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UNCERTAINTY ANALYSIS OF CALIFORNIA STREAMFLOW USING MULTIPLE CLIMATE CHANGE SCENARIOS

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1. INTRODUCTION

Atmosphere Ocean General Circulation Model (AOGCM) projections of 21st century climate with a transient increase in greenhouse gas emissions suggest that the global mean near-surface air temperature will increase by 1.4 to 5.8 °C, with a 95% probability interval of 1.7 to 4.9 °C (Wigley and Raper 2001) by 2100. The potential for impacts on California water resources due to global warming requires a downscaled analysis of local watershed hydrology. To quantify the uncertainty in streamflow, upper and lower temperature and precipitation projections and specified incremental temperature and precipitation changes are used as input forcing to hydrologic models.

2. ANALYSIS

Analysis of the range of climatological and corresponding hydrologic response is based on two AOGCM ensemble projections. The Hadley Centre's version 2 AOGCM (HadCM2 run 1) is a warm and wet projection and the National Center for Atmospheric Research Parallel Climate Model AOGCM (PCM run B06.06) is a cool and dry projection relative to the mean of the IPCC AOGCM projections. Projections for three time periods were analyzed in this study (2010-2039, 2050-2079, and 2080-2099). Climate change perturbations of the projected watershed mean-area temperature and precipitation were derived from the temperature (precipitation) difference (ratio) between the projected climatology and the simulated baseline (1961 to 1990). In addition to the AOGCM projections, uniform perturbations with increasing temperature (T) and precipitation (P) were used: (1) 1.5°C T, 9.0% P; (2) 3.0°C T, 0.00% P; (3) 3.0°C T, 18.0% P; (4) 5.0°C T, 0.00 % P; (5) 5.0°C T, 30.0 % P.

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The hydrologic response was investigated using well-calibrated versions of the Sacramento Soil Moisture Accounting Model with the Anderson Snow Model for a set of representative study basins (Smith, Sacramento, Feather, American, Merced, Kings) forced by the precipitation and temperature perturbations. Comparison between hydrologic response to the warm, wet projection and the cool, dry projection is provided along with the response to several of the uniform perturbations. Climatological streamflow, rain-to-snow ratio, and evapotranspiration are analyzed. The resulting range in streamflow return periods and frequency in multiple sequential dry years are also presented.

3. RESULTS

The warm and wet HadCM2 temperature increases at a faster rate than the cool and dry PCM temperature through the three time periods, but both climatologies increase as quasi-linear functions of temperature with time. The warm and wet HadCM2 run shows monthly precipitation increases during the December to March period and its precipitation maximum shifts from January to February. The cool and dry PCM total annual precipitation is close to the baseline simulated 1963-1992 climatology, however there is more significant drying for the 2010-2039 and 2080-2099 mean climates after the February peak precipitation has occurred. The rain-to-snow ratio is elevation dependent and changes for each projection. The wet HadCM2 increases total amounts of rain and snow, with an increasing rain-to-snow ratio. The dry PCM trends downward in total precipitation for all cases, losing snow and rain in both the upper and lower basins. The rain-to-snow ratios vary significantly with latitude and most importantly the level of the split between the lower and upper basins. The high elevation basins (e.g. Merced) that have a high partition (2000 m) result in higher snow accumulation and later runoff than the lower partitioned basins (e.g. Sacramento 1250 m) for the climate change scenarios. The attached figure shows streamflow climatologies for a subset of headwater basins [Sacramento (a), American (b), Merced (c)] forced by the historical time series, historical time series with imposed HadCM2 (1), PCM perturbations (2), and uniform perturbations (3).

The resulting HadCM2-forced peak flow occurs during the same month, and increases for the Sacramento (1a), American (1b) and Merced (1c) during 2010 to 2039. During 2050 to 2079 and the 2080 to 2099, the peak flow magnitude continues to increase, with the greatest increase among the three at the American. The peak flow timing during the 2080 to 2099 period for the American is a month earlier than the other time periods, occurring in February, while the Sacramento timing remains unchanged. The higher elevation Merced has peak flow that occurs one month later than the historical, it also shows a secondary peak flow during December. This secondary high flow is due to increased early season snowmelt and a higher snowline as the temperature increases.

The relatively cool, dry PCM-forced streamflow slightly decreases in total volume and significantly decreases during the March to July melt seasons. Peakflow remains close to the historical for the Sacramento (2a) and American (2b) for all projected periods, but the Merced (2c) shows an increase during the 2010 to 2039 period, and decreases during 2050 to 2079 and 2080 to 2099. For these projections, the American shows an earlier peak flow of one month, while the peak flow for the other two watersheds shown here remains consistent with the historical peak flow timing.

