Memo on General Use Projections

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- This research is funded by the California Energy Commission (CEC) through its Electric Program Investment Charge (EPIC) Program, which invests in scientific and technological research to accelerate the transformation of the electricity sector to meet the state's energy and climate goals.
- The research project, EPC-20-006, will integrate the latest downscaling approaches applied to the recently produced global climate models (GCMs) with an engagement process to develop a robust, usable, set of climate projections applicable for California.
- This memo and data here within are being shared to support transparent and timely consideration of interim deliverables that are relevant for energy stakeholders and all those interested in California's next generation of climate projections.

This memorandum is submitted to the CEC by UC San Diego's Scripps Institution of Oceanography. The report meets deliverable requirements under Task 3 of the California Energy Commission's Project EPC-20-006: Development of Climate Projections for California and Identification of Priority Projections.

General Use Projections

The climate data and projections developed for California as part of the California Energy Commission's Project EPC-20-006 consist of upwards of 20 TB of data, which can be overwhelming if one is not accustomed to working with such large data sets. To lower this data barrier and to reduce the number of individual projections that might initially be considered, a subset of the Global Climate Models (GCMs) and ensemble members was selected as "general use projections". The full suite of LOCA2-Hybrid projections is from 15 different GCMs that were selected based on their skill of representing historical climate variability (Krantz et al., 2022) with many GCMs having multiple ensemble members.[1] The full suite of LOCA2-Hybrid climate data is a result of the hybrid-statistical downscaling method.[2] This downscaling method created data for 15 GCMs with a total of 199 ensemble runs.

These *General Use Projections* are meant as an entry point to working with this larger full suite of LOCA2-Hybrid climate data and to begin to explore the range of possible outcomes. The general use projections are offered as a minimum set of GCMs that should be used in any analysis of climate change impacts and assessments. They can also serve as a smaller, common set of projections for comparison between cross-sector, cross-jurisdiction, and/or cross-agency work if not all agencies are using the same larger data set of LOCA2-Hybrid climate data GCMs and ensemble members. The general use projections should not be considered a preferred set of GCMs or ensemble members, but rather an entry point into climate data utilization that mitigates challenges from using the larger data set.

Although using the *General Use Projections* mitigates some climate data pitfalls, several limitations remain when using a smaller subset rather than the full suite of GCMs since smaller subsets do not represent the full range of all the possible climate projections, in particular in characterizing projected changes in extremes (as described below). For this reason, we always recommend using a broader set of models with as many of the GCMs as possible. The Cal-Adapt Analytics Engine[3] enables exploration and analysis of the full suite of climate data without having to download and process the data independently, though does require some training and experience with climate data. More information about the implication of model choice and sampling is available in the Guidance on how to use climate data that is available on the Cal-Adapt: Analytics Engine website (https://analytics.cal-adapt.org/guidance/).

Prioritized Criteria used to Select the General Use Projections

The process used to select the *General Use Projections* from the larger data set of LOCA2-Hybrid climate data included several criteria. These criteria were based on input from energy sector users, data availability, and scientific considerations. The list below states the criteria that were prioritized and why.

1. Ensured the models selected capture much of the range (see below, figure 1) of projected future changes in the GCMs and ensemble members for selected metrics, scenarios and time-periods. This selection aimed to help mitigate uneven sampling that might arise in using a smaller set of GCMs (e.g. not capturing possible extremes, biasing the results towards a certain projection) rather than all the LOCA2-Hybrid GCMs.

[1] Shown here: https://loca.ucsd.edu/loca-version-2-for-california-ca-may-2023/

[2] Please see https://www.energy.ca.gov/sites/default/files/2024-03/04_HybridDownscaling_DataJustificationMemo_Pierce_Adopted_ada.pdf

[3] https://analytics.cal-adapt.org/

2. Prioritized LOCA2-Hybrid GCMs and ensemble members that have also been dynamically downscaled by WRF with a priori bias correction. These WRF projections are considered to be superior to WRF runs with no a priori bias correction, and furthermore, this selected set enables the use of both dynamically downscaled and hybrid downscaled data sets if needed.
3. Prioritized ensemble members for which the full set of LOCA2-Hybrid downscaled variables were available (some GCM providers did not save all of the requisite data for LOCA2 downscaling) in order to provide a robust general use projection dataset.
4. Assessed future changes in California in both means and extremes (hot days, floods, and droughts) to ascertain that the general use subset of the LOCA2-Hybrid data suite covered a plausible range of extremes. A limited set of metrics was employed in this evaluation because having too many uncorrelated variables and metrics reduces the ability of the metrics to distinguish between models. Model range was assessed using temperature, precipitation, and wind.
5. Avoided metrics that are derivatives of several variables for the same reason as in 4. above.
6. Focused the assessment on the range of model outcomes for SSP370 with a 2045-2074 mid-century period based on input from the energy sector. This time period was used because it is far enough in the future to capture climate change signals, and energy users indicated that it is a high priority time horizon for planning and adaptation actions. SSP370 was considered because it is a mid-range climate forcing and climate change scenario that exhibits greenhouse gas emissions that are consistent with those that Earth is currently experiencing, and additionally is the only SSP for which WRF data that is part of EPC-20-006 is available.
7. Excluded GCMs that have a climate sensitivity that is unrealistically high compared to historical observations, based on Tokarska et al., 2020 and Hausfather et al., 2022. These models produce a rate of future warming that is unlikely to come to pass. This choice does not prevent any stakeholder from analyzing the data in terms of warming levels but avoids the requirement that the data from the general use projections must be analyzed in warming levels.

