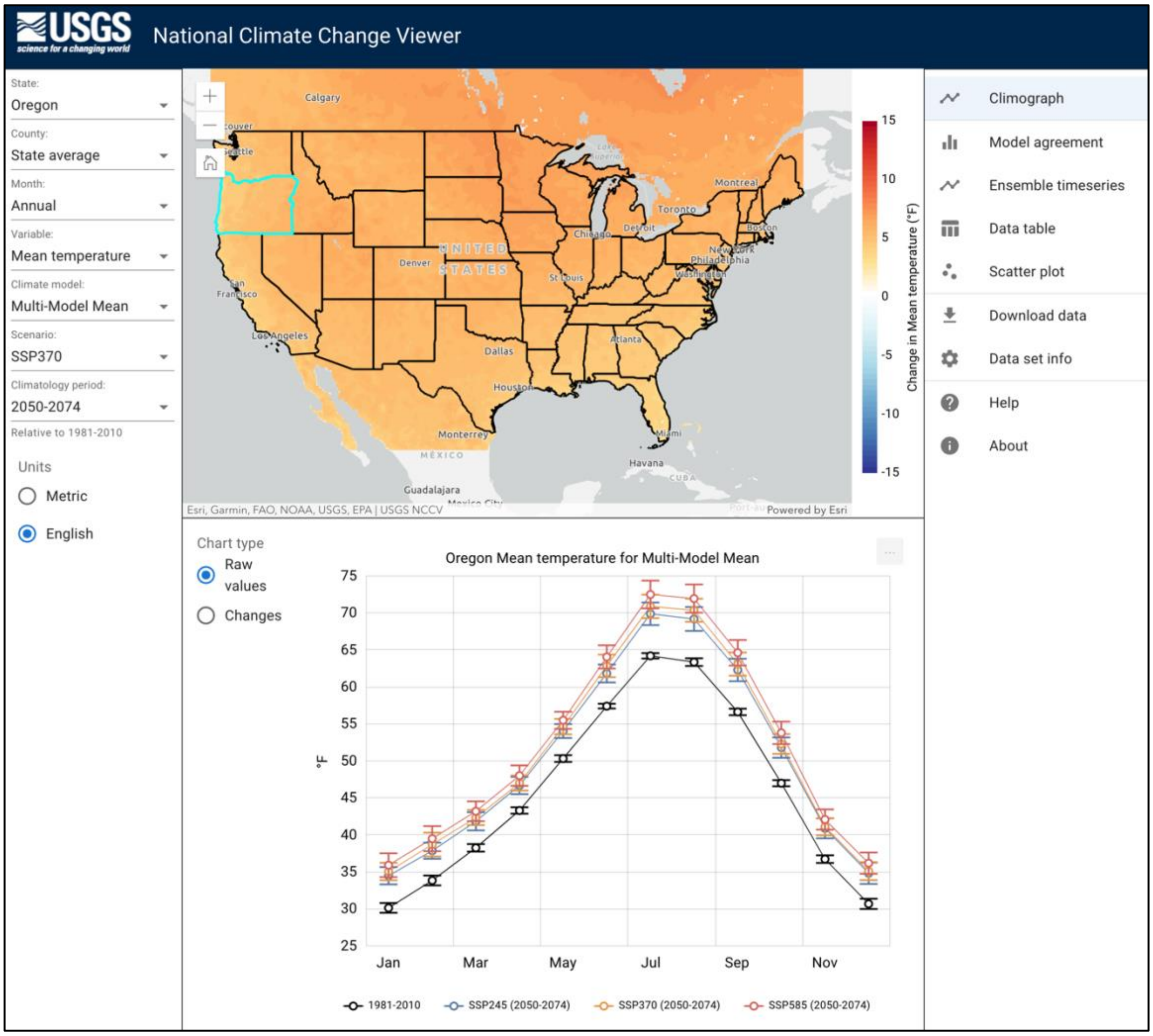
National Climate Change Viewer (NCCV v2.1) Documentation

By Jay R. Alder[1], and Steve W. Hostetler[2]



[1]Geology, Minerals, Energy, and Geophysics Science Center, USGS, Corvallis, OR.

[2]Northern Rocky Mountain Science Center, USGS, Corvallis, OR.

Introduction

Worldwide climate modeling centers participating in the 6th Climate Model Intercomparison Program (CMIP6) provided climate information for the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). The output from the CMIP6 models is on grids ranging from ~1 to 3 degrees in latitude and longitude (roughly 80 to 230 km at 45° latitude). To derive higher resolution data for regional climate change assessments, the Localized Constructed Analogs (LOCA2, Pierce et al., 2023. *Journal of Hydrometeorology*. https://doi.org/10.1175/JHM-D-22-0194.1) statistical method was applied to downscale maximum and minimum air temperature and precipitation from 27 of the CMIP6 models to produce the CMIP6-LOCA2 data set on a 1/16° (~6 km) grid over the continental United States (**Figure 1**). The data set was bias corrected using a modified version of the Livneh2015 observational dataset observational data set (Pierce et al. 2021, *Journal of Hydrometeorology*. https://doi.org/10.1175/JHM-D-20-0212.1).

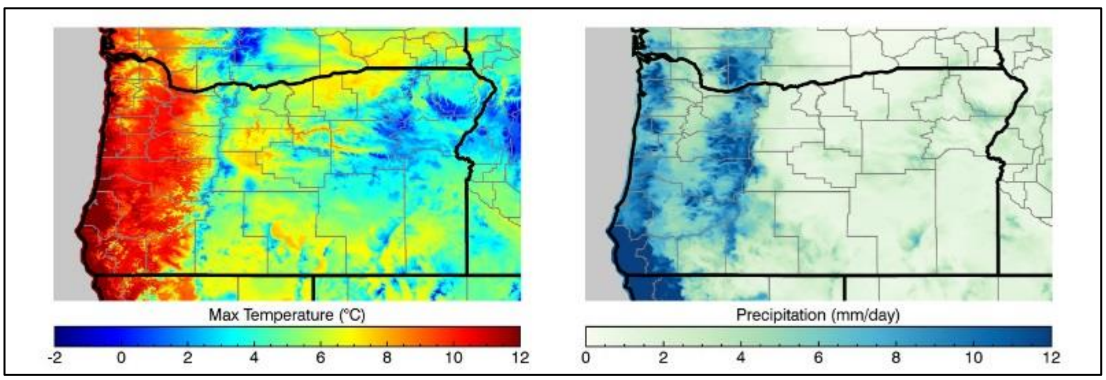


Figure 1. Example of downscaled temperature and precipitation over Oregon.

The NCCV includes CMIP6-LOCA2 data for 27 CMIP5 climate simulations. The monthly data span the historical (1950-2014) and 21st century (2015-2100) periods for three Shared Socioeconomic Pathways (SSPs) greenhouse gas (GHG) emission scenarios (SSP2-4.5, SSP3-7.0, and SSP5-8.5) developed for AR6. (Further details regarding the science behind developing and applying the SSPs are given by O'Neill et al., 2016. *Geoscientific Model Development*. https://doi.org/10.5194/gmd-9-3461-2016). The NCCV also includes water balance data for the contiguous United States (CONUS) over the historical and future time periods simulated using the CMIP6-LOCA2 temperature and precipitation data in a water balance model (Hostetler, S.W. and Alder, J.R., 2016. *Water Resources Research*. doi: https://doi.org/10.1002/2016WR018665).

In SSP2-4.5 GHG emissions are stabilized so as not to exceed a radiative equivalent of 4.5 Wm^{-2} after 2100, about 600 ppm CO_2 equivalent. (For perspective, the atmospheric CO_2 level is currently about 416 ppm). SSP5-8.5 is the most aggressive emissions scenario in which GHGs continue to rise unchecked through the end of the century leading to an equivalent radiative forcing of 8.5 Wm^{-2}, about 1100 ppm CO_2 equivalent. The SSP3-7.0 scenario is similar to the trajectory the Earth is currently experiencing, where radiative forcing reaches 7.0 Wm^{-2} at 2100, about 850 ppm CO_2 equivalent.

