Data Adoption Justification Memo (for California's Fifth Climate Change Assessment):
Hourly Sea Level Projections from CMIP6 climate and weather

Dan Cayan, Sam Iacobellis, Julie Kalansky, Scripps Institution of Oceanography, UCSD
CEC-funded agreement: EPC-20-006 Development of Climate Projections for California and Identification of General Use Projections
November 2023 (updated September 2024 with link to where the data is and to California's Sea-Level Rise Guidance)

Methods and Prior Relevant Work

As part of an EPIC-funded project (EPC-20-006), we have produced hourly sea level projections over the 21st century at 13 sites along the California coastline and within the San Francisco Bay (Figure 1). These projections follow a selected set of low, medium and high sea level rise scenarios as adopted by the state and described in the State of California Sea Level Rise Guidance Update 2023 (Ocean Protection Council, *forthcoming*). The hourly projections augment the SLR Guidance Update results with fine scale (hourly) detail that could be used to explore plausible event-scale occurrences within the longer-term trajectory of possible sea level futures. The hourly time sequences were developed from the same set of global earth system models as have been used in the downscaled weather and climate projections and associated hydrologic modeled land surface hydrology over California, both developed as part of the EPC-20-006 project.

Sea level is estimated as a combination of the predicted astronomical tide, a regression model estimated deviation due to meteorological influences (HMet) (Cayan et al. 2008), and an assumed contribution from long-term sea level rise. The added effects of surface waves and run-up are not included in the modeled sea level projections. Future values of HMet are projected by applying the regression model with forcing data derived from LOCA downscaled (Pierce et al. 2018) global earth system model output from Climate Model Intercomparison Project version 6 (CMIP6) ensemble. Eleven CMIP6 earth system models (ESMs) were employed, each containing one or more ensembles over three emission trajectories (Table 1; Figure 2). Hourly values of future astronomical tides at each tide or water gage location were obtained from the National Oceanographic and Atmospheric Administration (NOAA) website (tidesandcurrents.noaa.gov). Three different long-term sea level rise scenarios (Figure 2) were employed that are used in the California SLR Guidance Update, adopted from the recent NOAA study "Global and Regional Sea Rise Scenarios for the United States (Sweet et al 2022).

In total, 38 HMet weather projections were produced, from which different forms of projected sea level, e.g., at annual (Figure 3) and hourly (Figure 4) time scales can be investigated for each of the modeled locations. At each location, the dataset provides modeled total sea level for each hour from January 1, 1950 through December 31, 2099.

QA/QC & Uncertainty:

Some locations have been excluded, including those whose water level record is relatively short, those whose anomalous water level is poorly modeled using sea level pressure, winds and ocean temperature predictors (e.g., flood affected sites in the Sacramento Delta, and coastal locations that have nearby sites with long records (e.g., San Diego and Pt. Reyes). The ESMs employed to model HMet components were a subset of the most skillful CMIP6 ESMs (Krantz, Pierce et al. 2021) in simulating regional weather and climate phenomena relevant to California, wherein the ESM simulations employed were required to have requisite weather and climate variables for HMet modeling. Some weather influences are likely not linear or may not be captured by the linear predictors used here. Effects of ocean surface waves and run-up on water level anomalies are not included nor are effects of freshwater runoff. Future rates of global and regional sea level change are very likely to be positive, but the magnitude of these rates is not precisely known due to uncertainties in key drivers including future climate warming, melt and mechanical loss of grounded ice and snow, and oceanic processes such as the Pacific Decadal Oscillation and other forms of natural variability (Griggs et al. 2017).

Guidance or Caveats on Best Practices for Use of Data Products

Each CMIP6-driven HMet projection has been paired with three different (lower, medium, and higher) long-term sea-level rise scenarios. Users are advised to consider projections that might be appropriate to assess vulnerability

and impacts for their particular application(s). Some of the greatest impacts of sea levels will occur during relatively short period events, so users may wish to consider occurrences in the projected sea level series when multiple factors (e.g., high tides, large storms, and El Nino conditions) converge to create high sea level extremes. Several projections of sea level, e.g., for the intermediate SLR scenario in Figure 3, are provided at each location. The ensemble of projections may allow users to assess future possibilities such as the future occurrence of high hourly sea level extremes (e.g., Figure 4). The hourly sea level projections can be combined with the downscaled climate and weather projections to investigate the time evolution of compounding weather and climate factors within the respective projections, such as co-occurring extremes of sea level and terrestrial runoff. The hourly sea level projections and associated LOCA2 downscaled CMIP6 weather and climate projections will be made available through Cal-Adapt Analytics Engine (https://analytics.cal-adapt.org/data/updates/).

