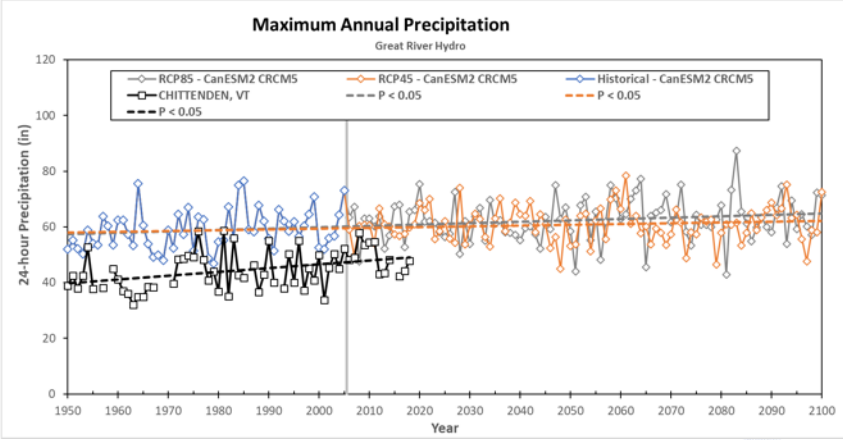



# 1. Station/Projection Trend (Annual) – Model 2

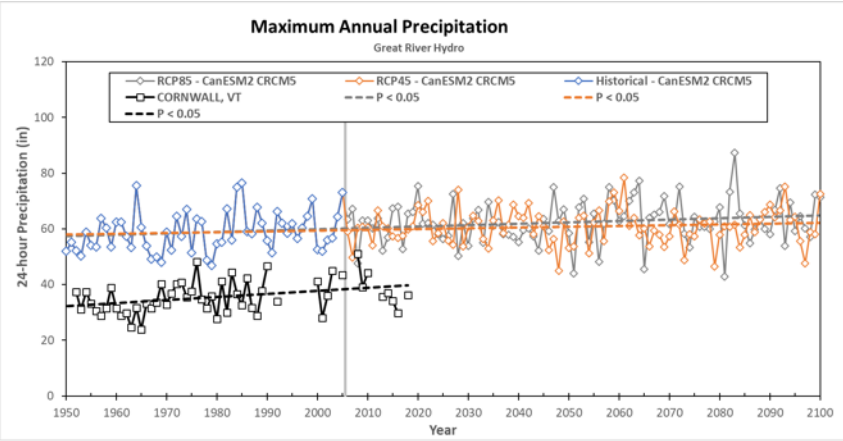


