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TECHNICAL MEMORANDUM

DATE: July 17, 2018

TO: Ron Duncan, Santa Cruz Mid-County Groundwater Agency

FROM: Georgina King, John Mejia, and Cameron Tana

PROJECT: Santa Cruz Mid-County Basin Groundwater Model

SUBJECT: Comparison of Climate Change Scenarios

1. BACKGROUND

For the Santa Cruz Mid-County Basin (Basin) Groundwater Flow Model using GSFLOW, we plan to run predictive simulations of groundwater management alternatives for the Santa Cruz Mid-County Groundwater Agency (MGA) using future climate change scenarios. One future climate change scenario based on a catalog of historical climate years has already been developed for the MGA (HydroMetrics WRI, 2016) but we are scoped to also run simulations using projections of climate change downscaled to the Basin. Simulations based on climate change projections are considered important for planning because projections generally have warmer temperatures than the historical record which could have a significant effect on the water resources of the Basin. There are a number of options available for climate change projections. This technical memorandum compares the suite of projections available.

Climate change projections are made primarily on the basis of coupled atmosphere-ocean Global Circulation Model (GCM) simulations under a range of future emission scenarios. Currently, climate projections used in climate change analysis are based on climate model simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The predecessor to CMIP5 was CMIP3.

Climate models in the CMIP5 use a set of emission scenarios called representative concentration pathways (RCPs) to reflect possible trajectories of greenhouse gas (GHG) emissions throughout this century. Each RCP defines a specific emissions trajectory and subsequent radiative forcing (a radiative forcing measures the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system).

For purposes of quantifying benefits or adverse impacts that could result from water storage projects proposed for the Water Storage Investment Program (WSIP) in California (California Water Commission, 2016), technical assistance included recommendations for the use of climate change projections. Twenty climate scenario-model combinations were selected based on recommendations by the California Department of Water Resources' (DWR) Climate Change Technical Advisory Group that they are the most appropriate for California water resources. The climate scenario-model combinations compose 10 global circulation models run with two emission scenarios: one optimistic (RCP 4.5) that stabilizes shortly after 2100 and one pessimistic (RCP 8.5) that is characterized by continuing increased GHG emissions over time.

Included in our comparison is the City of Santa Cruz's (City) climate change projection. The City, since 2008, uses CMIP3 GCM data adopted and made available by the CalAdapt program as the basis for their hydrologic and climate change modeling (Stratus, 2015). Specifically, they have selected the GFDL2.1 GCM for the A2 emissions scenario, which is the worst-case climate change dataset in the CalAdapt dataset. Under a subcontract to Pueblo Water Resources Inc., we have performed bias corrected spatial downscaling (Mejia et al., 2012) of the GFDL2.1-A2 projections to the climate stations in the Basin for use as input to represent climate for Water Years 2020-2069. We are currently using this climate input to simulate City of Santa Cruz Aquifer Storage and Recovery (ASR) preliminary alternatives.

A comparison of climate change projections will lead to a decision on what GCM projections should be used by the MGA for its simulations, including those simulations to guide the Basin's Groundwater Sustainability Plan (GSP). One option is the GFDL2.1-A2, which has already been downscaled to the Basin. If different GCM(s) are deemed appropriate, downscaling of those GCM(s) to climate stations in the Basin will be required to use with the Basin GSFLOW model.

2. COMPARISON OF DATASETS

Downscaling is commonly used to refine the coarse scale of GCM data to local regions. The CMIP5 ensemble of CGMs area available as downscaled projections using local constructed analogs (LOCA) for California on a 6 kilometer grid (Pierce, Cayan, and Dehann, 2016). WSIP used these downscaled projections for its set of 20 climate scenario-model combinations. Although further downscaling from LOCA, similar to what has been done for the GFDL2.1-A2 projection used by the City of Santa Cruz, will be required for the Basin GSFLOW model, we evaluated data from the LOCA cell in which the Santa Cruz Co-Op climate station is located, to compare climate change projections for the Basin region (Figure 1).