General Use Projections

We determined that the following 5 models and ensemble members best met the 7 prioritized criteria stated above.

- ACCESS-CM2 r1i1p1f1 (no WRF dynamical downscaled 3 km run)
- MPI-ESM1-2-HR r3i1p1f1
- EC-Earth r1i1p1f1
- FGOALS-g3 r1i1p1f1 (not a priori bias corrected prior to 3 km run)
- MIROC6 r1i1p1f1

More details and justification for these models and ensemble members being selected as general use projections are detailed below.

Selection Process of the General Use Projections

The variables and metrics for the *General Use Projections* selection process was based on input from the energy stakeholders and scientific considerations. Based on this we selected to use precipitation, maximum temperature and wind. These are the primary variables that were of interest from the energy sector in terms of extremes such as heat waves, droughts, and fire weather. We used the primary climate variables rather than the extreme because the extreme can be defined numerous ways. The relationship between the climate variable and the associated extremes are described below. Further, using a statewide metric was necessary for the general use projections to make the General Use Projections as relevant for as much of the state as possible. Temperature and precipitation trends are homogenous throughout California unlike some other metrics like solar radiation, which is strongly impacted by low level clouds along the coast for example.

The basis for the *General Use Projections* selection is largely captured in Figure 1, which shows each GCM ensemble member's changes in California statewide area averaged maximum daily temperature (Tmax) and annual precipitation for the SSP370 scenario for 2045-2074 relative to 1950-2014. From the plot, these two variables are largely independent, addressing prioritized criteria 1 and 4 above. Importantly, to prioritized criteria 1, we wanted to make sure the *General Use Projections* capture the range of projections and include a diversity of models that are the warm/wet, warm/dry, cool/wet and cool/dry as well as one near the center of the range for the mid-century time period. The selected *General Use Projections* represent these quadrants and the center. Further, the mean of all the SSP370 projections and the mean of all five of the *General Use Projections* are nearly the same for change in statewide Tmax and less than 3 percentage point different for the change in annual precipitation (Figure 1). Using the average of Tmax and precipitation from all five of the g *General Use Projections* therefore is a reasonable proxy for the average of all the LOCA2-Hybrid SSP3.7 runs.

The specific ensemble member to use for each of the models was determined based on the availability of data addressing prioritized criteria 2 and 3. Of the selected *General Use Projections*, four of the five have been dynamically downscaled using WRF to 3 km, three were *a priori* bias corrected (Rahimi, 2024), while one (FGOALS-g3) was not (Rahimi, 2022) as part of the EPC-20-006 project. ACCESS-CM2, was selected to cover the warm/wet quadrant of the SSP370 climate simulations ensemble members, a quadrant which did not contain a GCM that was dynamically downscaled with WRF. The specific ACCESS-CM2 ensemble member was selected because it is the only one of the three ACCESS-CM2 ensemble members that provided the necessary variables to produce downscaled LOCA2-Hybrid wind data. In a similar vein, the MPI-ESM1-2-HR ensemble member was selected because it was the only ensemble member that was dynamically downscaled using WRF to 3 km as part of this research.

