Contribution of environmental forcings to US runoff changes for the period 1950-2010

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Figure S1(a). Comparison between WaterWatch stations and station from Dai’s dataset (Dai et al., 2009). There are 59 stations in total.

Figure S1(b). Comparison between WaterWatch stations and station from Dai’s dataset (Dai et al., 2009). There are 57 stations in total (59 minus the two high leverage points from figure S1(a)).
| MsTMIP Model       | Meteorological Variables Used                                                                 |
|-------------------|------------------------------------------------------------------------------------------------|
| CLM4/CLM4VIC      | Surface Air Temperature, Precipitation, Incoming Longwave Radiation, Incoming Shortwave Radiation, Specific Humidity, Surface Pressure, and Wind Speed |
| ISAM              | Surface Air Temperature, Precipitation, Incoming Longwave Radiation, Incoming Solar Radiation, Specific Humidity, Surface Pressure, and Wind Speed |
| LPJ-wsl           | Surface Air Temperature, Precipitation, Incoming Longwave Radiation, and Incoming Shortwave Radiation |
| VISIT             | Surface Air Temperature, Precipitation, Incoming Longwave Radiation, Incoming Shortwave Radiation, Specific Humidity, and Wind Speed |
| TEM6              | Surface Air Temperature, Precipitation, and Incoming Shortwave Radiation                      |

Table S1. Meteorological Data Used by Each MsTMIP Model.
|        | Eastern       | Northern       | Southern       | Western       | US        |
|--------|---------------|----------------|----------------|---------------|-----------|
|        | 0.891         | 0.917          | 0.904          | 0.899         | 0.921     |
|        | (0.72, 0.576, | (0.759, 0.683, | (0.736, 0.586, | (0.885, 0.832, | (0.751, 0.704, |
|        | 0.889, 0.86,  | 0.841, 0.832,  | 0.925, 0.799,  | 0.906, 0.797,  | 0.852, 0.875, |
|        | 0.65, 0.905)  | 0.829, 0.784)  | 0.671, 0.858)  | 0.865, 0.877)  | 0.718, 0.922) |

|        | DJF           |                |                |                |           |
|--------|---------------|----------------|----------------|----------------|-----------|
|        | 0.848         | 0.8             | 0.913          | 0.896          | 0.87      |
|        | (0.619, 0.648,| (0.656, 0.471,  | (0.762, 0.693,  | (0.892, 0.878,  | (0.728, 0.746, |
|        | 0.914, 0.653, | 0.843, 0.389,  | 0.92, 0.806,   | 0.914, 0.748,  | 0.901, 0.684, |
|        | 0.638, 0.781) | 0.649, 0.466)  | 0.674, 0.852)  | 0.903, 0.822)  | 0.683, 0.78) |

|        | MAM           |                |                |                |           |
|--------|---------------|----------------|----------------|----------------|-----------|
|        | 0.878         | 0.878          | 0.910          | 0.887          | 0.916     |
|        | (0.732, 0.513,| (0.717, 0.685,  | (0.671, 0.62,  | (0.826, 0.831,  | (0.76, 0.665, |
|        | 0.916, 0.781, | 0.822, 0.78,   | 0.914, 0.858,  | 0.875, 0.823,  | 0.899, 0.841, |
|        | 0.741, 0.892) | 0.671, 0.779)  | 0.674, 0.9)    | 0.797, 0.82)   | 0.812, 0.913) |

|        | JJA           |                |                |                |           |
|--------|---------------|----------------|----------------|----------------|-----------|
|        | 0.859         | 0.9             | 0.754          | 0.739          | 0.789     |
|        | (0.764, 0.622,| (0.611, 0.67,  | (0.552, 0.452,  | (0.613, 0.444,  | (0.551, 0.555, |
|        | 0.87, 0.724, | 0.84, 0.703,   | 0.786, 0.612,  | 0.35, 0.738,   | 0.644, 0.644, |
|        | 0.731, 0.76)  | 0.783, 0.576)  | 0.638, 0.442)  | 0.272, 0.637)  | 0.701, 0.713) |

|        | SON           |                |                |                |           |
|--------|---------------|----------------|----------------|----------------|-----------|
|        | 0.891         | 0.897          | 0.752          | 0.863          | 0.891     |
|        | (0.788, 0.706,| (0.761, 0.768,  | (0.711, 0.496,  | (0.853, 0.673,  | (0.802, 0.67, |
|        | 0.885, 0.774, | 0.857, 0.75,   | 0.769, 0.673,  | 0.819, 0.743,  | 0.844, 0.765, |
|        | 0.554, 0.837) | 0.782, 0.807)  | 0.708, 0.644)  | 0.759, 0.812)  | 0.542, 0.827) |