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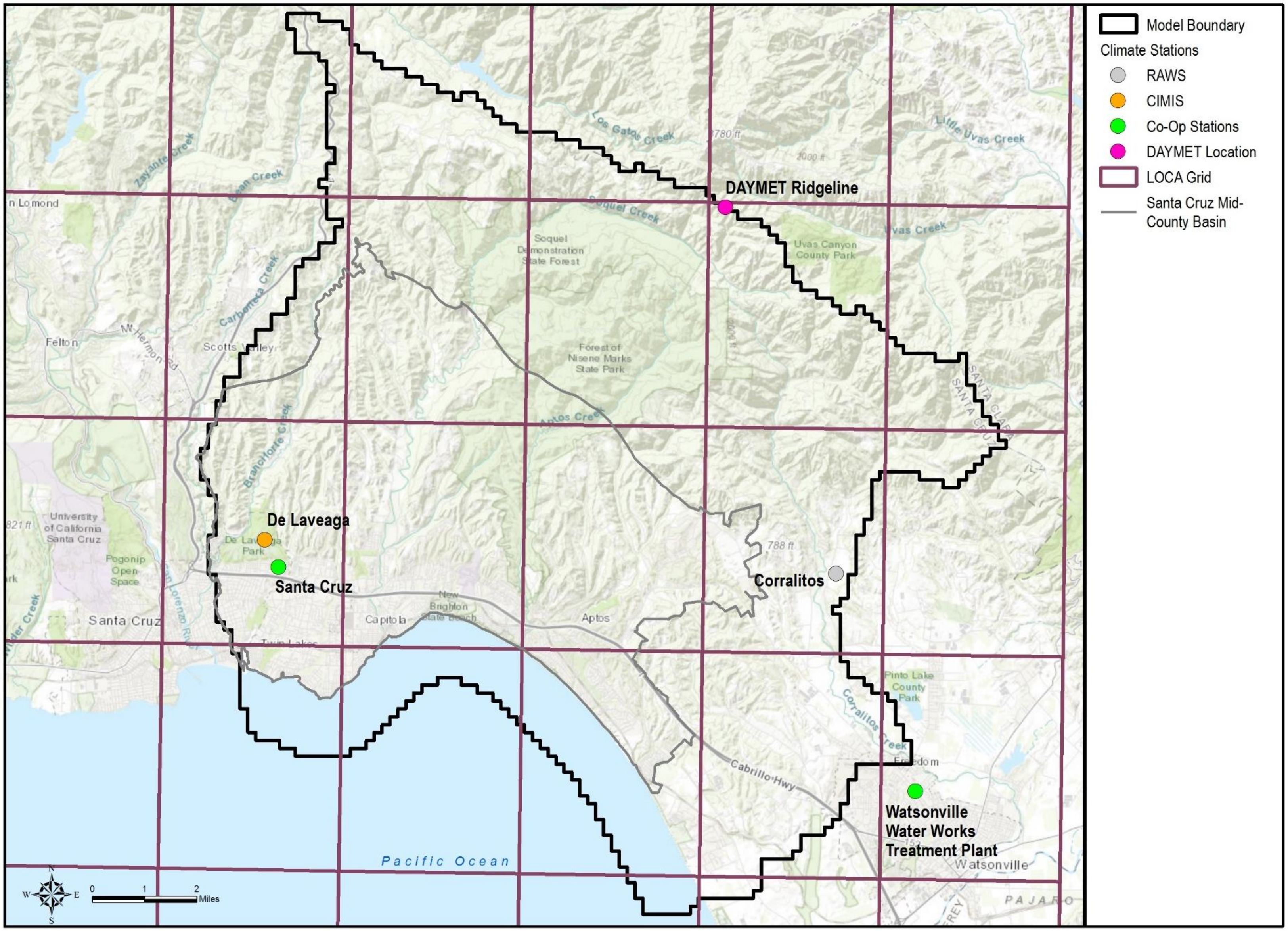

Figure 1. LOCA Grids in the Santa Cruz Area

Our comparison includes all available CMIP5 scenarios. The two different RCPs are compared separately, as are the 20 WSIP emission scenarios. Change in average precipitation, and minimum and maximum temperatures comparisons are summarized in Table 1. The values in the table represent changes between average projected 2020-2069 GCM climate and average reference historical 1984-2015 GCM climate for the grid cell. Comparing modeled results for these time periods are meant to represent the expected change in downscaled climate for a future period versus the Basin GSFLOW model calibration period of 1985-2015. Figure 2 plots the individual scenarios with a line connecting the average minimum and maximum temperature changes against a percentage change in average precipitation for each emission scenario.