References

Cayan, D.R., P.D. Bromirski, K. Hayhoe, M. Tyree, M.D. Dettinger, and R.E. Flick, 2008: Climate change projections of sea level extremes along the California Coast. *Climatic Change*, Special Issue on California Climate Scenarios, 87, (Suppl 1):S57-S73.

Griggs, G, J. Árvai, D. Cayan, R. DeConto, J. Fox, H.A. Fricker, R.E. Kopp, C. Tebaldi, E.A. Whiteman, (California Ocean Protection Council Science Advisory Team Working Group), 2017, *Rising Seas in California: An Update on Sea-Level Rise Science*. California Ocean Science Trust.

Krantz, W., D. Pierce, N. Goldenson, and D. Cayan, 2021: Memorandum on evaluating global climate models for studying regional climate change in California (interim deliverable for EPC-20-006). California Energy Commission, 24 pp., https://www.energy.ca.gov/media/7264.

Ocean Protection Council, 2024. State of California Sea-Level Rise Guidance Update 2023. https://opc.ca.gov/wp-content/uploads/2024/05/California-Sea-Level-Rise-Guidance-2024-508.pdf

Pierce, David W., Daniel R. Cayan, Julie F. Kalansky. (Scripps Institution of Oceanography). 2018. Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment, California Energy Commission. Publication number: CCCA4-CEC-2018-006.

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, (2022) Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp.

Table 1. CMIP6 Earth System Model (ESM) runs employed to produce hourly sea level projections, corresponding to Shared Socioeconomic Pathways (SSPs) 245, 370 and 585.

Model Name	Institution Home	Number of Ensembles per Emission Trajectory		
		SSP 245	SSP 370	SSP 585
ACCESS-CM2	Australia	1	1	1
CNRM-ESM2-1	France	1	1	1
EC-Earth3-Veg	Europe	5	4	4
EC-Earth3	Europe	3	2	3
GFDL-ESM4	United States	1	1	1
HadGEM3-CG31-LL	United Kingdom	1	0	3
INM-CM5-0	Russia	1	5	1
IPSL-CM6A-LR	France	5	10	4
MIROC6	Japan	3	3	5
MPI-ESM1-2-HR	Germany	2	6	2
MRI-ESM2-0	Japan	1	5	1
	Total	24	38	26

Figure 1. Locations of the 13 California tide gauge stations used in this study (note that Port Chicago is in the Sacramento-San Joaquin Delta -despite looking "land based' on the map)