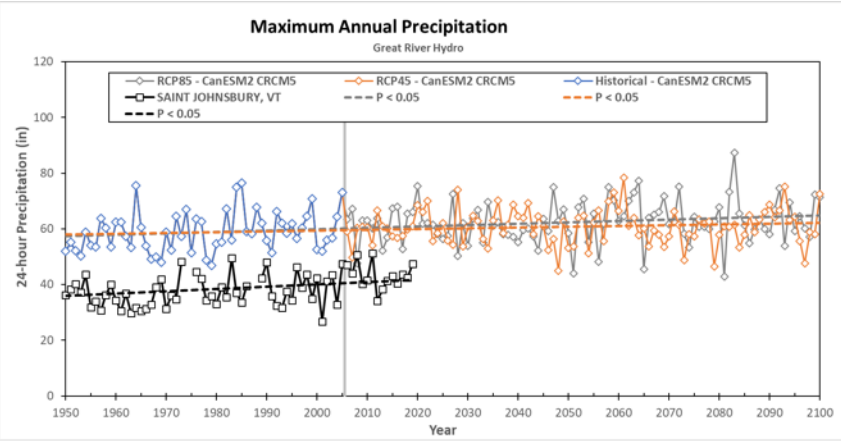



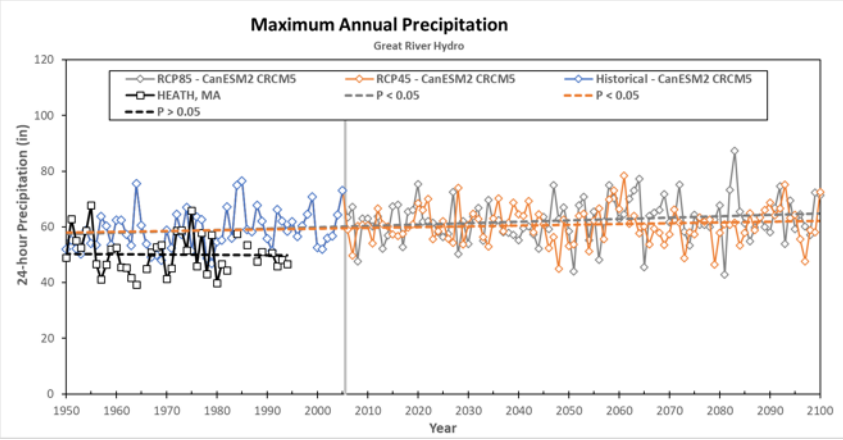



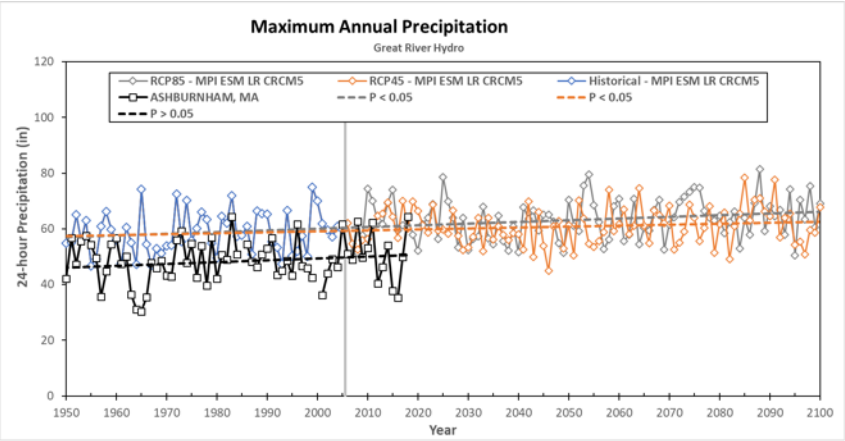
# 1. Station/Projection Trend (Annual) – Model 2