Table 1: Climate Change 2020-2069 Compared to Reference Historical 1984-2015 Period

Scenario	Average Precipitation (%)	Average Minimum Temperature (°F)	Average Maximum Temperature (°F)
CMIP5 all	3.16	2.68	2.59
CMIP5 all RCP4.5	1.68	2.35	2.26
CMIP5 all RCP8.5	4.66	3.02	2.91
CMIP5 WSIP	1.79	2.82	2.74
CMIP5 WSIP RCP4.5	0.47	2.48	2.45
CMIP5 WSIP RCP8.5	3.11	3.16	3.04
CMIP3-GFDL-CM-A2 downscaled at Santa Cruz Co-op Station	-1.46	1.2	2.2
Catalog at Santa Cruz Co-op Station	-10.2	0.78	2.29

Notes: Historical Reference for CMIP5 is GCM results for 1984-2015
Historical reference for GFDL and Catalog is 1984-2015 dataset at Santa Cruz Co-op station.

The California Department of Water Resources (DWR) has stated they will use the ensemble of WSIP scenarios as the basis for climate change projections provided to local Groundwater Sustainability Agencies for sustainable groundwater management planning (Hatch, 2017). Personal communication with Tyler Hatch of DWR's Sustainable Groundwater Management Branch, indicated that for sustainable groundwater planning, DWR will accept a climate change scenario that was more conservative than the WSIP ensemble, i.e., hotter and drier.