The NCCV allows the user to visualize projected changes in climate (mean, minimum, and maximum air temperature and precipitation) and components of the water balance (snow water equivalent, runoff, soil water storage, and evaporative deficit) for states, counties, and for USGS Hydrologic Units Codes (HUC) HUC4 and HUC8. USGS HUCs are hierarchical units of watershed area. For example, the California-Northern Klamath-Costal HUC4, spans an area of 4.3×10^4 km^2 whereas the Upper Klamath Lake, Oregon. HUC8 subbasin within that HUC4 spans an area of 1.8×10^3 km^2.

To create a manageable number of permutations in the viewer, we averaged the climate and water balance data into four climatology periods: 1981-2010, 2025-2049, 2050-2074, and 2075-2099. The 1981-2010 range represents the current climate normal period. The viewer provides many tools for exploring climate change such as maps, climographs (plots of monthly averages), histograms that show the distribution or spread of the model simulations, monthly time series spanning 1950-2100, the ability to view individual model spread by combinations of variables (e.g., temperature and snow water equivalent), and tables that summarize projections for each variable. Access is provided to download summary reports of climate and water balance variables in PDF format and CSV files of the monthly time series. Users can also download the chart data used within the application as compressed JSON files. The gridded CMIP6-LOCA2 data are available in NetCDF format from the LOCA web site (https://loca.ucsd.edu), and the gridded water balance data are available in NetCDF format from USGS ScienceBase (https://doi.org/10.5066/P9DWN1XL).

Overview of the USGS National Climate Change Viewer

Interpreting output from many climate models in time and space is challenging. To aid in addressing that challenge, the NCCV is designed to strike a balance between visualizing and summarizing climate information and the complexity of navigating the site. The features of the viewer are readily discovered and learned by experimenting and interacting; however, for reference we provide the following tutorial to explain most of the details of the viewer.

Controls, map navigation, and charts

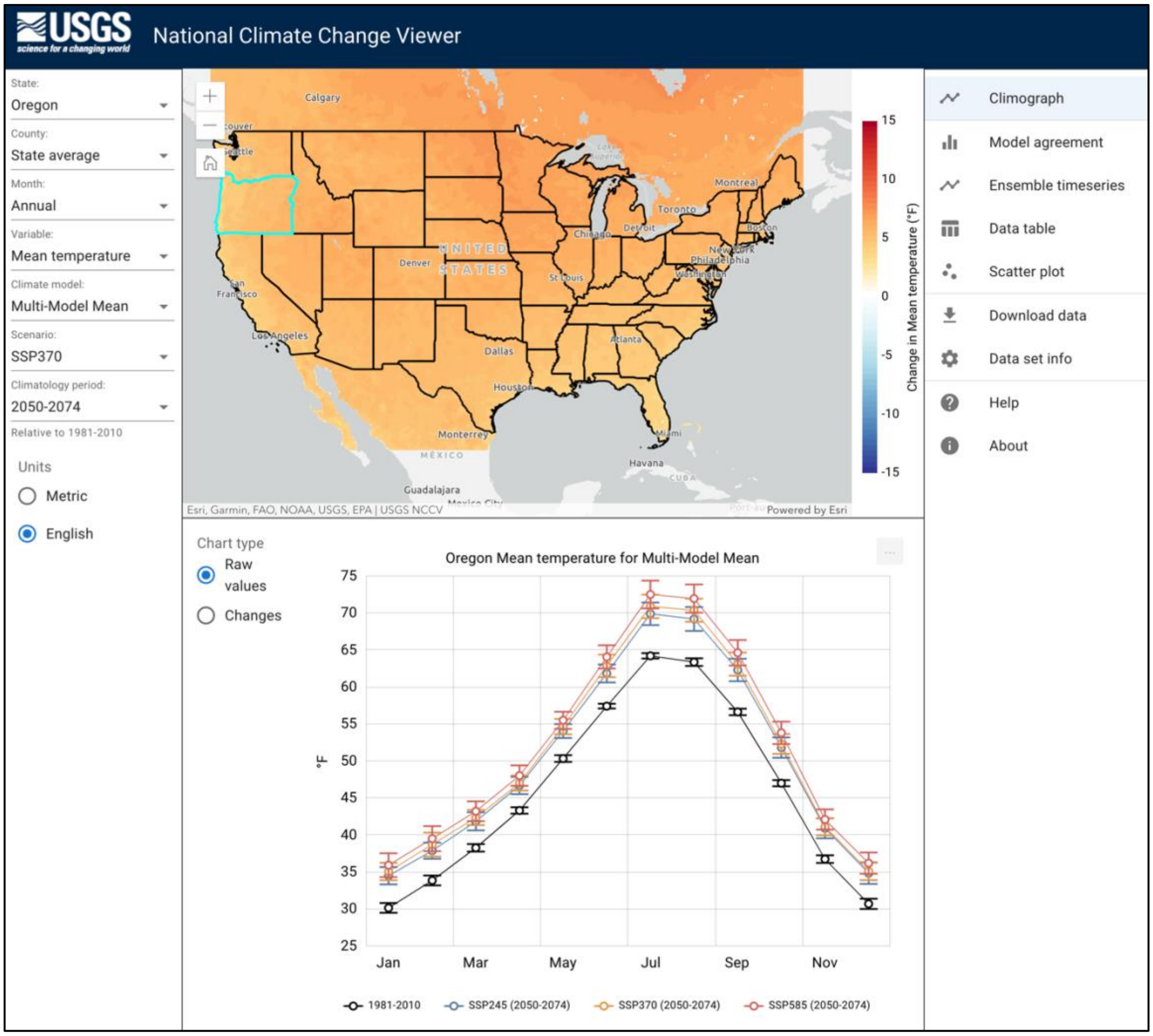


Figure 2 Overview of the NCCV.

The main window of the NCCV (**Figure 2**) displays maps of future change (the difference between the historical period and the selected period) for a selected climate or water-balance variable and related selectable charts and tables. The maps show the spatial variability of change across the contiguous United States, states, and counties or HUC watersheds. The dropdowns on the left-hand side of the application indicate the current selection of place, month or season, variable, climate model, emission scenario, and climatology period displayed in the maps and accompanying charts and tables. The application supports both English and metric units. Changing any of the settings updates all components of the viewer. The right-hand menu provides access to additional charts for further visualizing climate projections and access to the data files.

The county, state, or watershed of interested can be selected either by the dropdown menus in the left control panel or by clicking on the map; the current area of interest is highlighted in cyan color. The map can be panned and zoomed using the mouse, scroll wheel, + and – buttons in top left of map (**Figure 3**) or by using the keyboard (up, down, left, right keys to pan and + and – keys to zoom). The map needs to be selected for keyboard navigation (often the tab key or shift+tab keys are used to navigate web pages without the use of a mouse). The home icon in top left of map returns the map to view full CONUS.