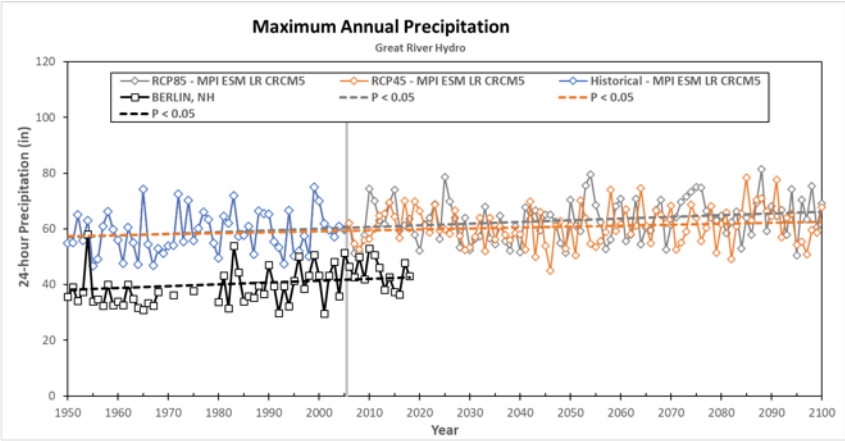


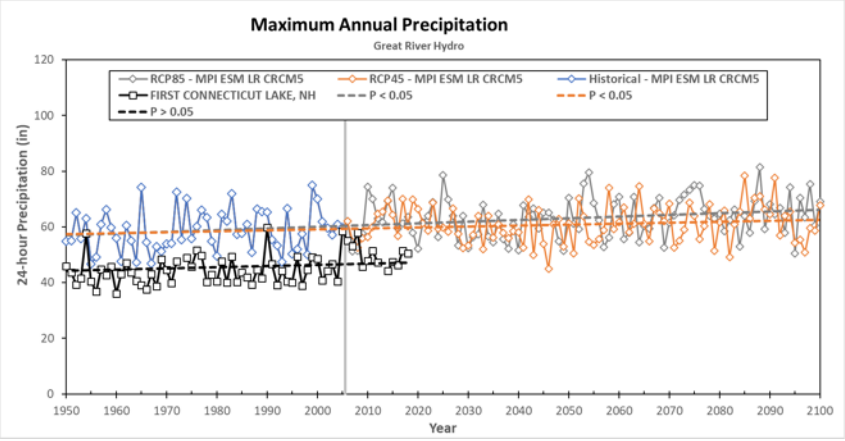



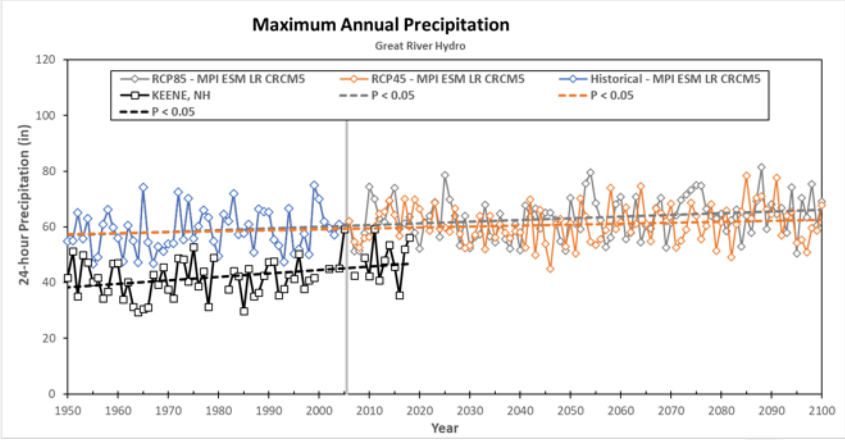



# 1. Station/Projection Trend (Annual) – Model 3

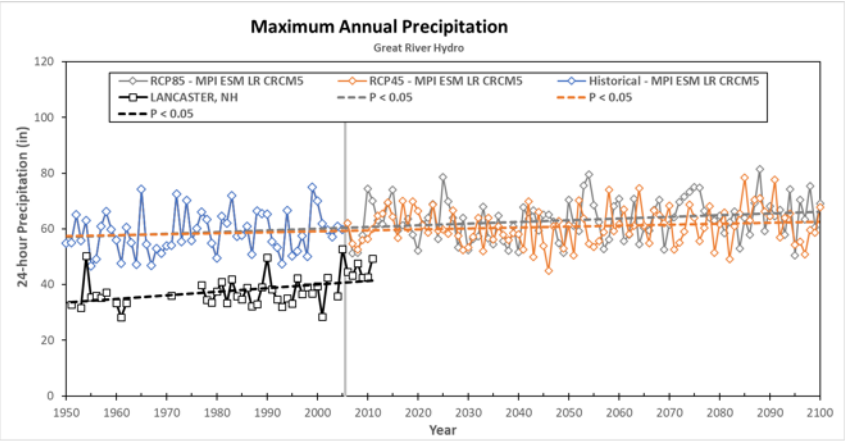


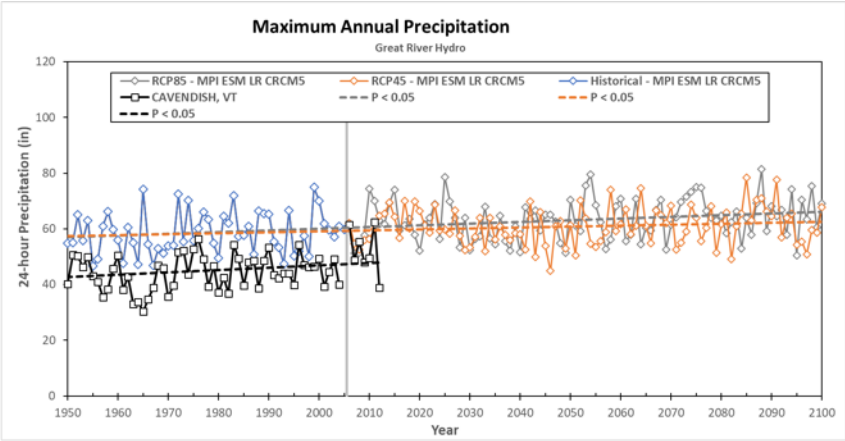