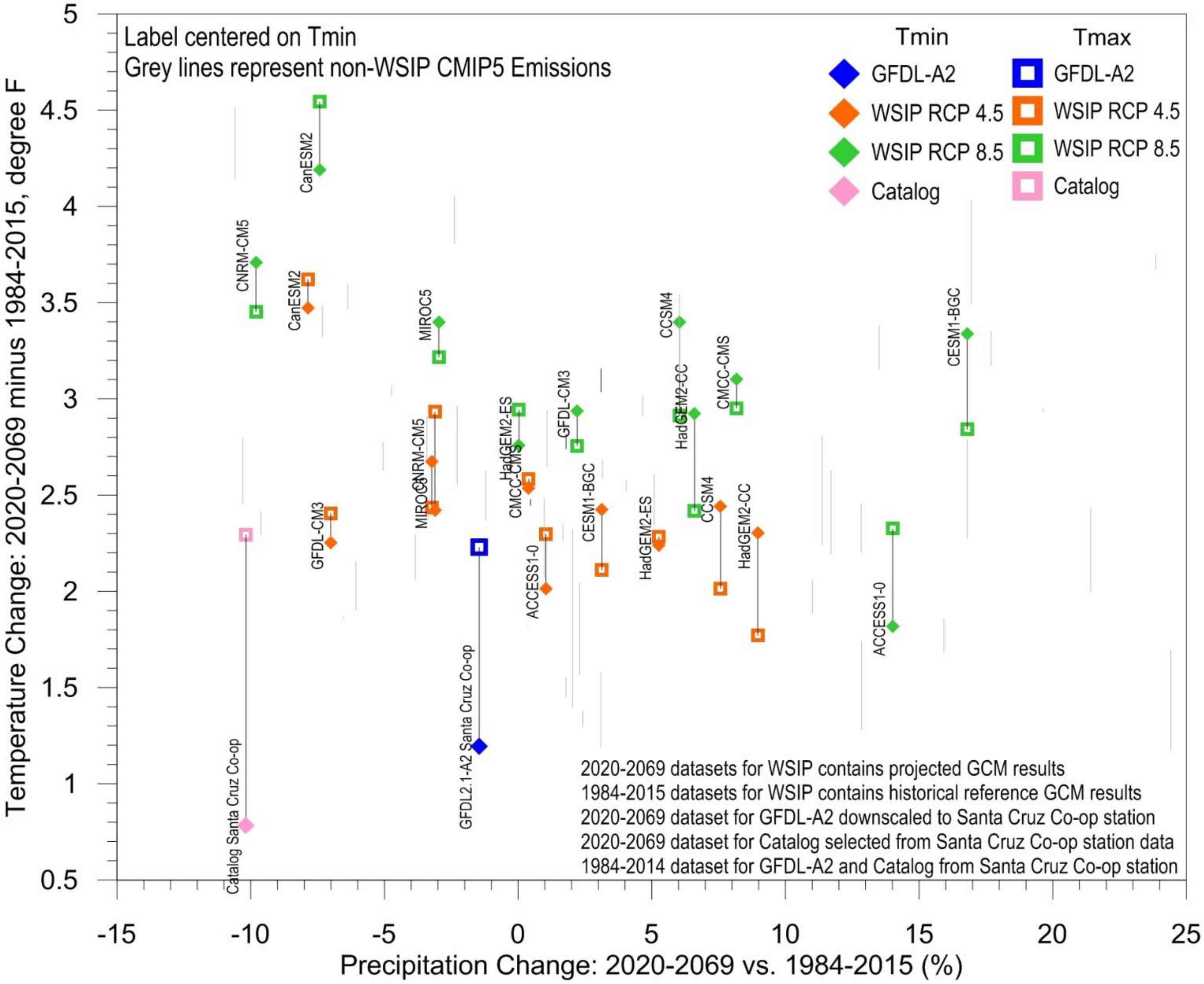

Figure 2. Climate Change 2020-2069 with Respect to Reference Period 1984-2015 for All CMIP5 Emissions

2.1. Precipitation Comparison

Average precipitation increases over 1984 – 2015 precipitation in all groups of CMIP5 scenarios (Table 1). The RCP 4.5 scenarios have lower precipitation increases than the RCP 8.5 scenarios. The WSIP scenarios have lower precipitation increases than the combined CMIP5 scenarios. Median daily precipitation plotted for each year (Figure 3) shows an increasing trend in the precipitation to 2069. Monthly averages of precipitation changes between 2020-2069 and 1984-2015 show only little change or increases every month for medians of all groups of CMIP5 scenarios. December through March precipitation increases in the WSIP scenarios is generally higher than the combined CMIP5 scenarios (Figure 4). The other months have similar daily precipitation changes.

Daily precipitation from the City's GFDL-A2 scenario compared to the full combination of WSIP scenarios is slightly wetter, with 2.04% more precipitation than 1984-2015 reference precipitation (Table 1). There is a notable reduction in precipitation after 2069, which is after our planned GSFLOW model period (Figure 3). GFDL-A2 precipitation from March through May has less precipitation than the reference historical period and less than the CMIP5 scenarios, however September, October, and February precipitation has greater increases than the CMIP5 scenarios (Figure 4).

2.2. Minimum Temperature Comparison

As expected, all RCP 8.5 scenarios are warmer than RCP 4.5 scenarios because of the projected increasing emissions that characterize those scenarios. The combined 20 WSIP scenarios' minimum temperature increases are overall greater than the full complement of CMIP5 scenarios, and more noticeably so in the RCP 8.5 group (Table 1). Figure 5 shows that the median RCP 8.5 minimum temperatures depart from temperatures in the other groups of scenarios around 2056 with an increasing trend.

GFDL-A2 average annual projections of minimum temperature are lower than median CMIP5 temperatures around 2038 and 2060 (Figure 5). Overall, this results in average minimum temperature increases than are lower than all other CMIP5 groups of scenarios (Table 1). Monthly averages for minimum temperatures are higher in all months for median RCP 8.5 emission scenarios than median RCP 4.5 emission scenarios. The average monthly minimum temperatures show less temperature increase in the GFDL-A2 scenario than the CMIP5 scenarios, except from May to August where they are more comparable to the RCP 4.5 scenarios (Figure 6).

2.3. Maximum Temperature Comparison

Similar to minimum temperatures, the combined 20 WSIP scenarios' maximum temperatures are overall slightly warmer than the full complement of CMIP5 maximum temperatures (Table 1). The months of June through October are when the WSIP scenario maximum temperature increases are noticeably greater than the combined CMIP5 scenarios (Figure 8).