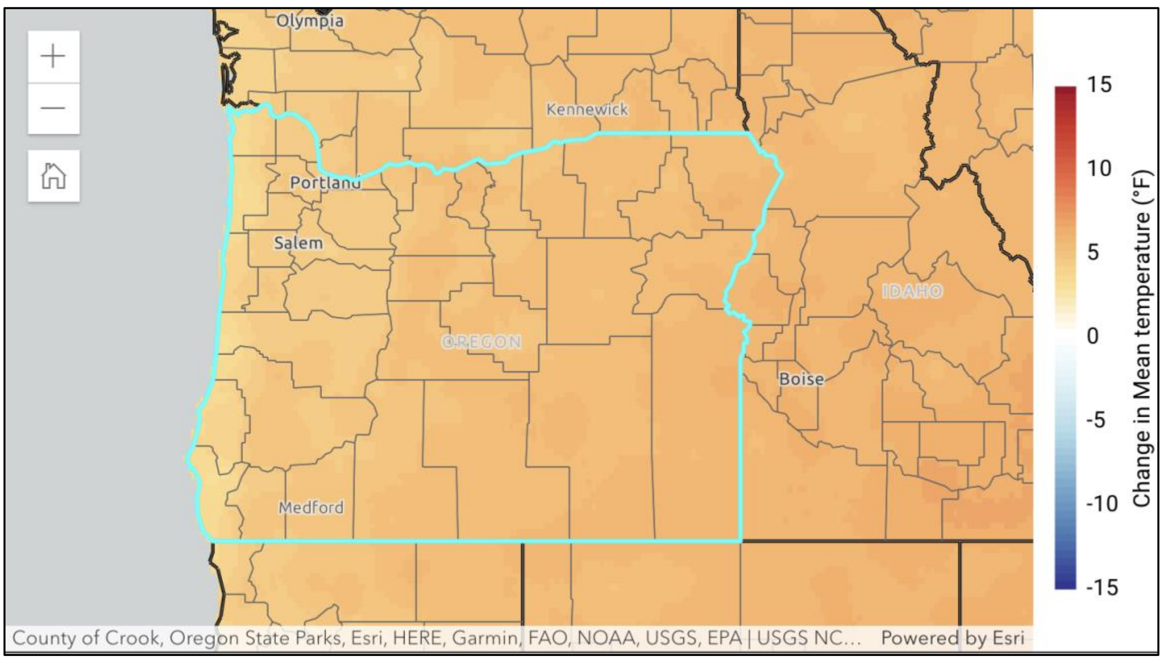


Figure 3 Example of state selection and map navigation.

Climate projections can be viewed for each of the twelve months, seasonal averages (i.e., Winter: December, January, February; Spring: March, April, May; Summer: June, July, August; Fall: September, October, November), and annual average. The Climograph chart only displays the twelve calendar months. The application currently displays eight variables: mean temperature (the average of min and max temperature), maximum temperature, minimum temperature, precipitation, surface runoff, snow water equivalent (SWE), soil storage, and the evaporative deficit, which is the difference between potential evapotranspiration and actual evapotranspiration and is a measure of aridity.

Individual climate models or the average of all the models (Multi-Model Mean) can be selected in the dropdown box (*also see Appendix - Weighting or filtering the Multi-Model Mean*. The scenario and climatology period menus (Figure 2) allows the user to select either the SSP2-4.5, SSP3-7.0, or SSP5-8.5 scenario and one of three time periods of interest: 2025-2049, 2050-2074, or 2075-2099. Changes are all relative to the 1981-2010 historical period. The maps always display anomalies (future minus historical differences), however the Climograph and Ensemble time series charts can display either raw values or anomalies.

Climograph

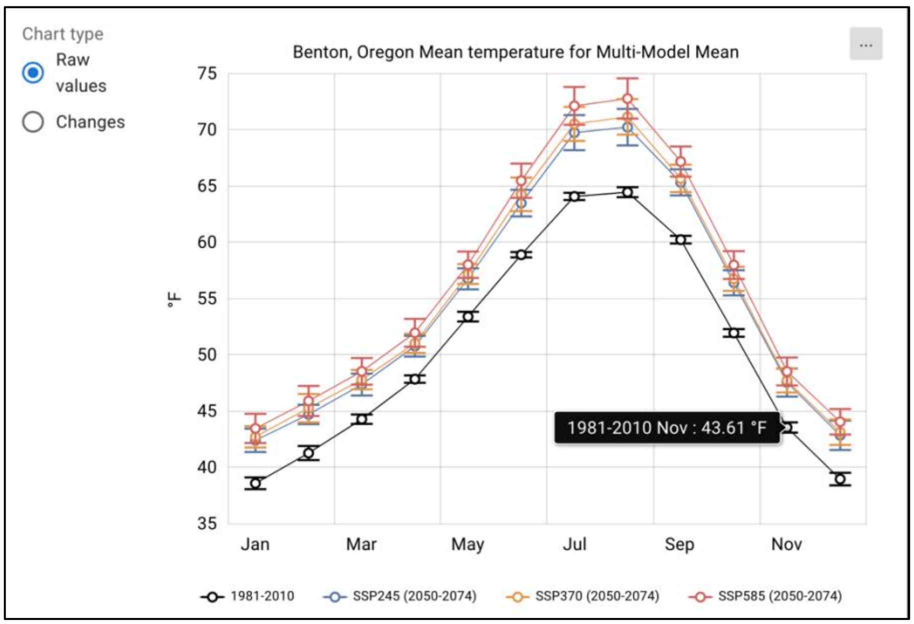


Figure 4 Climograph chart.

The Climograph chart displays the seasonal cycle for the selected location and climate variable and compares the historical period (1981-2010) to future period SSP scenarios (**Figure 4**). The error bars are ± 1 standard deviations within the respective climatology period and is a measure of temporal variability. If Weighted Multi-Model Mean is selected, the error bars are the weighted standard deviation (*see Appendix - Weighting or filtering the Multi-Mean Model*). The mouse can be used to hover over the month circle symbols to display the numeric values. Clicking the circle symbols changes the selected scenario, month, and updates the map display. Individual series can be shown or hidden by clicking on the legend.

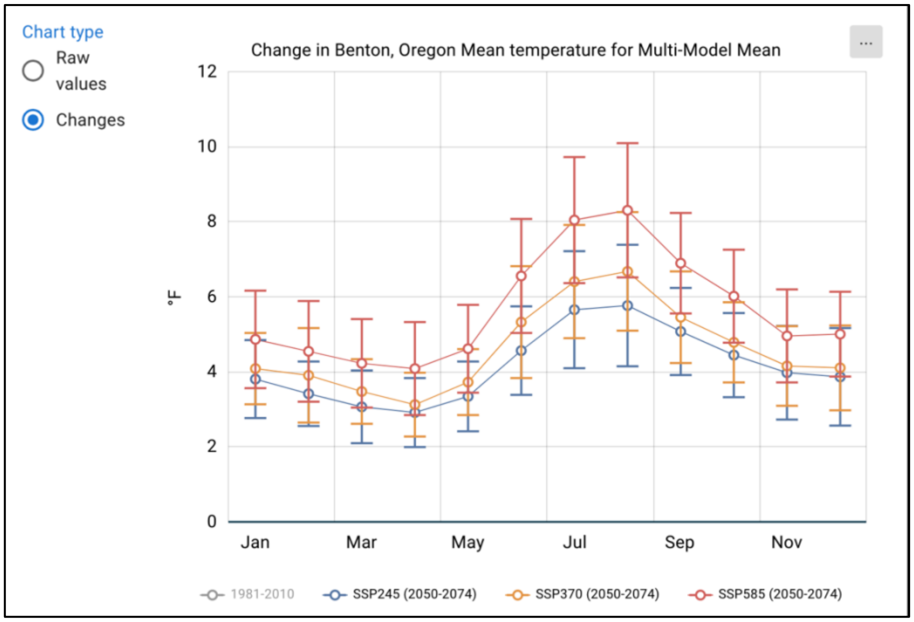


Figure 5 Climograph displaying anomalies.

The chart also displays raw values or changes for the seasonal cycle which highlights the magnitude of monthly change projected for a location (**Figure 5**).