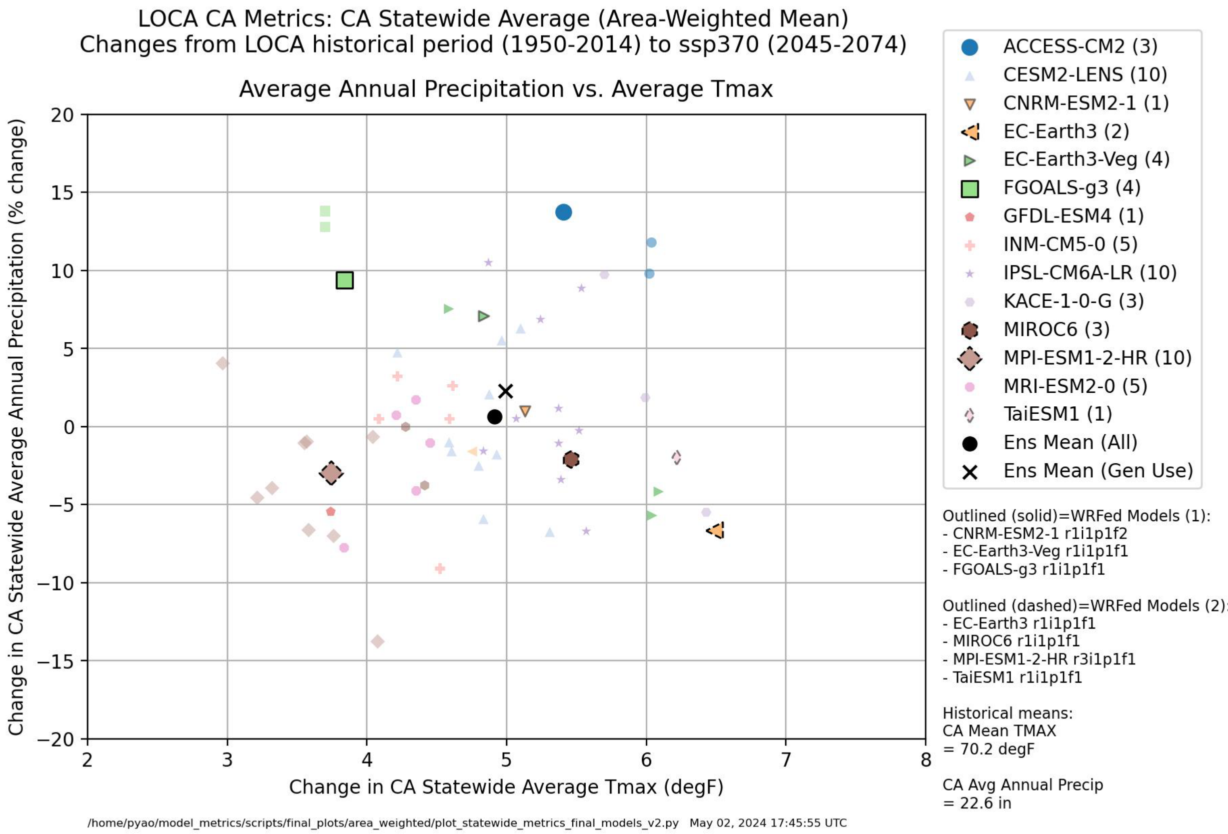

Figure 1. The change in CA statewide average Tmax (in deg F) compared to change in statewide average annual precipitation (as a percent change) for the SSP370 scenario during mid-century (2045-2074) relative to the historical period (1950-2014), with the symbol indicating the GCM. Many of the GCMs have multiple ensemble members, indicated in parentheses after each GCM in the legend. LOCA2-Hybrid downscaled multiple ensemble members, while there are not multiple ensemble members available from the dynamical downscaling with WRF. The shapes outlined in black are the GCM ensemble members that have been dynamically downscaled with WRF. Symbols for the 5 model ensemble members selected for the general use projections are larger and more opaque than the remaining models. The filled black circle is the mean of all the models while the black x is the mean of the general use projections.

Part of the *General Use Projection* selection process was to determine how other metrics, especially of extremes, were captured by the general use projections. As a result of prioritized criteria 4 and 5, we used a small number of variables for selection but wanted to ensure that the selected metrics of statewide precipitation and daily maximum temperature captured the range of extremes as well (please see below). This is possible because there are correlations between the extremes and the means in temperature and precipitation in California. For example, hotter statewide average temperatures are associated with the occurrence of more hot days, wetter years are correlated with a greater incidence of very wet days, etc.

For a temperature metric we used state- and annually-averaged Tmax. Energy sector users noted that heat waves are critical for their applications, and can be characterized in different ways, such as by temperature thresholds, peak values, durations, and return intervals. To demonstrate the relationship between heat extremes and mean Tmax, we show a strong relationship between projected future changes in 2-day heatwaves and changes in statewide, annually averaged Tmax (Figure 2).