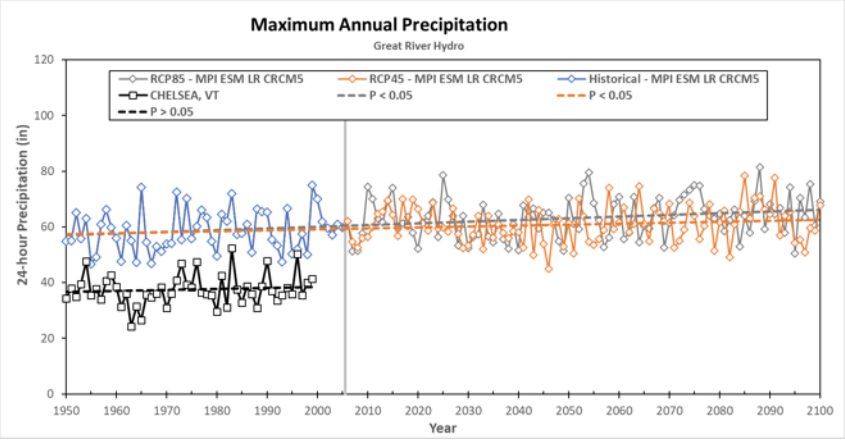



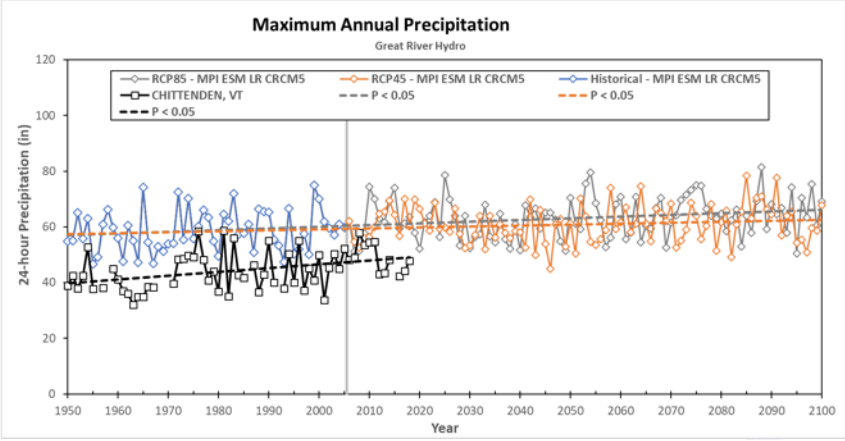



# 1. Station/Projection Trend (Annual) – Model 3

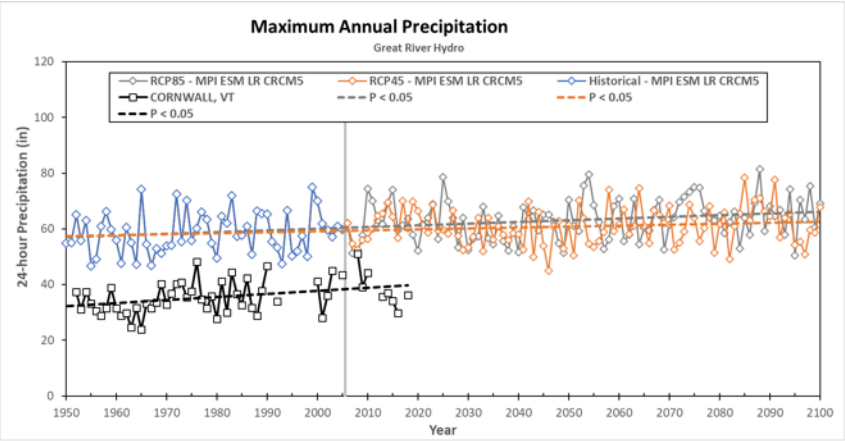


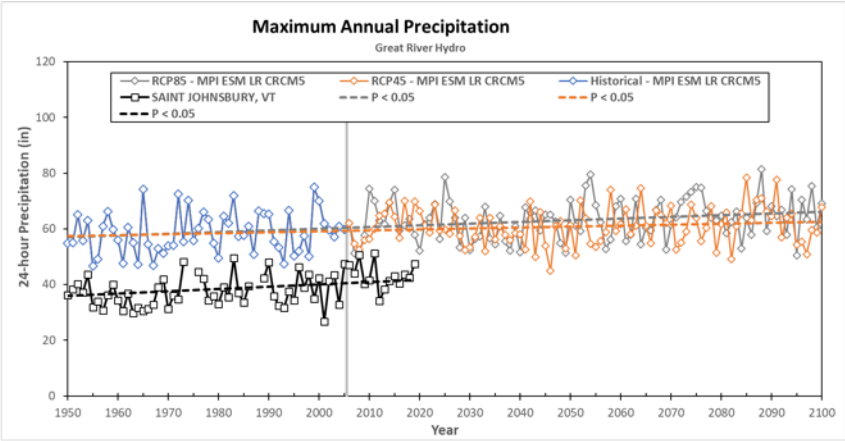



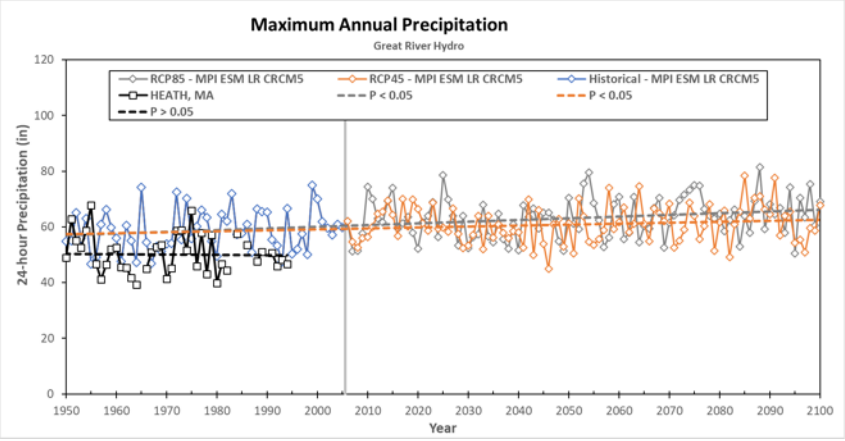