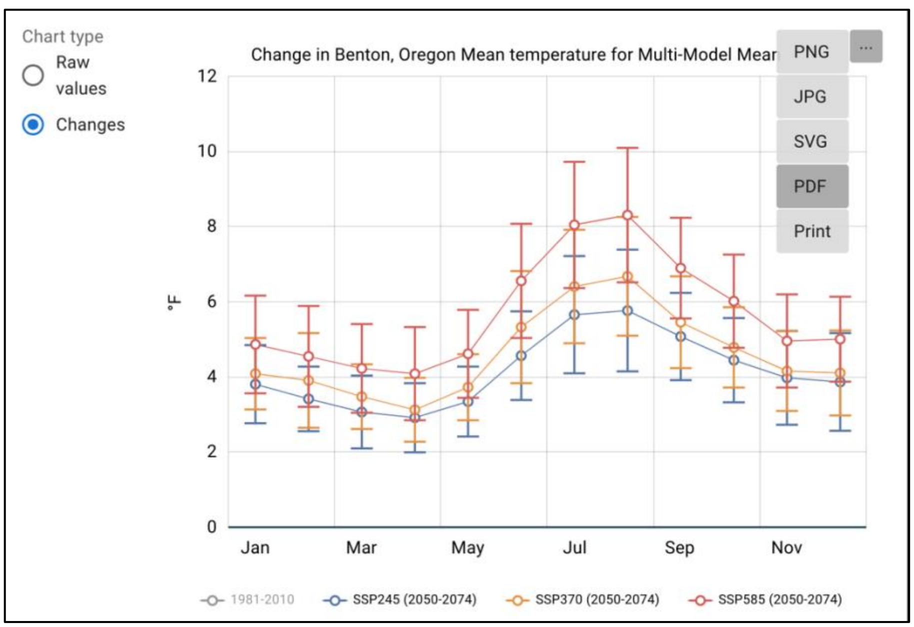


Figure 6 Figure export menu.

All charts within the application can be downloaded in various image formats by clicking the […] menu in the top right of each graphic (**Figure 6**).

Model agreement

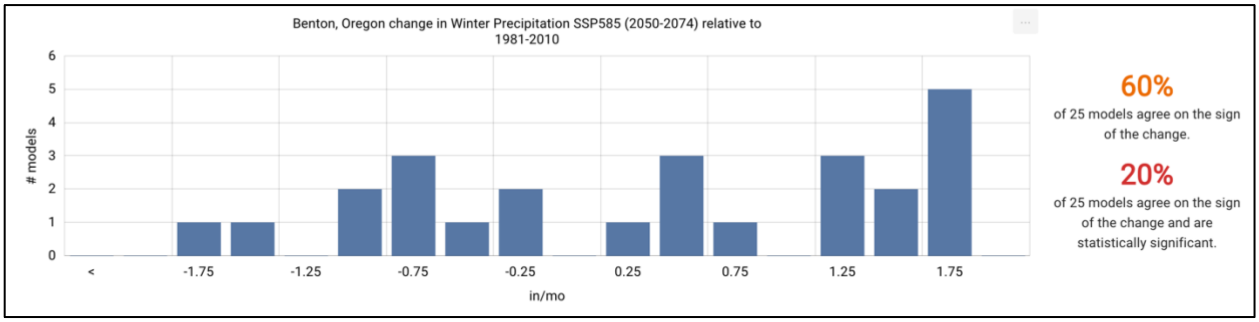


Figure 7 Model agreement chart.

The model agreement chart displays a histogram of the future changes simulated by all climate models (**Figure 7**). This graphic is useful for examining the range or spread of the change simulated by the models. The example above is winter precipitation in Benton County, Oregon in 2050-2074 under the SSP5-8.5 scenario. The range of change in this example is ±1.75 in/mo. Hovering the mouse over the histogram columns displays the models in each bin. Simulated future changes that are statistically significant are denoted with an asterisk in the popup. Clicking on the histogram column cycles through the models within each bin.

As shown by the top numbers to the right of the histogram 15 out of 25 (60%) climate models simulate an increase, whereas 10 of 25 (40%) simulate a decrease. The magnitude of the increase ranges from 0.25 to 1.75 in/mo.

Two measures of model agreement and statistical significance of the simulated changes are shown to the right of the histogram. The top number is the percent of the models that share the same sign as the multi-model median. [The text is color coded into three categories: low (red, <60% agreement), medium (orange: 60 ≤ 80% agreement), high (green > 80% agreement)]. The bottom number indicates the percent of the models that share both the same sign as the multi-model median and simulated changes are statistically significant based on a Mann-Whitney rank test (95% confidence level). In the example, a majority (60%, 15/25 models) of the models simulate increased winter precipitation in Benton County, Oregon and 20% (5/25 models) of the model changes are both positive and statistically significant. This is corroborated in the Data table view.

Ensemble timeseries

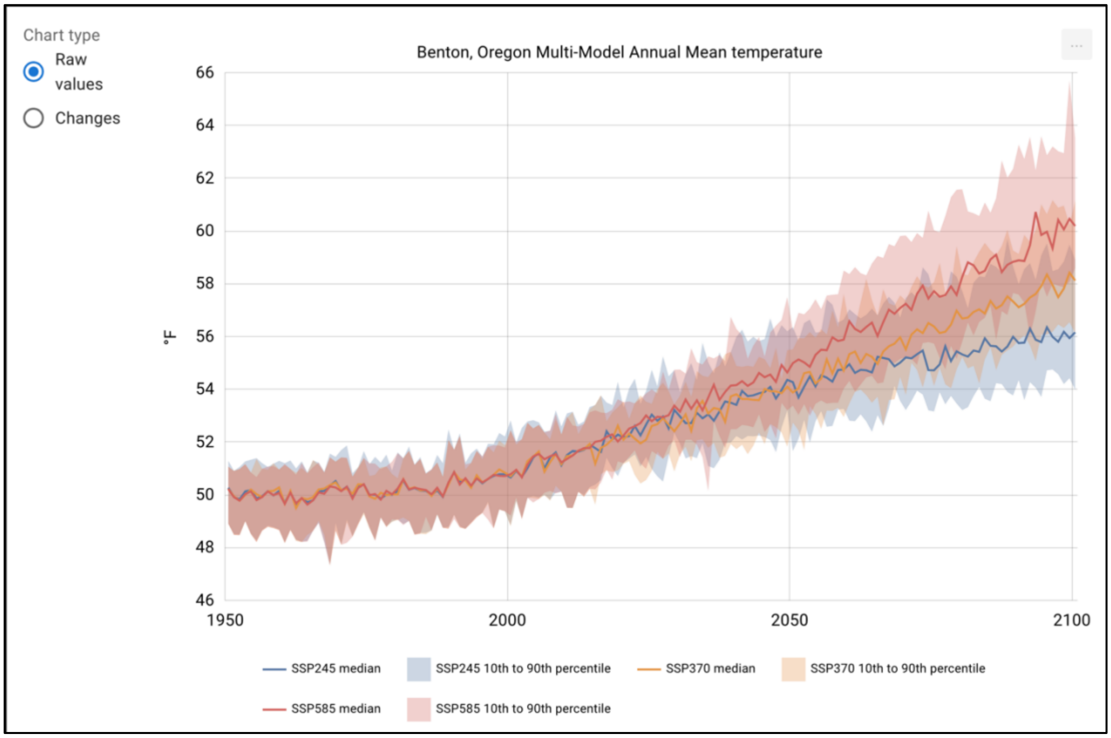


Figure 8 Timeseries chart.

The timeseries chart displays the year-by-year climate projections for the Multi-Model median and the 10th to 90th percentile range from 1950-2100 (**Figure 8**). The percentile range includes 80% of the models and omits models outside of the 10th to 90th percentile range. Unlike the previous charts, model selection in left control panel does not apply here the Multi Model median and range is displayed rather than an individual model. The map will still reflect the currently selected climate model. Like the Climograph chart, the timeseries can be viewed as either raw values or change (relative to the 1981-2010 base period) (**Figure 9**). Hovering the mouse over the time series displays detailed information for an individual year.

