The Importance of Anthropogenic Aerosols to Recent Trends in Southwest US Precipitation

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1. Abstract

Observations show an increase in precipitation over the Southwest United States (SW U.S.) from 1950-1980, followed by a decrease from 1980-2009. Model simulations from the Coupled Model Inter-comparison Project v5 (CMIP5) also yield similar multi-decadal variability, with anthropogenic aerosols only (CMIP5-AA) simulations accounting for most of the signal. Moreover, CMIP5-AA reproduces the observed Sept-Oct-Nov maximum in SW U.S. precipitation trends. We associate these precipitation changes to the evolution of the leading pattern of sea surface temperature variability in the North Pacific, the Pacific Decadal Oscillation (PDO). A positive PDO phase is associated with equatorward displacement of the Northern Hemisphere mid-latitude jet stream, which tends to bring more precipitation to the SW U.S. The negative PDO phase exhibits the opposite teleconnection. Both observations and models, particularly models forced by anthropogenic aerosols only, yield a reversal in the trend of the PDO, consistent with the SW U.S. precipitation changes. Our results suggest that anthropogenic aerosols have driven recent trends in SW U.S. precipitation by modulating the PDO, and its associated atmospheric teleconnections.

2. Data and Methods

HadISST is used for the observed SSTs (Rayner et al., 2002), while University of Delaware (UDEL) precipitation data is used for precipitation. Model data comes from Coupled Model Inter-comparison Project Version 5.0 (CMIP5). In this study, we used CMIP5 all forcing (CMIP5-ALL) experiments as well as CMIP5 aerosol only forcing (CMIP5-AA) experiments. We first selected the subset of models that have aerosol only runs to maintain consistency between CMIP5-ALL and CMIP5-AA models. The PDO is derived as the leading principal component (PC) of monthly SST anomalies in the North Pacific Ocean, poleward of 20^0N. Models are selected based on their ability to reproduce the observed PDO pattern. We selected the models that have a spatial correlation with the observed PDO pattern of 0.7 or higher in the North Pacific (20-50^0N). With this criterion, we selected 10 CMIP5-ALL models, yielding a total of 32 realizations. Using the same criterion, we selected the same 10 CMIP5-AA models, yielding 18 realizations. We then averaged all realizations for CMIP5-ALL, and CMIP5-AA, to get the corresponding ensemble means.

A recent study (Dai, 2013) showed the influence of the Inter-decadal Pacific Oscillation (IPO) on SW U.S. precipitation. Allen et al. (2013) showed that a strong relationship exists between the PDO and tropical expansion. Therefore, it is important to look at the change in atmospheric circulation associated with the PDO and its impact on the precipitation pattern. Tropical expansion is associated with poleward movement of large-scale atmospheric circulation systems, such as jet streams, which could shift precipitation patterns; a positive PDO phase (cold Northern Hemispheric mid-latitude SST anomalies and warm tropical eastern Pacific SST anomalies) is associated with equatorward displacement of the NH mid-latitude jet stream, which tends to bring more precipitation to the SW U.S. (Mantua et al. 1997). We therefore looked at the zonal wind (U) at 300 hPa, which is typically used as a measure of the jet streams. NCEP/NCAR Reanalysis 1 (NCEP) is used as the observed U-wind data whereas U-wind from CMIP5-ALL and CMIP5-AA are used for the comparison. The time series are first smoothed with a 9-yr running mean for the analysis.

3. Results

Precipitation Trends

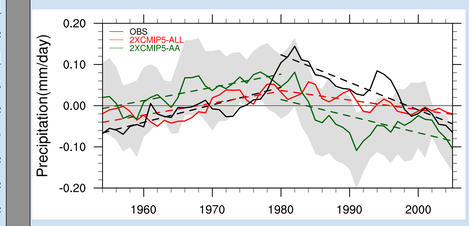

Figure 1. Annual average precipitation anomalies over the Southwest United States (30-40^0N, 105^0-120^0W). Anomalies are calculated relative to 1950-2009 mean. The black line is based on the UDEL precipitation data set. The red and green lines are based on the ensemble average of CMIP5 all forcing (CMIP5-ALL) and CMIP5 aerosol only forcing (CMIP5- AA) experiments respectively. The precipitation for the models is multiplied by a factor of 2. The gray shading represents the standard deviation of 18 CMIP5-AA realizations. The linear trends for 1950-1980 and 1980-2009 are plotted as dashed lines in their respective colors. The trend (mm day^{-1} / decade) and its significance after accounting for autocorrelation (in parentheses) are : **0.04 (99%)** for **OBS**, **0.02 (95%)** for **CMIP5-ALL**, and **0.02 (95%)** for **CMIP5-AA** for 1950-1980. For 1980-2009, the corresponding trends are **-0.07 (99%)** for **OBS**, **-0.01 (99%)** for **CMIP5-ALL**, and **-0.02 (95%)** for **CMIP5-AA**.