# 1. Station/Projection Trend (Annual) – Model 3



# 3b. $Ppt_{max}$ Analysis (CanESM2 CanRCM4)

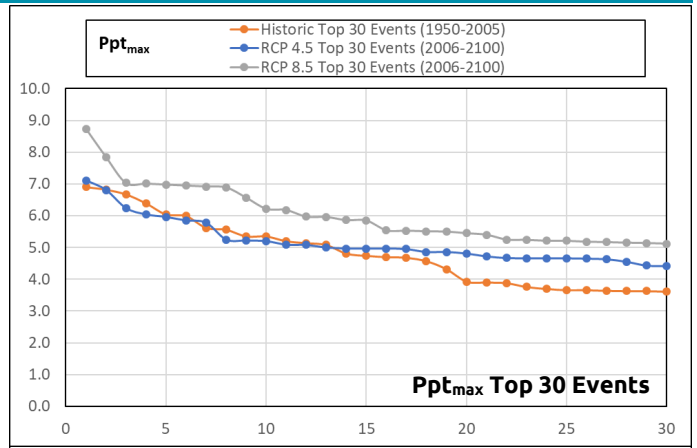
- Estimate **3-day** **$Ppt_{adj}$** for top 30 3-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated **$Ppt_{adj}$** value for each event (**P * r)**