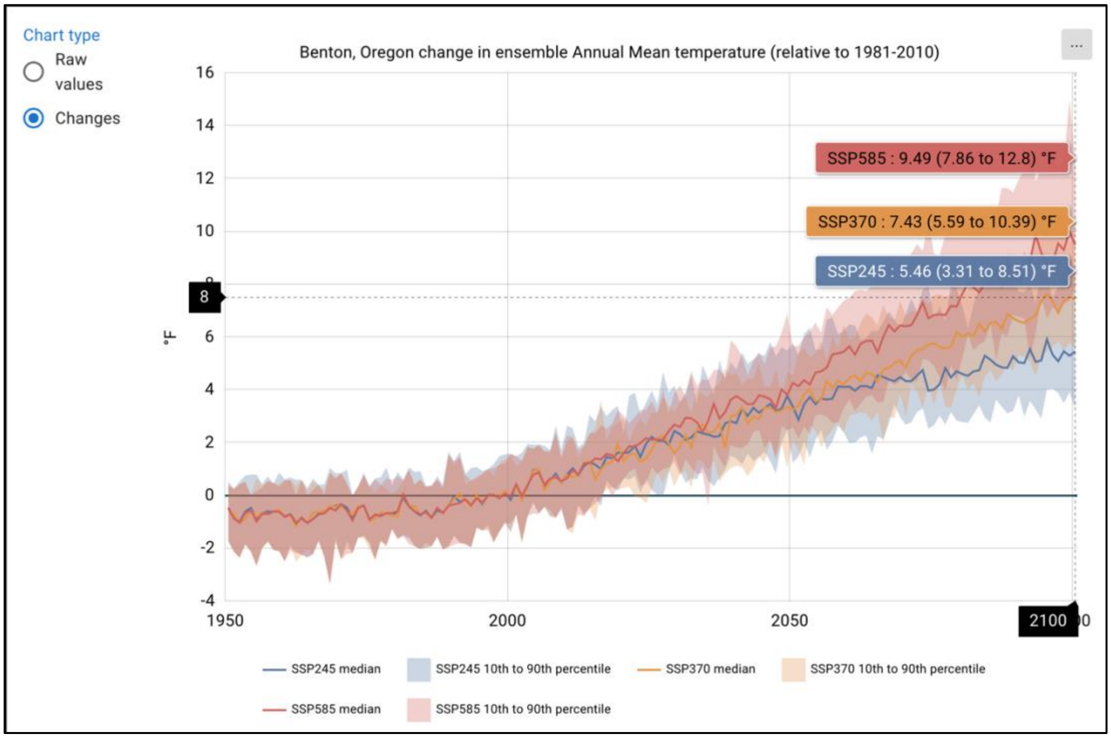
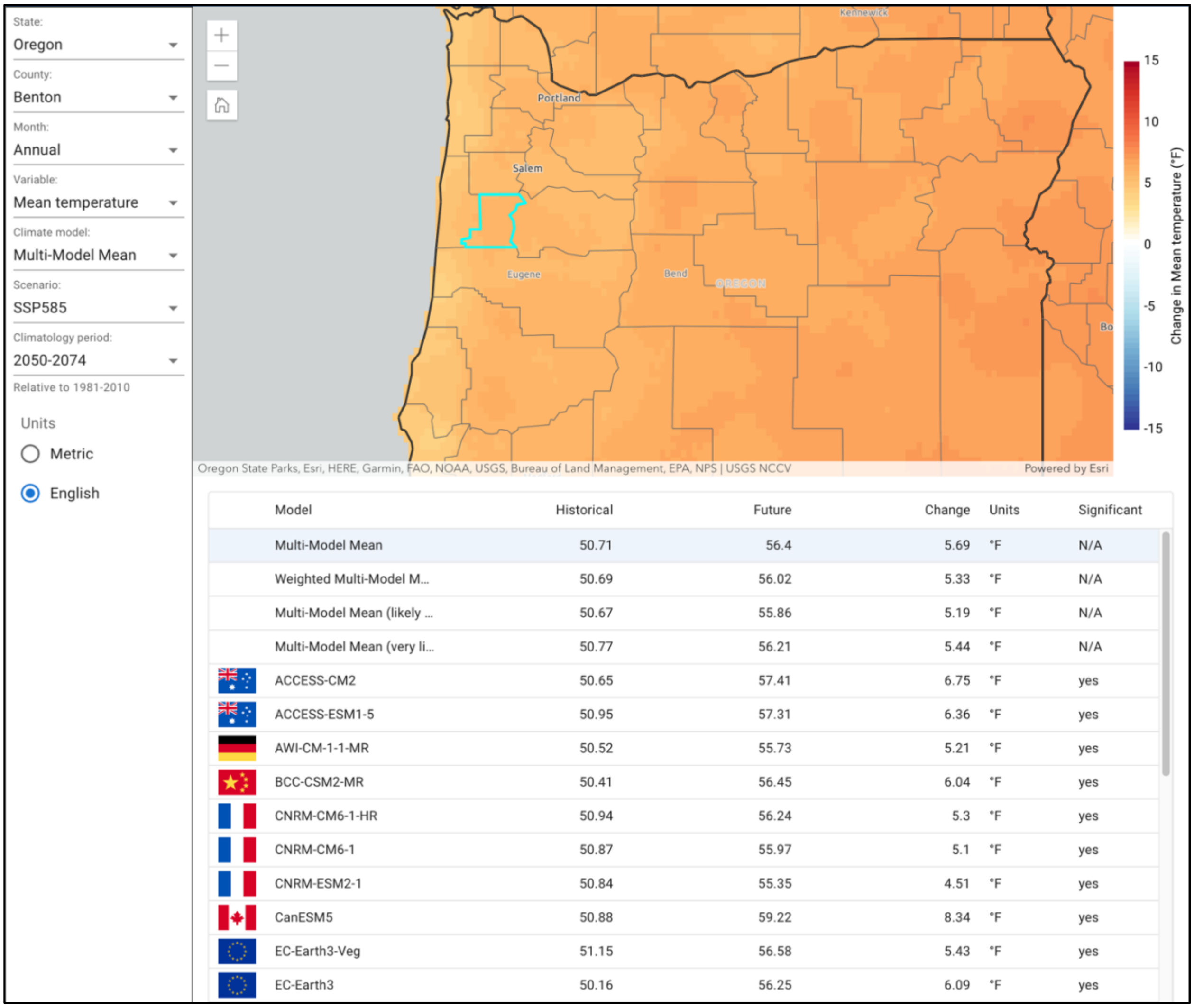


Figure 9 Timeseries displaying anomalies.

Data table



Model	Historical	Future	Change	Units	Significant
Multi-Model Mean	50.71	56.4	5.69	°F	N/A
Weighted Multi-Model M...	50.69	56.02	5.33	°F	N/A
Multi-Model Mean (likely ...	50.67	55.86	5.19	°F	N/A
Multi-Model Mean (very li...	50.77	56.21	5.44	°F	N/A
ACCESS-CM2	50.65	57.41	6.75	°F	yes
ACCESS-ESM1-5	50.95	57.31	6.36	°F	yes
AWI-CM-1-1-MR	50.52	55.73	5.21	°F	yes
BCC-CSM2-MR	50.41	56.45	6.04	°F	yes
CNRM-CM6-1-HR	50.94	56.24	5.3	°F	yes
CNRM-CM6-1	50.87	55.97	5.1	°F	yes
CNRM-ESM2-1	50.84	55.35	4.51	°F	yes
CanESM5	50.88	59.22	8.34	°F	yes
EC-Earth3-Veg	51.15	56.58	5.43	°F	yes
EC-Earth3	50.16	56.25	6.09	°F	yes

Figure 10 Data table.