Figure 7 shows that the GFDL-A2 scenario maximum temperatures follows the general trend of the WSIP RCP 8.5 emission scenarios better than other scenarios. However, similar to minimum temperature, around 2038 and 2060, the projection of maximum temperature falls below most CMIP5 scenarios (Figure 7). Overall, the average maximum temperature increases for the GFDL-A2 scenario are lower than the WSIP maximum temperatures increases. Monthly averages for maximum temperatures are higher in all months for median RCP 8.5 emission scenarios than median RCP 4.5 emission scenarios. The monthly distribution of average maximum monthly temperatures also show higher temperature increases in the GFDL-A2 scenario than the CMIP5 scenarios from May through August, and generally lower temperature increases in the other months (Figure 8).

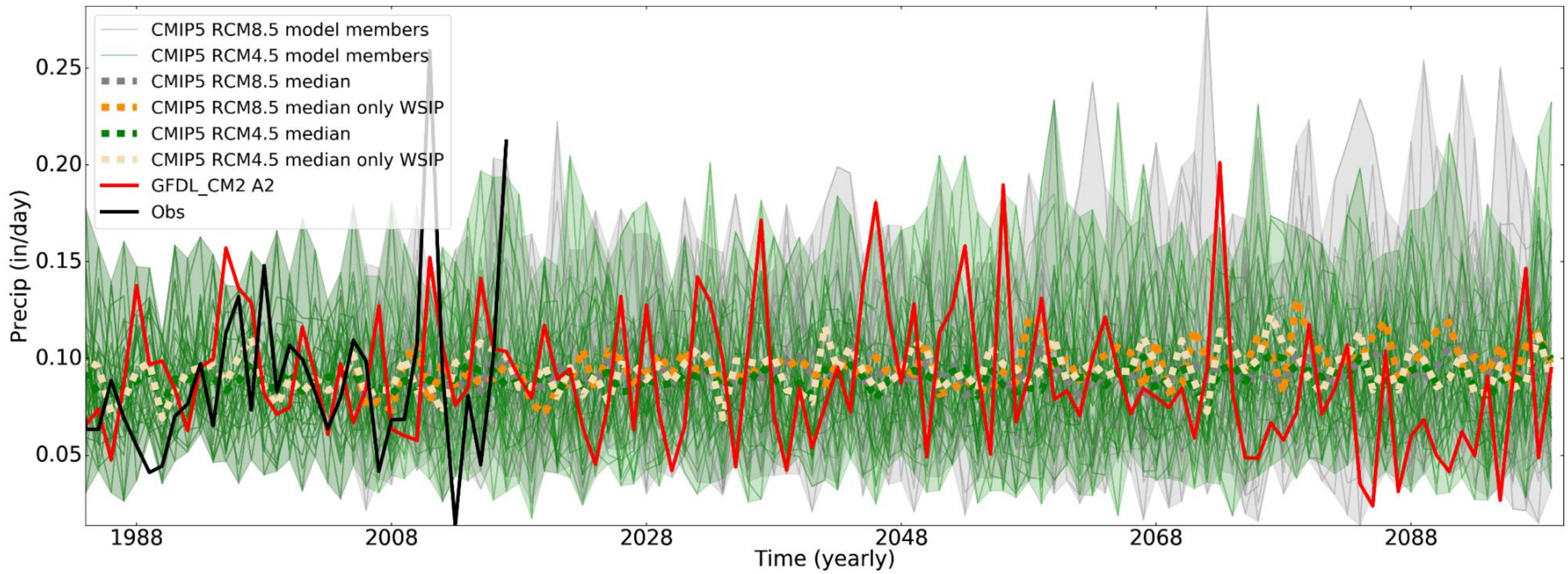

Figure 3. Average Annual Daily Projections for Precipitation

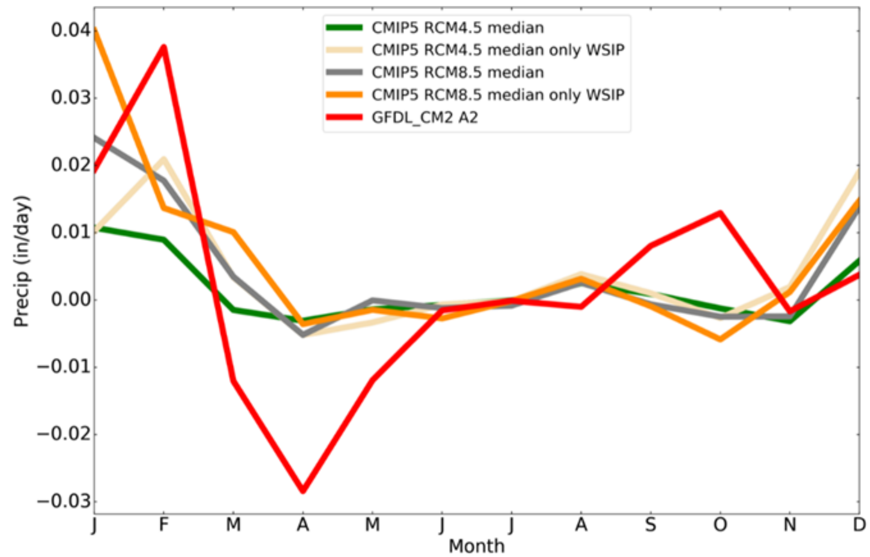

Figure 4. Average Monthly Projections for Precipitation Changes between 2020-2069 and 1985-2015

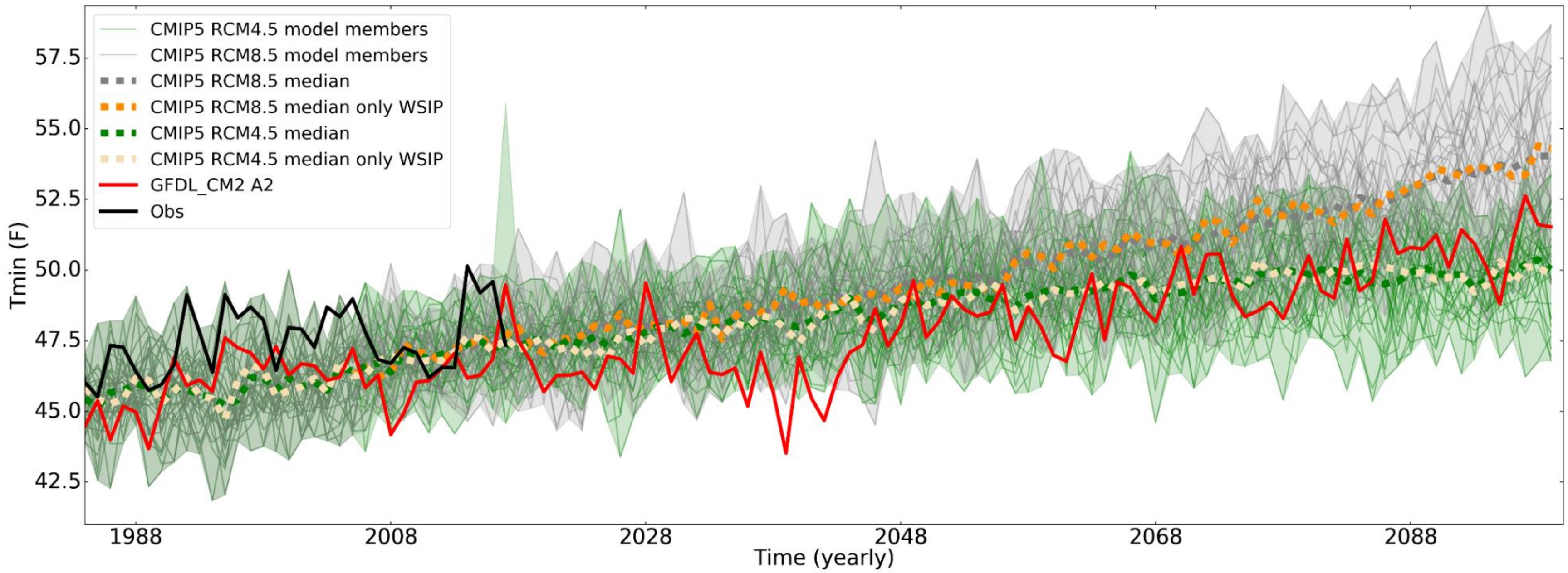

Figure 5. Average Annual Daily Projections for Minimum Temperature (Tmin)