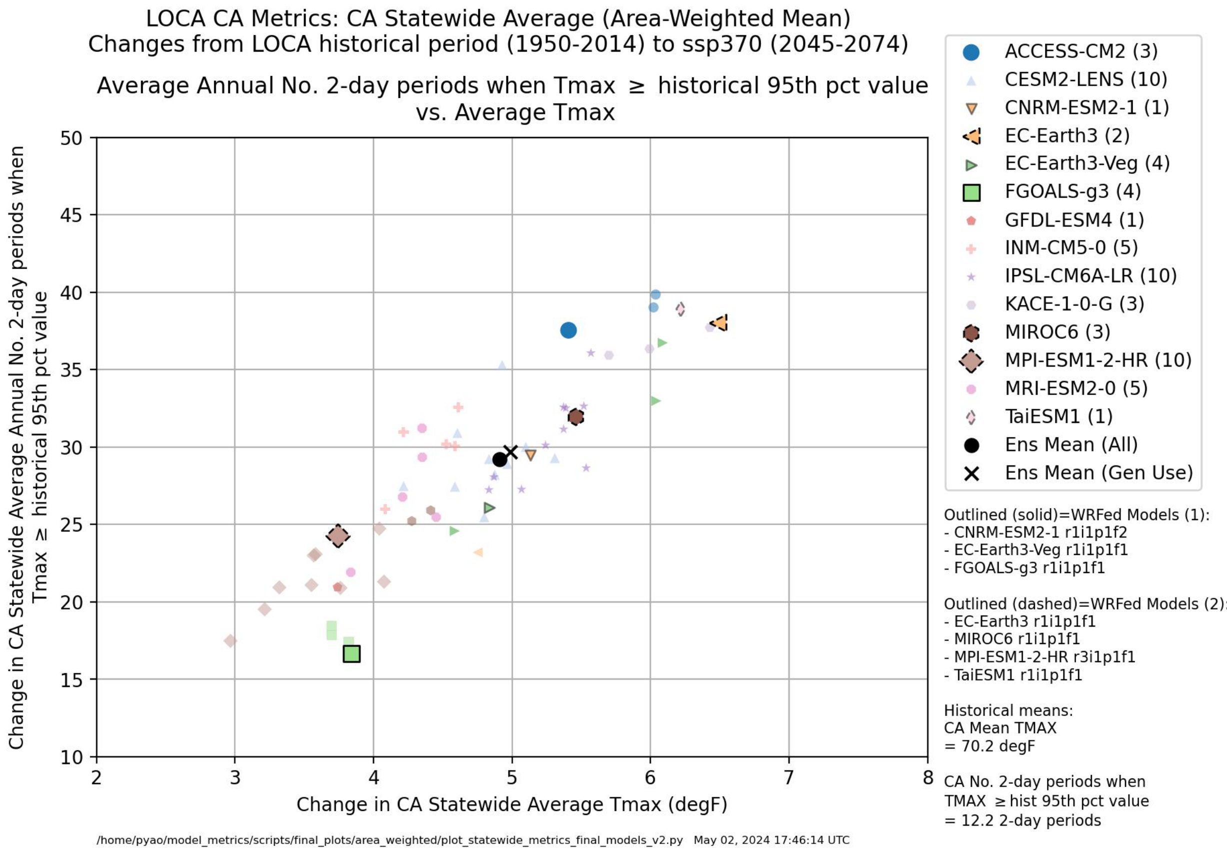

Figure 2. Same as Figure 1 but for the change in CA annually averaged statewide average (Tmax) as compared to heatwaves, the number of 2-day periods when Tmax is greater than the historical 95th percentile value.

Similarly, there is also a correlation between Tmax changes and changes in cold snaps, though this is not as strong of a relation as heatwaves (Figure 3), likely because of the use of Tmax rather than Tmin. In both short-period heatwaves and cold snaps, the correlation with statewide annual Tmax change support using Tmax as a metric and show the selected general use projections represent the range for both cold and hot extremes. We note that we chose Tmax over Tmin as the variable to use in the selection process based on the energy sector input that extreme heat was of the greatest interest as compared to cold snaps.