The Data table displays the full tabular information for the current selection of location, variable, scenario, and climatology period for all climate models. The columns can be sorted by value and the rows. Clicking on a row and column selects an individual climate model. Used in combination, these features are useful to sort the climate models by the magnitude of the future change and visualize how the spatial patterns of change vary among high or low sorted models.

Scatter plot

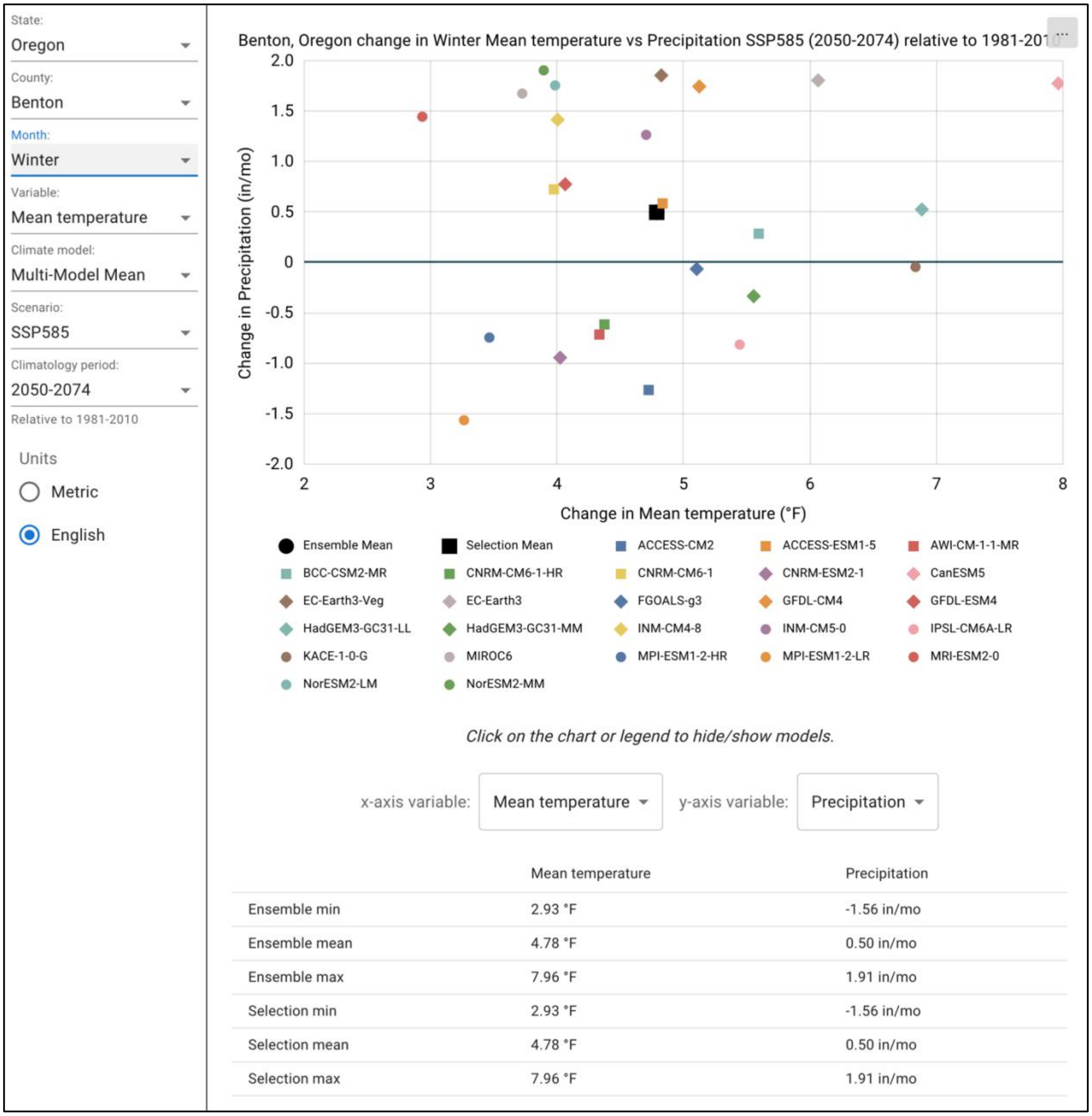


Figure 11 Scatter plot chart.

The Scatter plot graph is used to explore bivariate responses of climate change for a given location (**Figure 11**). The graph plots the future minus historical changes for any two climate or water balance variables for a given month, scenario, and climatology period. This chart is useful to for users interested in screening climate models for additional analysis, such as for the warmest/coldest or wettest/driest or removing models that may be outliers relative to the larger ensemble. Individual climate models can be turned on and off by clicking on the symbol in the chart or on the legend. Below the chart the table displays the full mean and range of all models in addition to the current selection mean and range when a group of models is excluded.

In the example of **Figure 12**, 19 out of 25 models have been disabled. As indicated by the close agreement of the 6-model selection mean (black square) and the full 25-model ensemble mean (black circle) the change in temperature and precipitation means and ranges in the subset of 6 models is preserved, indicating that these models are largely representative of the full ensemble for the location and selected variables.