Table S2. R-Squared for Each Season Using WaterWatch and ALL. Results are for the model ensemble mean and the values shown in parenthesis correspond to the values for the individual models (CLM4, CLM4VIC, ISAM, LPJ-wsl, VISIT, TEM6).
Figure S2. Spatial Patterns of Trends and Dominant Forcings using Pre-whitened 5-year Means from WaterWatch and MsTMIP Multi-Model Ensemble Mean (MME) Forcings. (a-f) WaterWatch and MsTMIP MME pre-whitened 5-year mean runoff trends for 1950-2010, (mm/yr)/5 years with dots representing grid cells with significant trends ($\alpha = 0.05$, Mann-Kendall). The ‘zyp’ R package function based on Zhang (1999) was used to obtain the pre-whitened 5-year means and their corresponding Theil-Sen trends and Mann-Kendall Significance (Kendall, 1975; Mann, 1945; Sen, 1968; Theil, 1950). (g) Dominant forcing when the trend values of CLMT, CO2, NDEP, and LULCC are compared to ALL. Lighter (darker) colors represent negative (positive) trends whereas white grid cells show spaces where the sign of the trends for the forcings disagreed with the ALL forcing. (h) Same as (g), but CLMT is not included.
Figure S3. SYNMAP Vegetation Type Trend using Theil-Sen (Sen, 1968; Theil, 1950). Trends are for the percent plant functional type of each cell for (a) trees and (b) crops.
**Figure S4.** Dominant Season. The dominant season is the season that has the largest trend which has the same sign as the trend for ALL. White grid cells show locations where the sign of the trends for the seasons disagreed with the ALL forcing.
Figure S5. Spatial Pattern of Trends for DJF Runoff from WaterWatch and MsTMIP Multi-Model Ensemble Mean (MME) Forcings and Dominant Forcings. (a-f) WaterWatch and MsTMIP MME DJF runoff trends for 1950-2010, mm/yr² with dots representing grid cells with significant trends ($\alpha = 0.05$, Mann-Kendall). (g) Dominant forcing when the trend values of CLMT, CO2, NDEP, and LULCC are compared to ALL. Lighter (darker) colors represent negative (positive) trends whereas white grid cells show spaces where the sign of the trends for the forcings disagreed with the ALL forcing. (h) Same as (g), but CLMT is not included.
Figure S6. Spatial Pattern of Trends for MAM Runoff from WaterWatch and MsTMIP Multi-Model Ensemble Mean (MME) Forcings and Dominant Forcings. (a-f) WaterWatch and MsTMIP MME MAM runoff trends for 1950-2010, mm/yr$^2$ with dots representing grid cells with significant trends ($\alpha = 0.05$, Mann-Kendall). (g) Dominant forcing when the trend values of CLMT, CO2, NDEP, and LULCC are compared to ALL. Lighter (darker) colors represent negative (positive) trends whereas white grid cells show spaces where the sign of the trends for the forcings disagreed with the ALL forcing. (h) Same as (g), but CLMT is not included.
Figure S7. Spatial Pattern of Trends for JJA Runoff from WaterWatch and MsTMIP Multi-Model Ensemble Mean (MME) Forcings and Dominant Forcings. (a-f) WaterWatch and MsTMIP MME JJA runoff trends for 1950-2010, mm/yr² with dots representing grid cells with significant trends (α = 0.05, Mann-Kendall). (g) Dominant forcing when the trend values of CLMT, CO2, NDEP, and LULCC are compared to ALL. Lighter (darker) colors represent negative (positive) trends whereas white grid cells show spaces where the sign of the trends for the forcings disagreed with the ALL forcing. (h) Same as (g), but CLMT is not included.
**Figure S8.** Spatial Pattern of Trends for SON Runoff from WaterWatch and MsTMIP Multi-Model Ensemble Mean (MME) Forcings and Dominant Forcings. (a-f) WaterWatch and MsTMIP MME SON runoff trends for 1950-2010, mm/yr² with dots representing grid cells with significant trends ($\alpha = 0.05$, Mann-Kendall). (g) Dominant forcing when the trend values of CLMT, CO2, NDEP, and LULCC are compared to ALL. Lighter (darker) colors represent negative (positive) trends whereas white grid cells show spaces where the sign of the trends for the forcings disagreed with the ALL forcing. (h) Same as (g), but CLMT is not included.
S9(a). Root Mean Square Difference (RMSD) Values between WaterWatch and ALL Annual Totals. The RMSD values were normalized by the RMSD value corresponding to approximately the 99th percentile of values. The 99th percentile was chosen rather than the maximum due to extreme values.