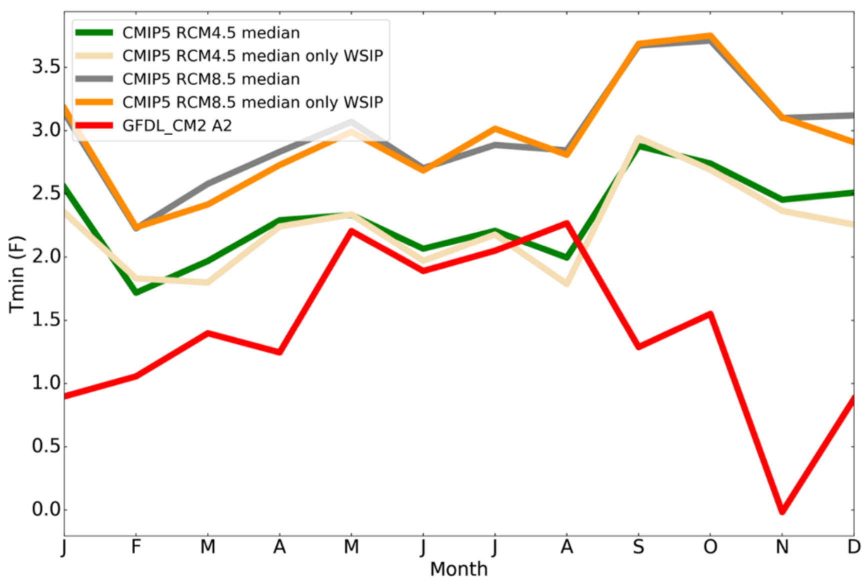

Figure 6. Average Monthly Projections for Minimum Temperature (Tmin) Changes between 2020-2069 and 1985-2015