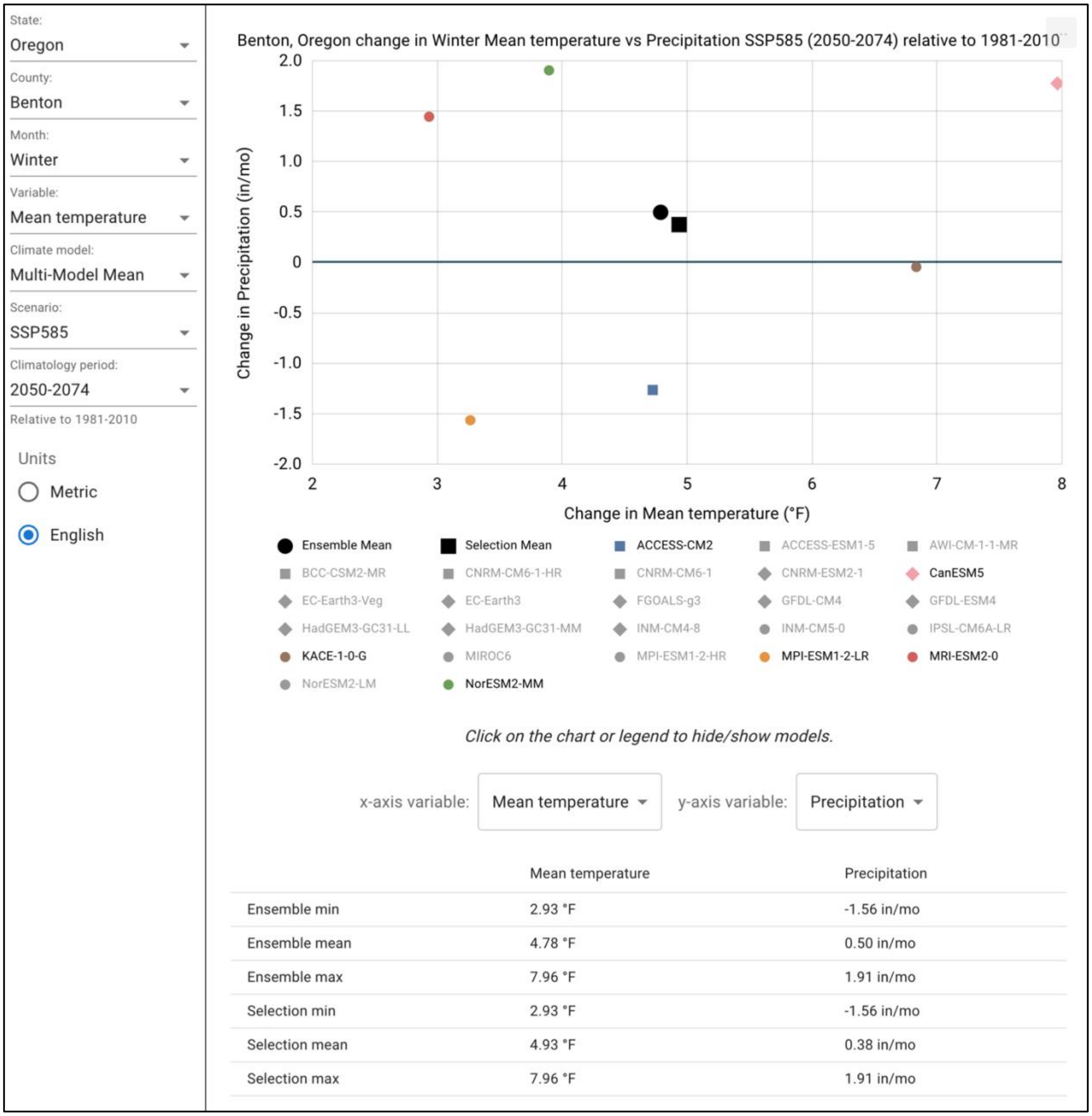


Figure 12 Scatter plot with sub selection.

Download data

Chart data, monthly time series, and summary PDF reports for each county, state, and watershed can be downloaded in either English or metric units (**Figure 13**). The PDF reports (**Figure 14**) provide a comprehensive summary of the climate projections for a selected location through graphics like those found in the viewer. Graphics are provided for all the variables used in the application. The PDF reports summarize the model ensemble rather than an individual model.

The downloadable comma separated variable (CSV) files contain the 1950-2100 monthly timeseries of all variables for the three SSPs (**Figure 15**). Time series files for each model are available for additional analysis outside the application. Metadata is included to describe the file contents and the monthly values for the three scenarios are registered in time by the model year and month. Note that the data are the raw averages and not the differences between the scenarios and the historical period. The data files used to create the charts within the application can also be downloaded as compressed JSON files. While not in the Download data view, any chart displayed in the application can be downloaded by clicking the […] menu in the top right of each graphic (see **Figure 6**).

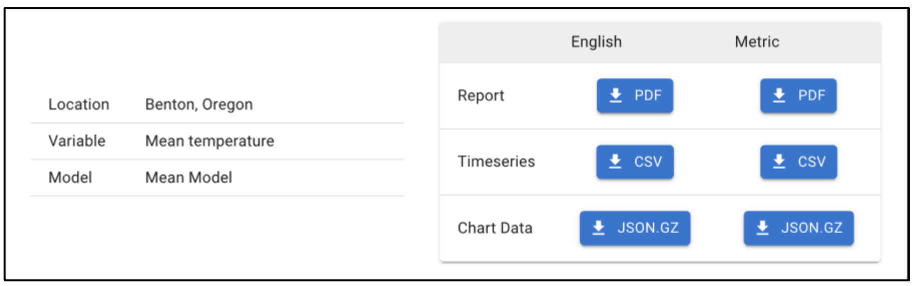


Figure 13 Download data option menu.

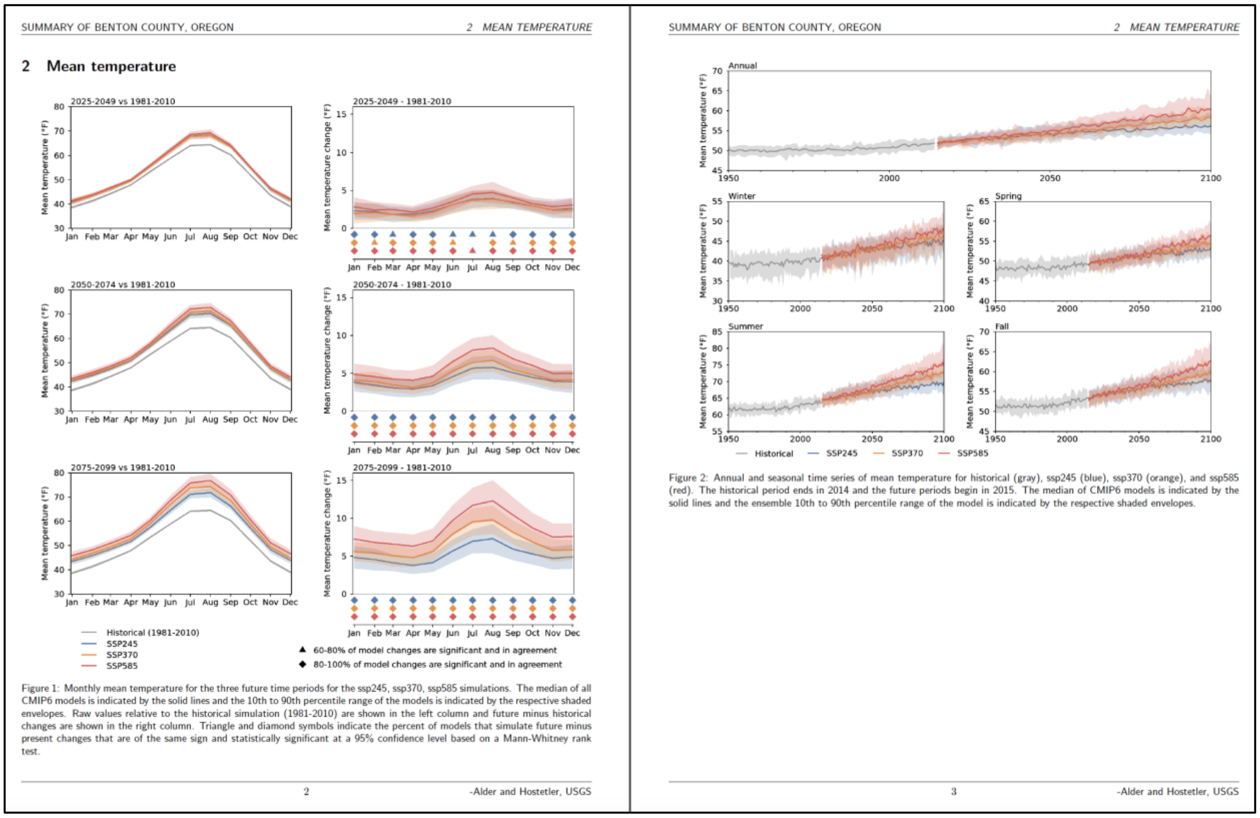
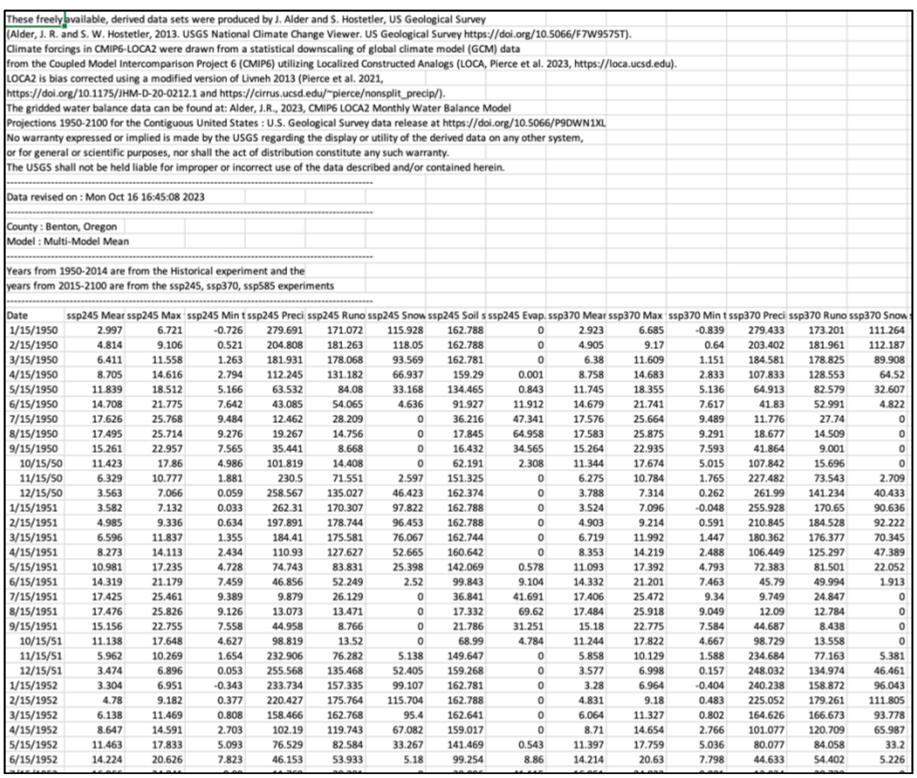