**Figure S9(b).** DJF RMSD. This figure is the same as figure S9(a) but instead of annual totals, the DJF season was used to determine the RMSD values.
Figure S9(c). MAM RMSD. This figure is the same as figure S9(a) but instead of annual totals, the MAM season was used to determine the RMSD values.

Figure S9(d). JJA RMSD. This figure is the same as figure S9(a) but instead of annual totals, the JJA season was used to determine the RMSD values.
Figure S9(e). SON RMSD. This figure is the same as figure S9(a) but instead of annual totals, the SON season was used to determine the RMSD values.
**Figure S10.** Regional Trends of Annual Total Values for the MsTMIP MME (black bars) and Each Individual Model. Each black bar denotes the beginning of a region. The regions are ordered as follows: east, north, south, west, and US as a whole. The orders of the individual models are:

| Category | Models                       |
|----------|------------------------------|
| ALL      | CLM4, CLM4VIC, ISAM, LPJ-wsl, VISIT, TEM6 |
| CLMT     | CLM4, CLM4VIC, ISAM, LPJ-wsl, VISIT, TEM6 |
| CO2      | CLM4, CLM4VIC, ISAM, LPJ-wsl, VISIT, TEM6 |
| NDEP     | CLM4, CLM4VIC, TEM6          |
| LULCC    | CLM4, CLM4VIC, ISAM, LPJ-wsl, TEM6 |
Figure S11(a). Spatial Distributions of D&A Scaling Factors for DJF. The D&A methodology was applied to each grid cell. Not detected (purple) denotes a scaling factor whose corresponding 95% confidence interval was less than zero or included zero. If the 95% confidence interval was greater than zero but did not include one, the forcing was detected (yellow). A positive confidence interval was labeled as attributed (pink) if it included one.

Figure 11(b). Same as figure S11(a) but for MAM.
Figure 11(c). Same as figure S11(a) but for JJA.

Figure 11(d). Same as figure S11(a) but for SON.
Figure S12(a). Autocorrelation Plot of the Residuals from the Regression using Northern Annual Totals. Blue lines represent the bounds for white noise.

Figure S12(b). Autocorrelation Plot of the Residuals from the Regression using Southern MAM.
Figure S12(c). Autocorrelation Plot of the Residuals from the Regression using Northern JJA.

Figure S12(d). Autocorrelation Plot of the Residuals from the Regression using US JJA.
Figure S12(e). Autocorrelation Plot of the Residuals from the Regression using Northern SON.
Figure S13. Scaling Factor Estimates (black asterisks) and Corresponding 95% Confidence Intervals for Annual Totals (a) and Seasonal Means (b-e) Using the MME of CLM4, CLM4VIC, and TEM6. Dashed lines denote the values 0 and 1. Thick gray lines separate the results into different regions. A red asterisk in the bottom left corner for a region denotes where the residuals were autocorrelated.
Figure S14. Scaling factor estimates (asterisk) and corresponding 95% confidence intervals for 5-year means of the annual totals (a) and seasonal means (b-e). Dashed lines denote the values 0 and 1. Thick gray lines separate the results into different regions. Red asterisk in the bottom left corner for a region denotes where the residuals were autocorrelated.
Figure S15(a-e). CRU-NCEP vs PRISM Annual Precipitation for Each Region and the US CONUS Over the Period 1950 – 2010. Included within each figure is the 1950 – 2010 time series, mean value for the time period, Theil-Sen trend estimate, and Mann-Kendall Significance (Kendall, 1975; Mann, 1945; Sen, 1968; Theil, 1950). A significant trend is denoted by red dots on the trend line.
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