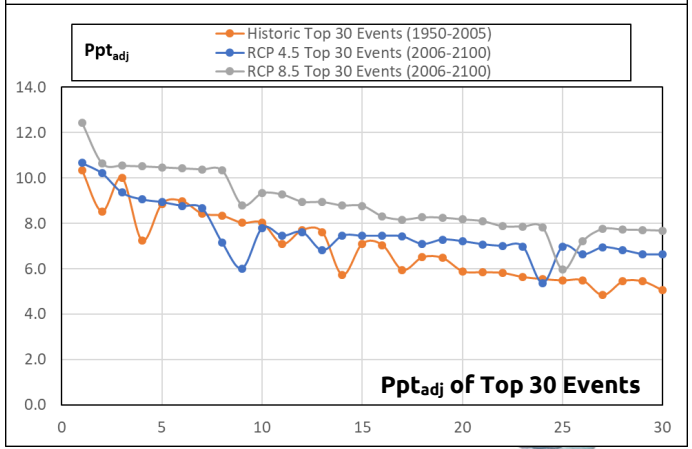
**CanESM2 CanRCM4**

| $Ppt_{max}$ | (in) | Pct Change |
|---|---|---|
| **Historical** | 6.9 | - |
| **RCP45** | 7.1 | 103% |
| **RCP85** | 8.7 | 126% |

| $Ppt_{adj}$ | (in) | rank | Pct Change |
|---|---|---|---|
| **Historical** | 10.4 | 1 | - |
| **RCP45** | 10.7 | 1 | 103% |
| **RCP85** | 12.4 | 1 | 119% |

+++ values represent 3-day not 72-hour



# 3b. $Ppt_{max}$ Analysis (CanESM2 CRCM5)

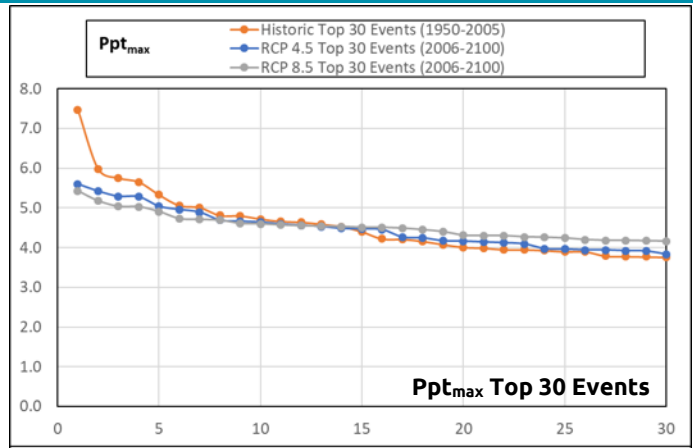
- Estimate **3-day** **$Ppt_{adj}$** for top 30 3-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated **$Ppt_{adj}$** value for each event (**P * r)**