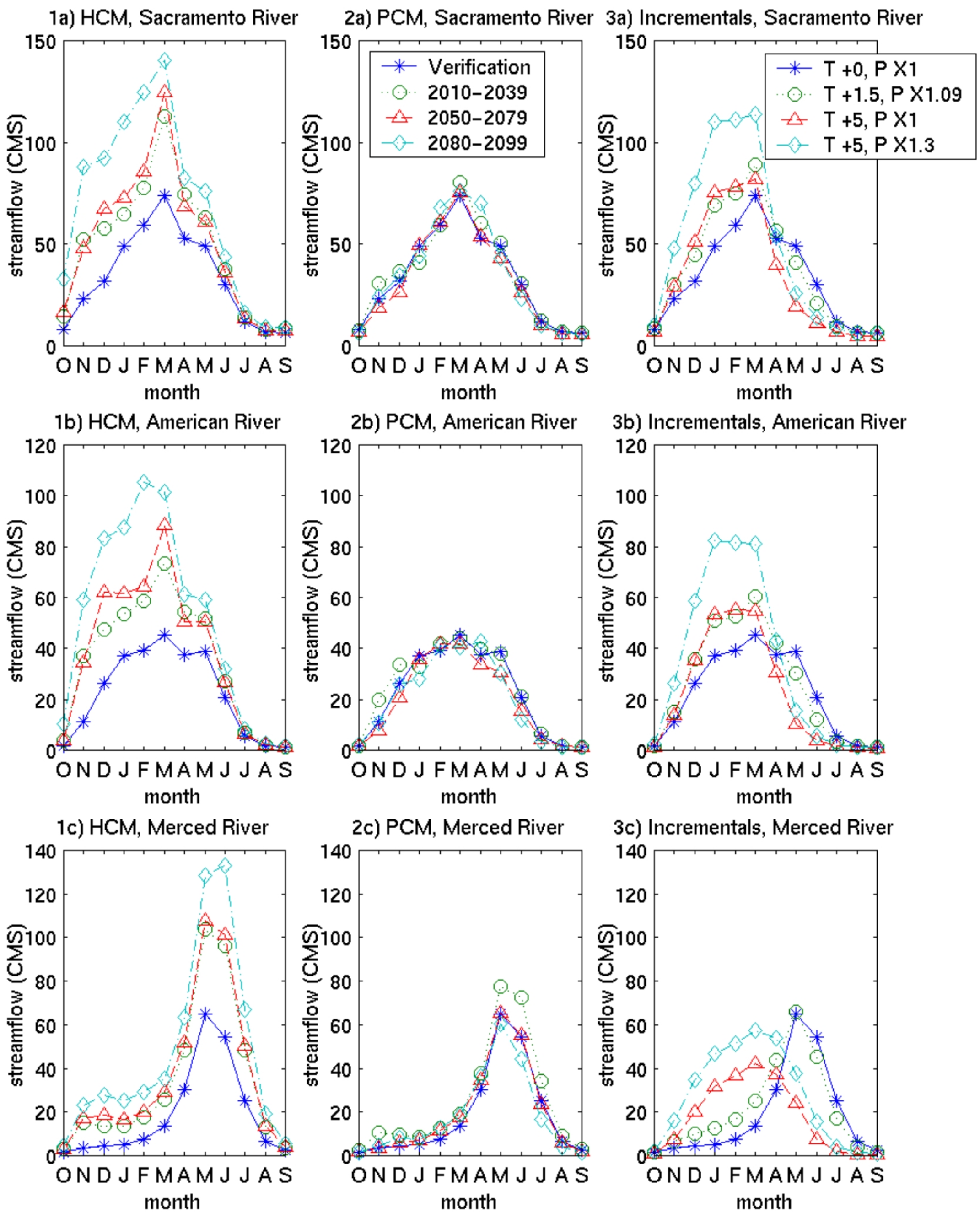
Figure (3) shows the subset with the uniform perturbations that bracket the IPCC temperature interval. In addition, a 9% precipitation and a 30% precipitation increase were evaluated. The 1.5 ºC increase and 9% precipitation increase does not change the peakflow timing, but generally increases the October to February magnitude and slightly decreases the magnitude during the snow melt period. The peakflow magnitude is higher for the Sacramento (3a) and American (3b), but not the high elevation Merced (3c). The 1.5 ºC increased temperature with historical precipitation has an increased peak flow, except for the Merced, with decreased melt season streamflow and an annual total similar to the historical. The 5 ºC increase in temperature with historical precipitation is very similar to the 1.5 ºC temperature and 9% precipitation increase for the Sacramento and the American, except during the melt season where it is lower. The Merced peak flow significantly decreases and occurs three months earlier (February) due to the substantial heating. The extreme 5 ºC temperature and 30% precipitation increases has early season peak flow approximately twice the magnitude of the historical for the Sacramento and American, for December to February, while the Merced peak flow is near the historical magnitude, but two months earlier (March). This extreme case represents a scenario with a high likelihood of more flood events and decreased snow melt runoff.

4. SUMMARY

Under the scenarios studies here, California Sierra Nevada peak flow will likely occur earlier and with increased magitude. Summer season flow will likely decrease. This is most pronounced for basins with snowlines that are in the middle of the basin area and change dramatically with global warming. High elevation basins, such as the Merced, are less sensitive this warming, but show a peakflow shift under the incremental changes. The range of outcomes suggests that peakflow magnitudes can shift from 100% increases to 50% decreases.

Results from this analysis represent the Sacramento-San Joaquin drainage and have been applied to water demand and agro-economic analyses. Providing the upper and lower limits of climate change impacts on streamflow will help water resource decision makers determine the how to modify existing systems.

Wigley, T.M.L. and S.C.B. Raper, 2001: Interpretation of high projections for global-mean warming. Science, 293, 451-454.



The above figure shows the climatological streamflow for three watersheds, (a) Sacramento to Delta, (b) American to North Fork Dam, and (c) Merced to Pohono Bridge. For each watershed, climatologies are given for two GCM projections, (1) HadCM2r1 and (2) PCMrB06.06 at 2010-2039 (circles), 2050-2079 (triangles), and 2080-2099 (diamonds), and for (3) a set of specified incrementals. The incrementals shown are a 1.5 ºC and 9% precipitation increase (circles), 5.0 ºC and 0% precipitation increase (triangles), and 5.0 ºC and 30% precipitation increase (diamonds). The verification (stars) in (1) and (2) is the same as the 0.0 ºC and 0% precipitation increase in (3).