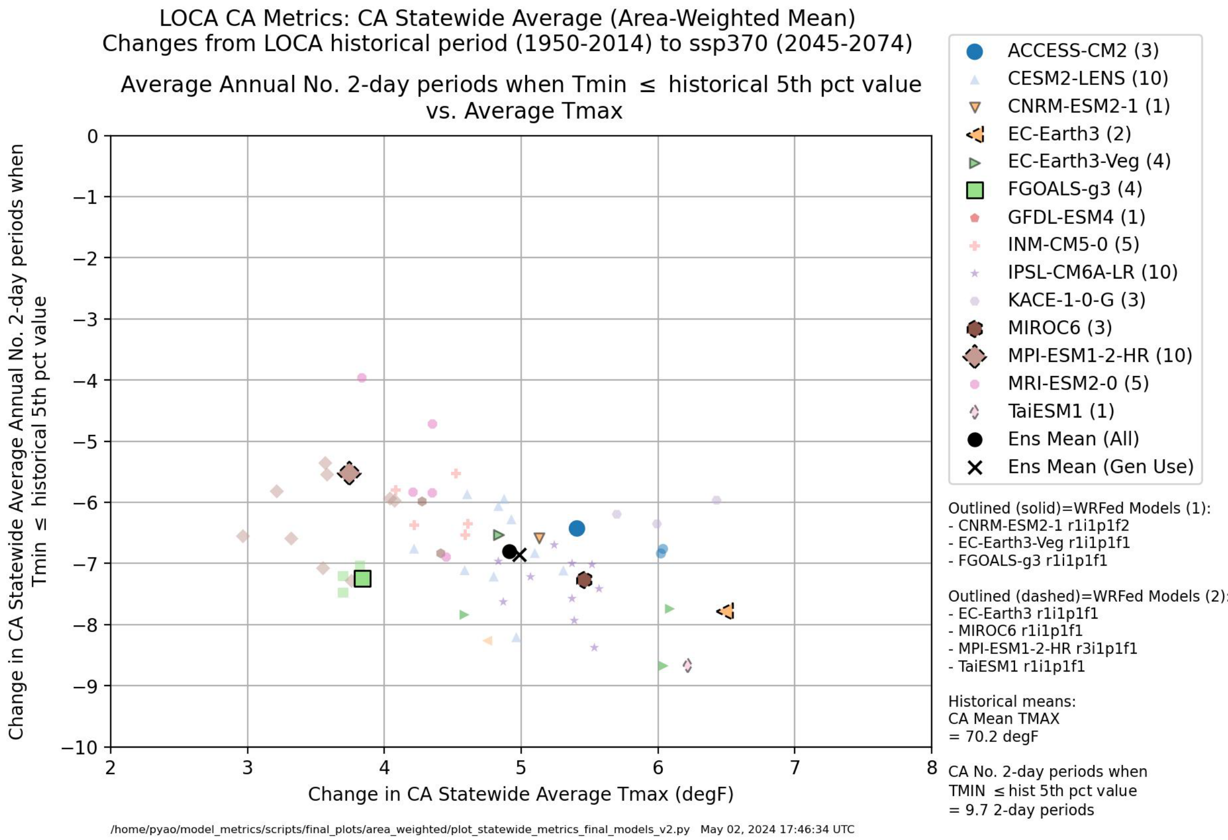

Figure 3. Same as Figure 1 except for cold snaps, change in the number of 2-day periods when Tmin is below the historical 5th percentile instead of precipitation change. While there is a relationship with Tmax, the relationship is not as strong as the heatwave metric.

In addition to the temperature extremes, we also examine precipitation extremes, both flood and drought. There are strong relationships between model-projected annual change in precipitation and projected changes in extreme 3-day precipitation (flood) and drought (3 year dry periods; Figure 4). These relationships support using annual change in precipitation as the basis for the *General Use Projection* selection.

Two of the MPI-ESM1-2-HR ensemble members show a decrease of about 20% in the annual number of extreme wet 3-day periods as compared to the chosen MPI-ESM1-2-HR ensemble member (Figure 4a). The same two MPI-ESM1-2-HR ensemble members also show more extreme drought (Figure 4b) than the selected ensemble member. This motivated us to examine an annual precipitation time series of the selected MPI-ESM1-2-HR ensemble, which does have an extended drought at the end of the century that is not captured in the mid-century analysis used for the *General Use Projection* selection process. This highlights one of the limitations of using the *General Use Projections*; a smaller subset such as these do not represent the full range of all the possible climate extremes. The two ensemble members with dry conditions were not chosen as members of the set of *General Use Projections* because they did not have data available from the dynamical downscaling WRF runs. The analysis from the larger set of LOCA2-Hybrid runs allows us to place the selected *General Use Projections* into the wider context of data available from the CMIP6 archive.