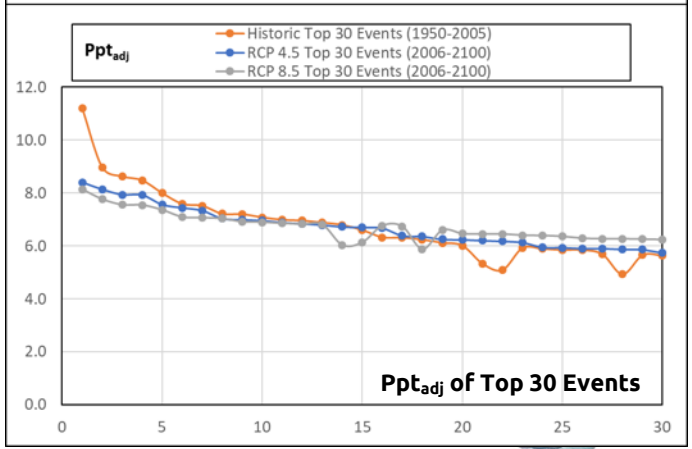
**CanESM2 CRCM5**

| $Ppt_{max}$ | (in) | Pct Change |
|---|---|---|
| **Historical** | 7.5 | - |
| **RCP45** | 5.6 | 75% |
| **RCP85** | 5.4 | 72% |

| $Ppt_{adj}$ | (in) | rank | Pct Change |
|---|---|---|---|
| **Historical** | 11.2 | 1 | - |
| **RCP45** | 8.4 | 1 | 75% |
| **RCP85** | 8.1 | 1 | 72% |

+++ values represent 3-day not 72-hour



# 3b. $Ppt_{max}$ Analysis (MPI ESM LR CRCM5)

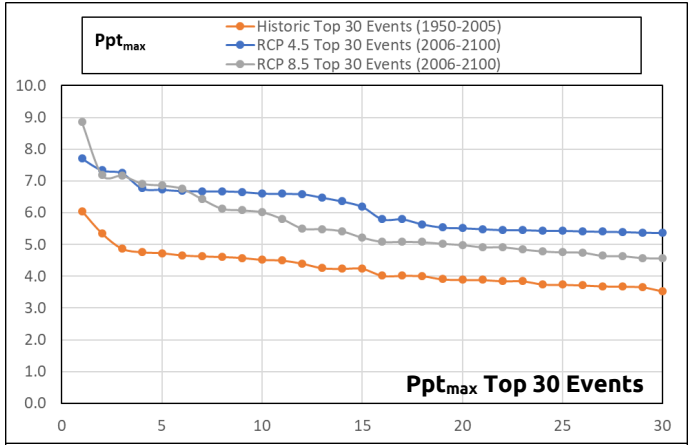
- Estimate **3-day** $Ppt_{adj}$ for top 30 3-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated $Ppt_{adj}$ value for each event (**P * r)**

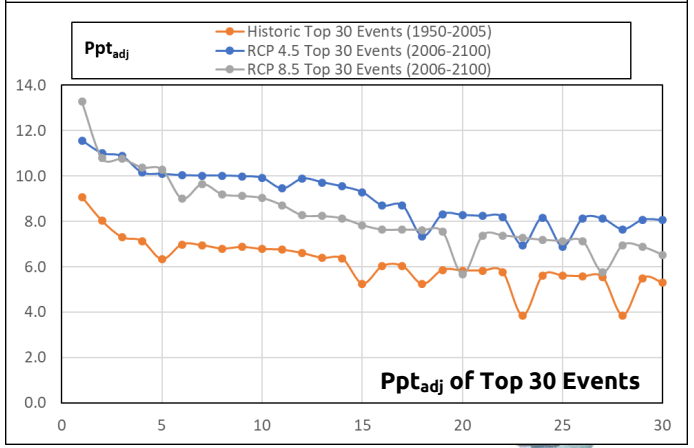
**MPI ESM LR CRCM5**

| $Ppt_{max}$ | (in) | Pct Change |
|---|---|---|
| **Historical** | 6.1 | - |
| **RCP45** | 7.7 | 126% |
| **RCP85** | 8.9 | 146% |

| $Ppt_{adj}$ | (in) | rank | Pct Change |
|---|---|---|---|
| **Historical** | 9.1 | 2 | - |
| **RCP45** | 11.6 | 1 | 127% |
| **RCP85** | 13.3 | 1 | 146% |

+++ values represent 3-day not 72-hour



# 4. Summary (Frequency of 1-day and 3-day events)

**Frequency of 1-day and 3-day events greater than 1-, 2-, 3-, 4-, 5-, and 6-inches**