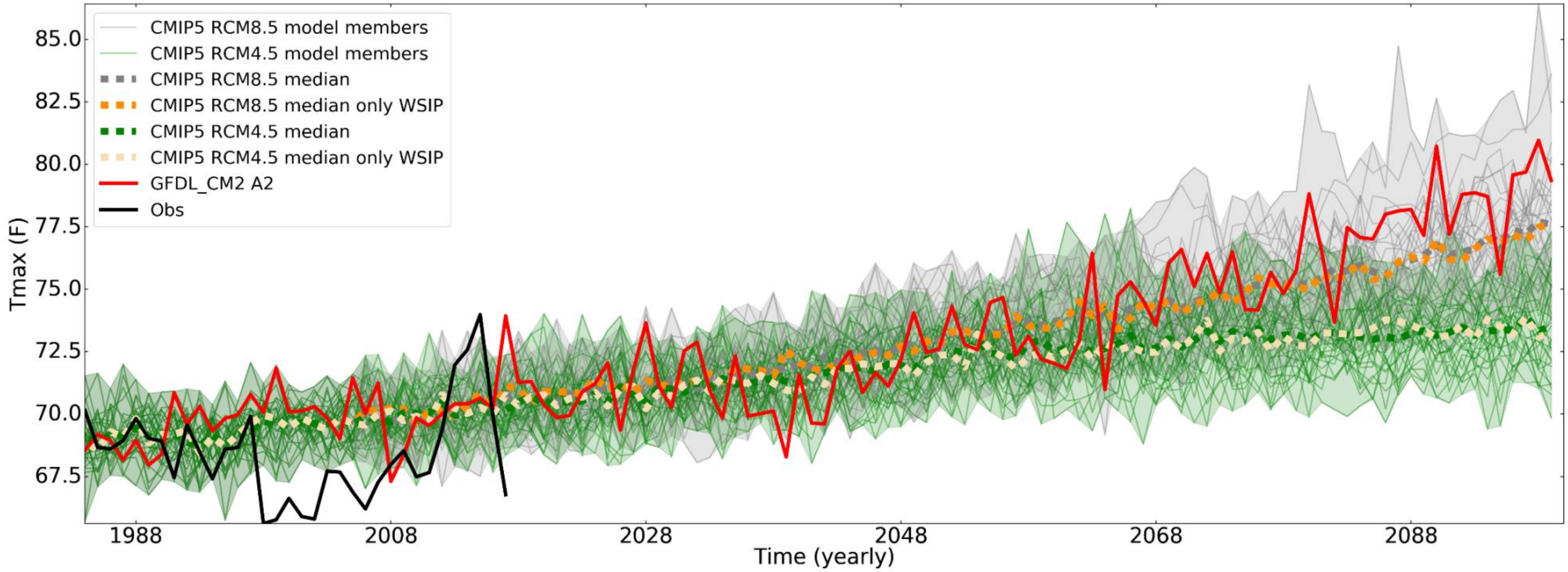

Figure 7. Average Annual Daily Projections for Maximum Temperature (Tmax)

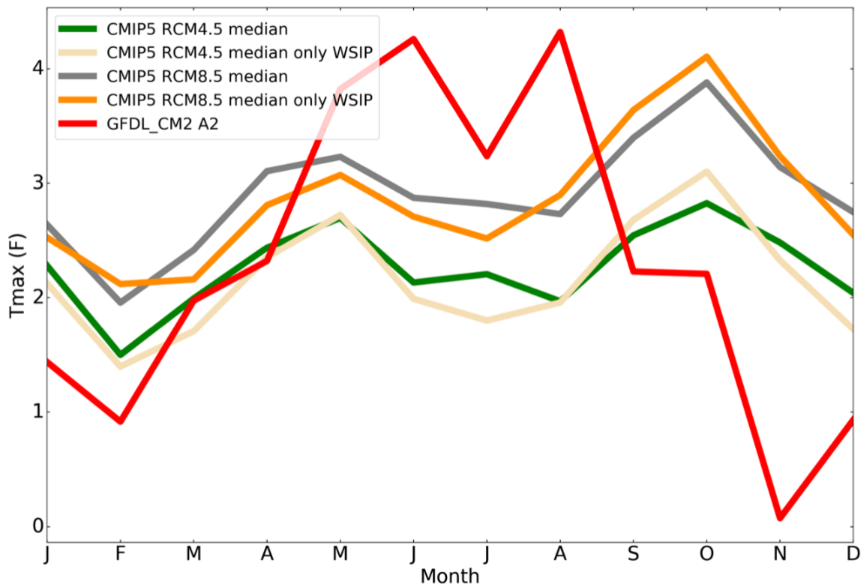

Figure 8. Average Monthly Projections for Maximum Temperature (Tmax) Changes between 2020-2069 and 1985-2015

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. Conclusions

1. All projected average scenario ensembles (CMIP5 and WSIP) are wetter than the reference historical period.
2. The WSIP emission scenarios are drier and warmer than the combined CMIP5 scenarios.
3. The City's GFDL-A2 scenario is both wetter and cooler than many WSIP scenarios, although its maximum temperatures are warmer than WSIP RCP 4.5 scenarios.

3.2. Recommendations

It is expected that for groundwater sustainability planning, DWR will accept a climate change scenario that is more conservative than the WSIP ensemble, i.e., hotter and drier. Since the City's GFDL-A2 scenario does not fulfill this condition, a potential alternative needs to be selected. Although most projections show an increase in precipitation, we recommend selecting a projection that shows a decrease in precipitation. This will contribute to the robustness of groundwater sustainability planning by taking into account the possibility that water supply is reduced. Any projection that shows higher than average increases in temperature than the WSIP ensemble should also meet the requirements for groundwater sustainability planning.

We recommend selecting a scenario from the one of the 20 WSIP scenarios. WISP scenarios that are potential candidates are: MIROC5 RCP 8.5, CanESM2 RCP 4.5, CanESM2 RCP 8.5, and CNRM-CM5 RCP 8.5. These are shown on to have lower projected average precipitation than the reference historical period and higher temperatures than most other CMIP5 scenarios.

- CanESM2 RCP 8.5, CanESM2 RCP 4.5, and CNRM-CM5 RCP 8.5 are extreme scenarios that have over 7% less precipitation and some of the highest temperatures of all projections (Figure 2); such an extreme selection may not be justified.
- A fourth less extreme option is MIROC5 RCP 8.5 has 3% less precipitation than the reference historical period, and average temperatures that are higher than the majority of other scenarios.

4. REFERENCES

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