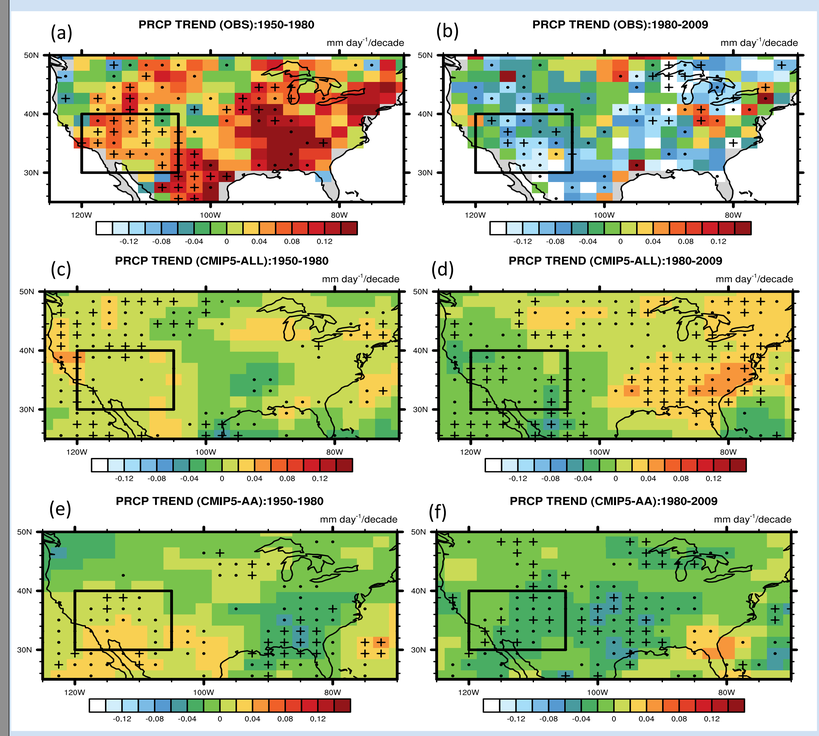

Figure 2. Annual mean precipitation anomaly trends for 1950-1980 and 1980-2009. Panels show the observation (a,b) CMIP5-ALL (c,d) and CMIP5-AA (e,f) ensemble mean. Trend symbols represent significance at 99% (plus) and 95% (dot) confidence level, accounting for autocorrelation. Trend units are in mm day^{-1} /decade. The rectangle represents the area over which precipitation is averaged to get the SW U.S. time series in Figure 1.

SEASON		Trend(1950-1980/1980-2009) PDO	Precipitation
DJF	OBS	**0.206 (95%)/-0.351 (95%)**	**0.043 (99%)**/-0.035 (<90%)
	CMIP5-ALL	**0.223 (95%)/-0.175 (90%)**	**0.027 (99%)**/-0.013 (<90%)
	CMIP5-AA	**0.149 (99%)/-0.183 (90%)**	**0.014 (90%)**/-0.013 (<90%)
MAM	OBS	**0.319 (95%)/-0.283 (99%)**	0.040 (<90%)/**-0.070 (99%)**
	CMIP5-ALL	**0.199 (99%)/-0.170 (90%)**	0.008 (<90%)/0.004 (<90%)
	CMIP5-AA	**0.163 (95%)**/-0.146 (<90%)	0.007 (<90%)/-0.002 (<90%)
JJA	OBS	**0.370 (99%)/-0.352 (95%)**	-0.017 (<90%)/**-0.070 (95%)**
	CMIP5-ALL	**0.239 (95%)/-0.252 (90%)**	0.005 (<90%)/**-0.018 (95%)**
	CMIP5-AA	**0.219 (95%)**/-0.044 (<90%)	0.009 (<90%)/-0.028 (<90%)
SON	OBS	**0.313 (99%)/-0.513 (95%)**	**0.103 (99%)/-0.091 (95%)**
	CMIP5-ALL	**0.278 (95%)/-0.288 (90%)**	0.019 (<90%)/**-0.020 (95%)**
	CMIP5-AA	**0.220 (99%)/-0.100 (95%)**	**0.034 (99%)/-0.040 (99%)**

Table 1: Summary of seasonal PDO and precipitation trends (mm day^{-1} / decade) for 1950-1980 and 1980-2009. Trend significance is shown as percentage in parenthesis.