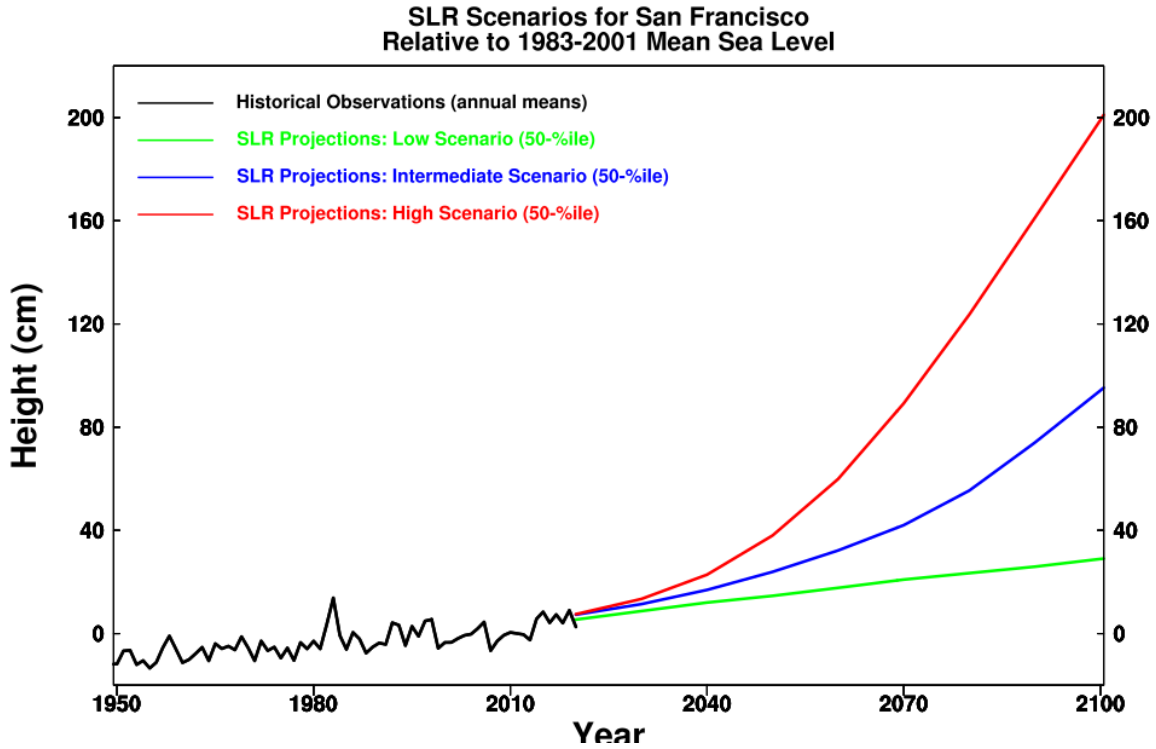

Figure 2. Low (green), Intermediate (blue) and High (red) 50th percentile SLR Scenarios for San Francisco, from those adopted by California Sea Level Rise Update, 2023 (forthcoming). Annual historical observed sea level for San Francisco beginning in 1950 is plotted as black line.