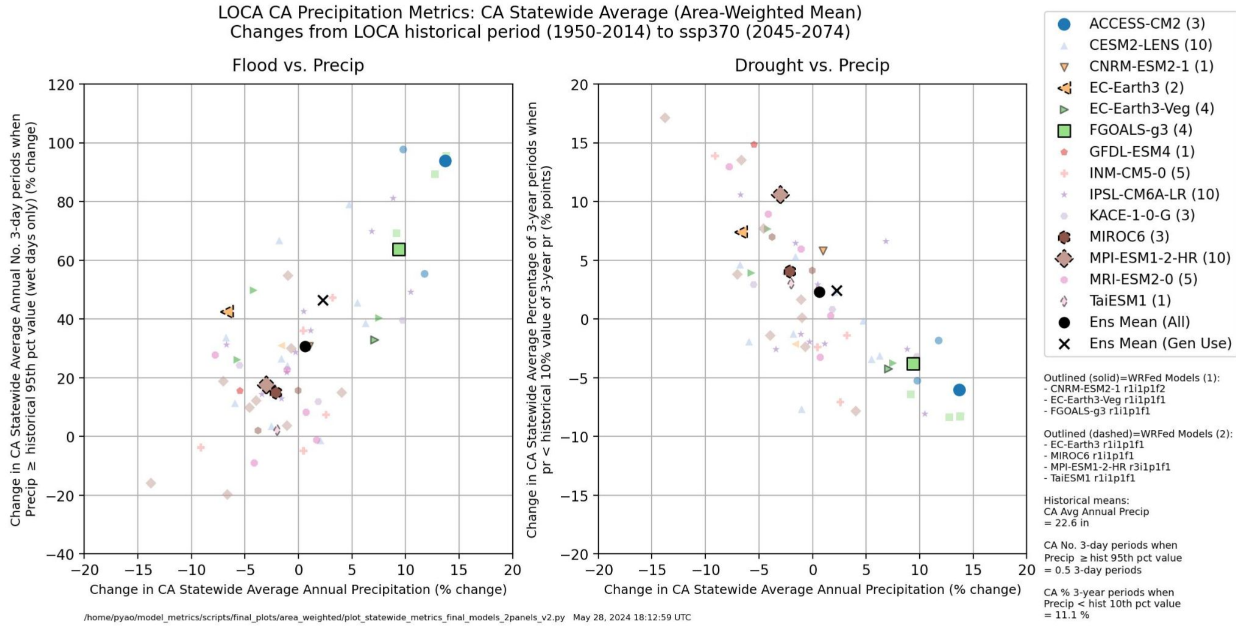

Figure 4. Both panels are structured similarly to Figure 1, however the variables are different. Both panels show the annual percent change of precipitation relative to precipitation extremes. Flood extremes are represented by 3-day values greater than the historical 95th percentile (right) and dry extremes are represented by 3-year dry periods less than the historical 10% value (left).

Energy sector users identified wind as an important metric, thus we reviewed wind as a possible metric for the general use selection. It is important to note that FGOALS-g3 did not save the necessary variables for LOCA2-Hybrid downscaling of winds, so there are only four *General Use Projection* that have LOCA2-Hybrid wind data. Overall, the GCMs project a change in wind speeds averaged over CA that range from about a 1% increase to a 3% decrease. The four *General Use Projections* with wind data represent the ranges of the projected changes in statewide averaged wind speed (Figure 5) and therefore meet the criteria for selecting *General Use Projection* (prioritized criteria #,1 above). However, upon further examination of the wind data, we found that future changes in winds projected by different GCMs varied by location in the state. Thus, it could be unrepresentative to formally adopt statewide averaged wind as a metric for the general use selection (Figure 6), and this is why wind was considered but ultimately not included in the final general use projection selection process. Users who require future projected changes in wind at specific locations should evaluate the broader set of models for their specific location of interest rather than relying solely on the reduced set of *General Use Projection*.