PDO-Precipitation Correlation

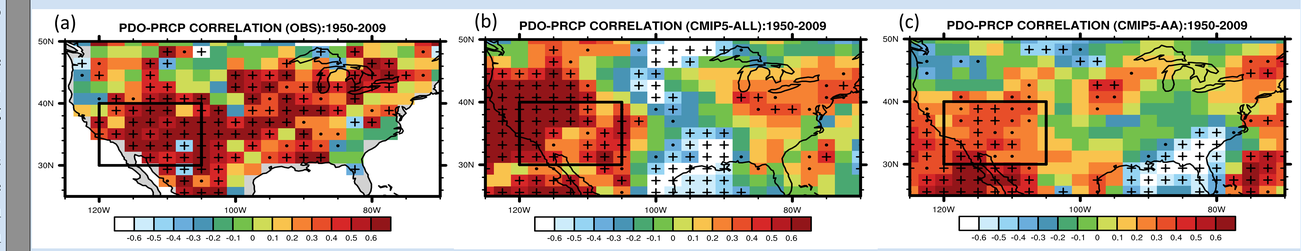

Figure 3. Annual correlation of PDO and precipitation anomaly for the time period 1950-2009. Panel shows observation(a), CMIP5 all forcing ensemble mean (b) and CMIP5 aerosol only forcing ensemble mean(c). Symbols represent significance at 99% (plus) and 95% (dot) confidence level.

PDO Trends

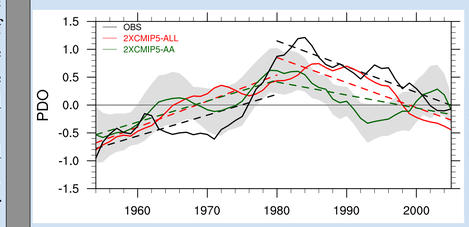

Figure 4. Annual average of the PDO time series. The black line is based on the HadISST SST data set. The red, and green lines are based on the ensemble average of CMIP5 all forcing (CMIP5-ALL) and CMIP5 aerosol only forcing (CMIP5- AA) respectively. The PDO for the models is multiplied by a factor of 2. The gray shading represents the standard deviation of the 18 aerosol only realizations. The linear trends for 1950-1980 and 1980-2009 are plotted as dashed lines. The trend (standard deviation/decade) and its significance after accounting for autocorrelation (in parentheses) are : **0.37 (99%)** for **OBS**, **0.23 (99%)** for **CMIP5-ALL**, and **0.19 (95%)** for **CMIP5-AA** for 1950-1980 time period whereas **-0.46 (95%)** for **OBS**, **-0.22 (90%)** for **CMIP5-ALL**, and **-0.12 (90%)** for **CMIP5-AA** for 1980-2009 time period.

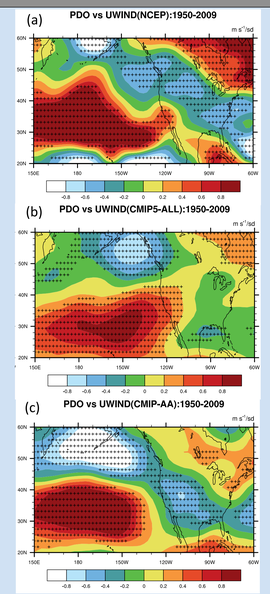

Figure 5: Regression of 300 hPa monthly zonal wind anomalies onto the PDO time series. Panels show observations (a), CMIP5-ALL (b) and CMIP5-AA (c) ensemble mean respectively. Units are in ms^{-1} /sd. Symbol (plus) represents significance at 99% confidence level.

4. Summary and Conclusions

- The CMIP5-ALL ensemble mean reproduces the SW U.S. precipitation trends (although underestimated), implying the trends are externally forced. The CMIP5-AA ensemble mean trends are nearly the same as CMIP5-ALL, which implies anthropogenic aerosols are driving the trends. SW U.S. precipitation trends are consistent with the PDO reversal and the corresponding north-south shift in the jet stream. CMIP5-ALL also tend to reproduce these trends, suggesting the PDO trends are externally forced. CMIP5-AA PDO trends are nearly as large as CMIP5-ALL, implying anthropogenic aerosols are primarily responsible for the PDO trend.
- Our study shows that the recent trends in the SW U.S. precipitation can largely be attributed to anthropogenic aerosols.
- Future decreases in anthropogenic aerosols emissions may have significant impacts on the hydrological cycle of the SW U.S.

Future work

- A similar analysis will be done using CMIP5 greenhouse gas (GHG) forcing only experiments and natural forcing (NAT) experiments.
- Determine how significant the model trends are relative to the unforced, preindustrial control experiments.
- Investigate mechanisms by which aerosols force trends in the PDO.

References

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