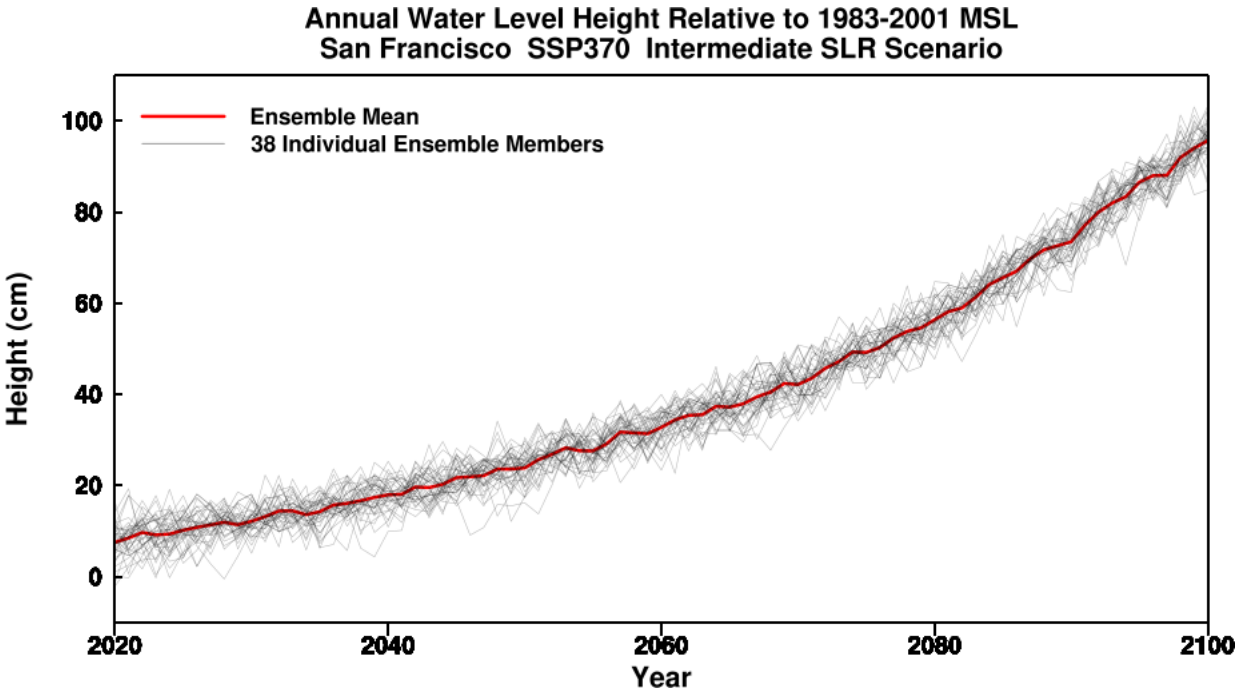

Figure 3. Time series of annual mean water level height at San Francisco from 38 individual model/ensemble members (gray lines) and the ensemble mean (red line). Projections produced with SSP370 emission trajectory and the intermediate SLR scenario. Heights shown are relative to mean sea level (MSL) during the 1983-2001 period.

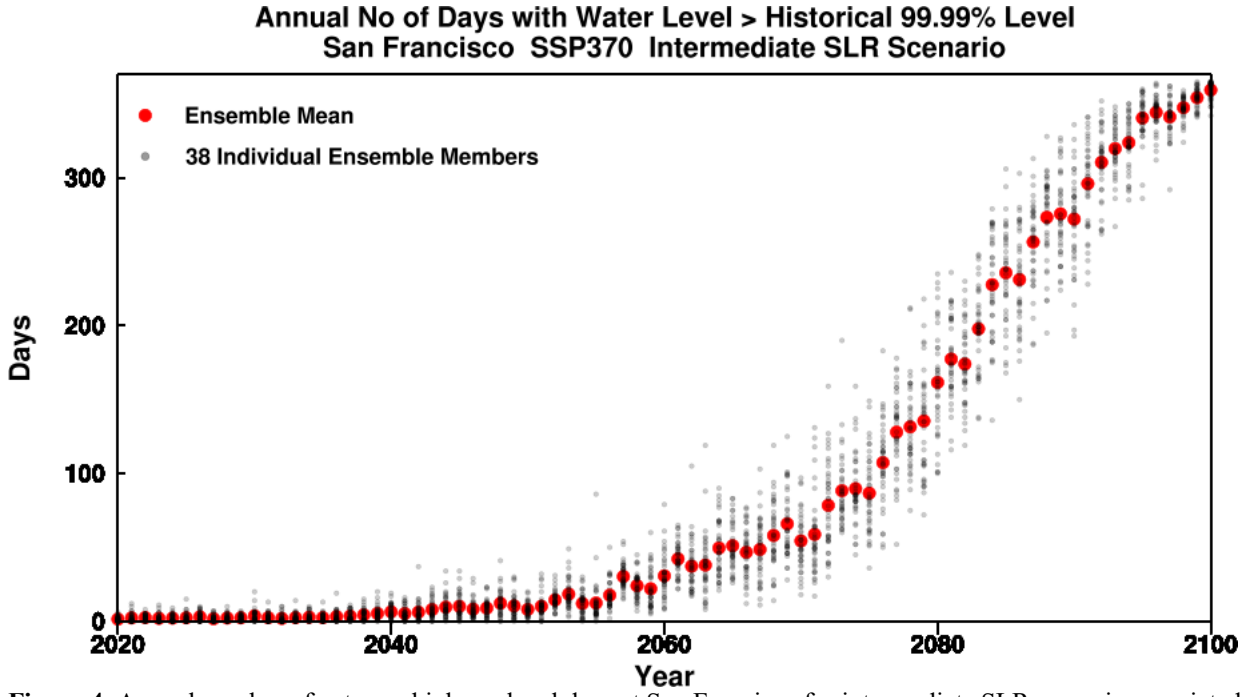

Figure 4. Annual number of extreme high sea level days at San Francisco for intermediate SLR scenario associated with SSP370 emission trajectory. Extreme days are defined as those with at least one hour above the historical (1950-2019) 99.99% hourly water level height at San Francisco for 38 individual model/ensemble members (gray dots) and the ensemble mean (red dots).