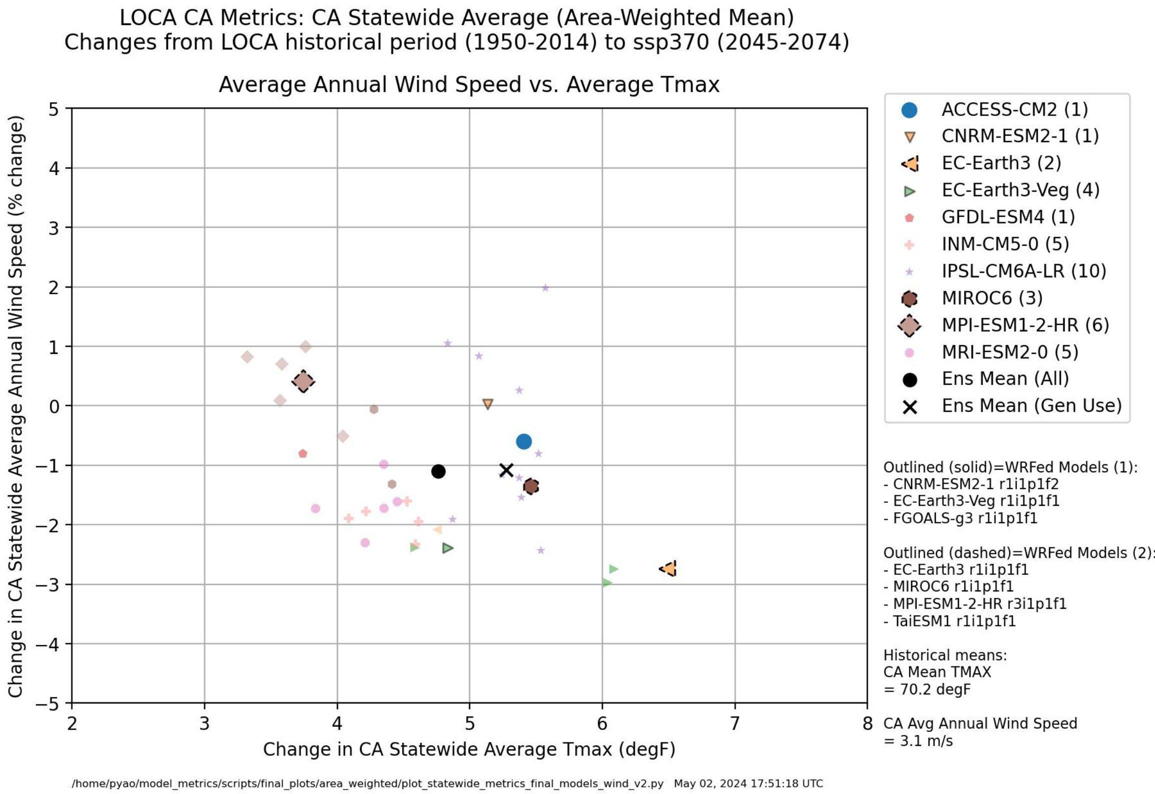

Figure 5. Same as Figure 1 except change in average annual statewide wind speed is on the y-axis. The general use projections generally capture the change in wind speeds but does not have a model that represents the quadrant of cool and decreased wind speeds.

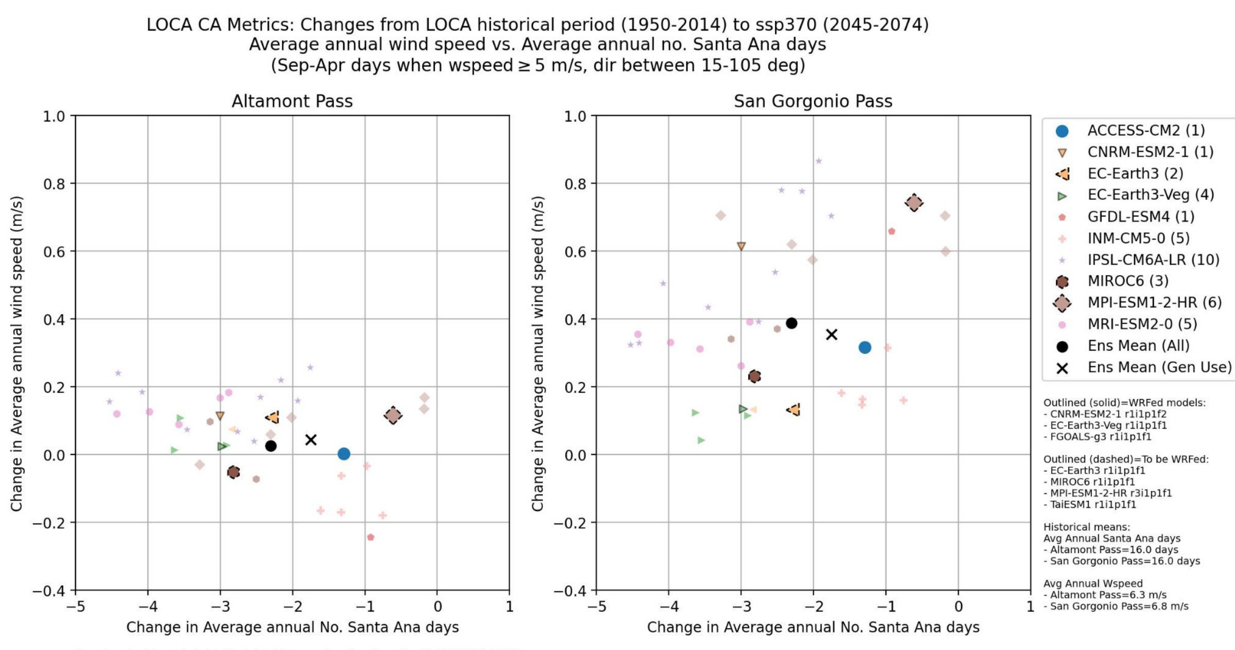

Figure 6. Assessment of number of Santa Ana Winds days and Average Annual wind speed at Altamont Pass, located in Alameda County (left), and San Gorgonio Pass, located in Riverside County (right). Each panel is designed as Figure 1. The two locations show wide variation in the changes in wind speed.

Limitations of the General Use Selection Process

Since the *General Use Projections* provide only a small subset of models, there are limitations to what they can represent. The *General Use Projections* were selected based on the seven prioritized criteria listed above. These considerations did not include how the *General Use Projections* capture the range of future changes during different time periods, for example, mid- vs. end-century. However, when we checked this by examining the change in Tmax and precipitation at the end of the century and found that the *General Use Projections* capture the range of projections during this period as well (Figure 7). Nonetheless, as was shown in the precipitation extremes (Figure 4), the reduced number of models cannot account for all of the variability between the different models and ensemble members for end of century precipitation, which is especially true for climate extremes.

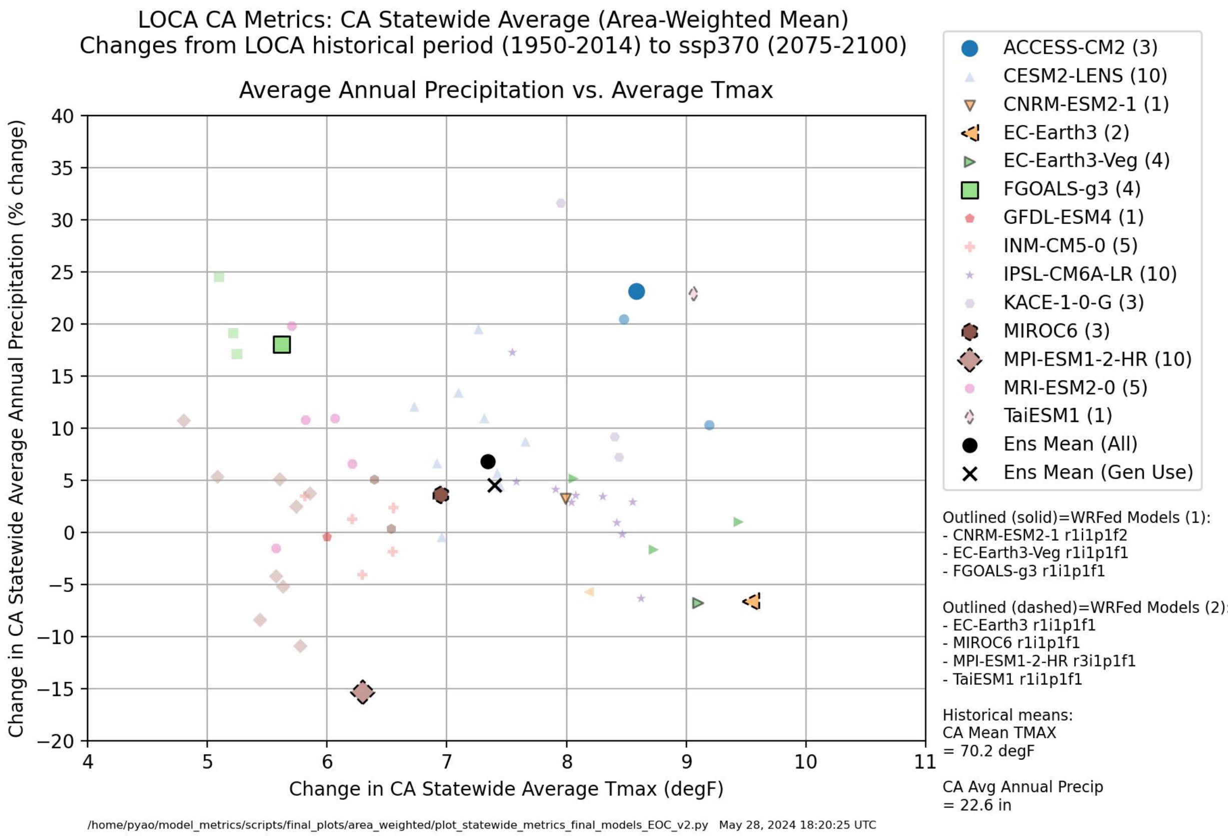

Figure 7. Same as Figure 1 but for the end of century (2075-2100) rather than mid-century.

Conclusion

We encourage all users of the downscaled California climate model projections to use as many models as possible in their evaluations of the impacts of future climate change. However, we understand that not all users have the facilities to analyze the full data set, which is extensive. The *General Use Projection*s were designed to be an entry point into assessing climate data and help ensure that users who can only analyze a reduced subset of the full model data are at least using models that span the range of mid-century California temperature and precipitation changes. Users should not interpret this as a “preferred” set or “recommended” set of models, but rather as a smaller set of projections to serve as a good starting point for examining climate data.

We use the criteria listed above as we considered these are some of the important factors in selecting the general use projections for the widest variety of stakeholders. These selected members achieve many of the goals of representing a range of projections that span a plausible range of future changes in California’s temperature and precipitation, in both means and extremes (hot days, floods, and droughts). They are, nonetheless, limited in representing the complete GCM and ensemble range, especially in how they represent extremes in a selected area of interest. By their nature, extreme climate impacts on a local scale cannot be understood solely from a selection of a limited number of statewide averages.

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