Figure 14 Sample PDF report.



These freely available, derived data sets were produced by J. Alder and S. Hostetler, US Geological Survey
(Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T).
Climate forcings in CMIP6-LOCA2 were drawn from a statistical downscaling of global climate model (GCM) data
from the Coupled Model Intercomparison Project 6 (CMIP6) utilizing Localized Constructed Analogs (LOCA, Pierce et al. 2023, https://loca.ucsd.edu).
LOCA2 is bias corrected using a modified version of Livneh 2013 (Pierce et al. 2021,
https://doi.org/10.1175/JHM-D-20-0212.1 and https://cirrus.ucsd.edu/~pierce/nonsplit_precip/).
The gridded water balance data can be found at: Alder, J.R., 2023, CMIP6 LOCA2 Monthly Water Balance Model
Projections 1950-2100 for the Contiguous United States : U.S. Geological Survey data release at https://doi.org/10.5066/P9DWN1XL
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Data revised on : Mon Oct 16 16:45:08 2023

County : Benton, Oregon
Model : Multi-Model Mean

Years from 1950-2014 are from the Historical experiment and the
years from 2015-2100 are from the ssp245, ssp370, ssp585 experiments
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Date	ssp245 Mear	ssp245 Max	ssp245 Min t	ssp245 Preci	ssp245 Runo	ssp245 Snow	ssp245 Soil s	ssp245 Evap.	ssp370 Mear	ssp370 Max	ssp370 Min t	ssp370 Preci	ssp370 Runo	ssp370 Snow
1/15/1950	2.997	6.721	-0.726	279.691	171.072	115.928	162.788	0	2.923	6.685	-0.839	279.433	173.201	111.264
2/15/1950	4.814	9.106	0.521	204.808	181.263	118.05	162.788	0	4.905	9.17	0.64	203.402	181.961	112.187
3/15/1950	6.411	11.558	1.263	181.931	178.068	93.569	162.781	0	6.38	11.609	1.151	184.581	178.825	89.908
4/15/1950	8.705	14.616	2.794	112.245	131.182	66.937	159.29	0.001	8.758	14.683	2.833	107.833	128.553	64.52
5/15/1950	11.839	18.512	5.166	63.532	84.08	33.168	134.465	0.843	11.745	18.355	5.136	64.913	82.579	32.607
6/15/1950	14.708	21.775	7.642	43.085	54.065	4.636	91.927	11.912	14.679	21.741	7.617	41.83	52.991	4.822
7/15/1950	17.626	25.768	9.484	12.462	28.209	0	36.216	47.341	17.576	25.664	9.489	11.776	27.74	0
8/15/1950	17.495	25.714	9.276	19.267	14.756	0	17.845	64.958	17.583	25.875	9.291	18.677	14.509	0
9/15/1950	15.261	22.957	7.565	35.441	8.668	0	16.432	34.565	15.264	22.935	7.593	41.864	9.001	0
10/15/50	11.423	17.86	4.986	101.819	14.408	0	62.191	2.308	11.344	17.674	5.015	107.842	15.696	0
11/15/50	6.329	10.777	1.881	230.5	71.551	2.597	151.325	0	6.275	10.784	1.765	227.482	73.543	2.709
12/15/50	3.563	7.066	0.059	258.567	135.027	46.423	162.374	0	3.788	7.314	0.262	261.99	141.234	40.433
1/15/1951	3.582	7.132	0.033	262.31	170.307	97.822	162.788	0	3.524	7.096	-0.048	255.928	170.65	90.636
2/15/1951	4.985	9.336	0.634	197.891	178.744	96.453	162.788	0	4.903	9.214	0.591	210.845	184.528	92.222
3/15/1951	6.596	11.837	1.355	184.41	175.581	76.067	162.744	0	6.719	11.992	1.447	180.362	176.377	70.345
4/15/1951	8.273	14.113	2.434	110.93	127.627	52.665	160.642	0	8.353	14.219	2.488	106.449	125.297	47.389
5/15/1951	10.981	17.235	4.728	74.743	83.831	25.398	142.069	0.578	11.093	17.392	4.793	72.383	81.501	22.052
6/15/1951	14.319	21.179	7.459	46.856	52.249	2.52	99.843	9.104	14.332	21.201	7.463	45.79	49.994	1.913
7/15/1951	17.425	25.461	9.389	9.879	26.129	0	36.841	41.691	17.406	25.472	9.34	9.749	24.847	0
8/15/1951	17.476	25.826	9.126	13.073	13.471	0	17.332	69.62	17.484	25.918	9.049	12.09	12.784	0
9/15/1951	15.156	22.755	7.558	44.958	8.766	0	21.786	31.251	15.18	22.775	7.584	44.687	8.438	0
10/15/51	11.138	17.648	4.627	98.819	13.52	0	68.99	4.784	11.244	17.822	4.667	98.729	13.558	0
11/15/51	5.962	10.269	1.654	232.906	76.282	5.138	149.647	0	5.858	10.129	1.588	234.684	77.163	5.381
12/15/51	3.474	6.896	0.053	255.568	135.468	52.405	159.268	0	3.577	6.998	0.157	248.032	134.974	46.461
1/15/1952	3.304	6.951	-0.343	233.734	157.335	99.107	162.781	0	3.28	6.964	-0.404	240.238	158.872	96.043
2/15/1952	4.78	9.182	0.377	220.427	175.764	115.704	162.788	0	4.831	9.18	0.483	225.052	179.261	111.805
3/15/1952	6.138	11.469	0.808	158.466	162.768	95.4	162.641	0	6.064	11.327	0.802	164.626	166.673	93.778
4/15/1952	8.647	14.591	2.703	102.19	119.743	67.082	159.017	0	8.71	14.654	2.766	101.077	120.709	65.987
5/15/1952	11.463	17.833	5.093	76.529	82.584	33.267	141.469	0.543	11.397	17.759	5.036	80.077	84.058	33.2
6/15/1952	14.224	20.626	7.823	46.153	53.933	5.18	99.254	8.86	14.214	20.63	7.798	44.633	54.402	5.226

Figure 15 Sample CSV file.

Water Balance Variables

In addition to temperature and precipitation, related projections of future change in the terrestrial hydrological cycle are of interest. We applied a simple water-balance model driven by the 6-km CMIP6-LOCA2 temperature and precipitation from all the included models to simulate changes in the monthly water balance through the 21st century. Access to water balance maps, graphs, charts, PDF summaries, and data in the viewer is identical to temperature and precipitation (**Figure 16**).

> The values for all variables are given in units of average depth (e.g., inches or millimeters) over the area of the selected state, county or HUC.

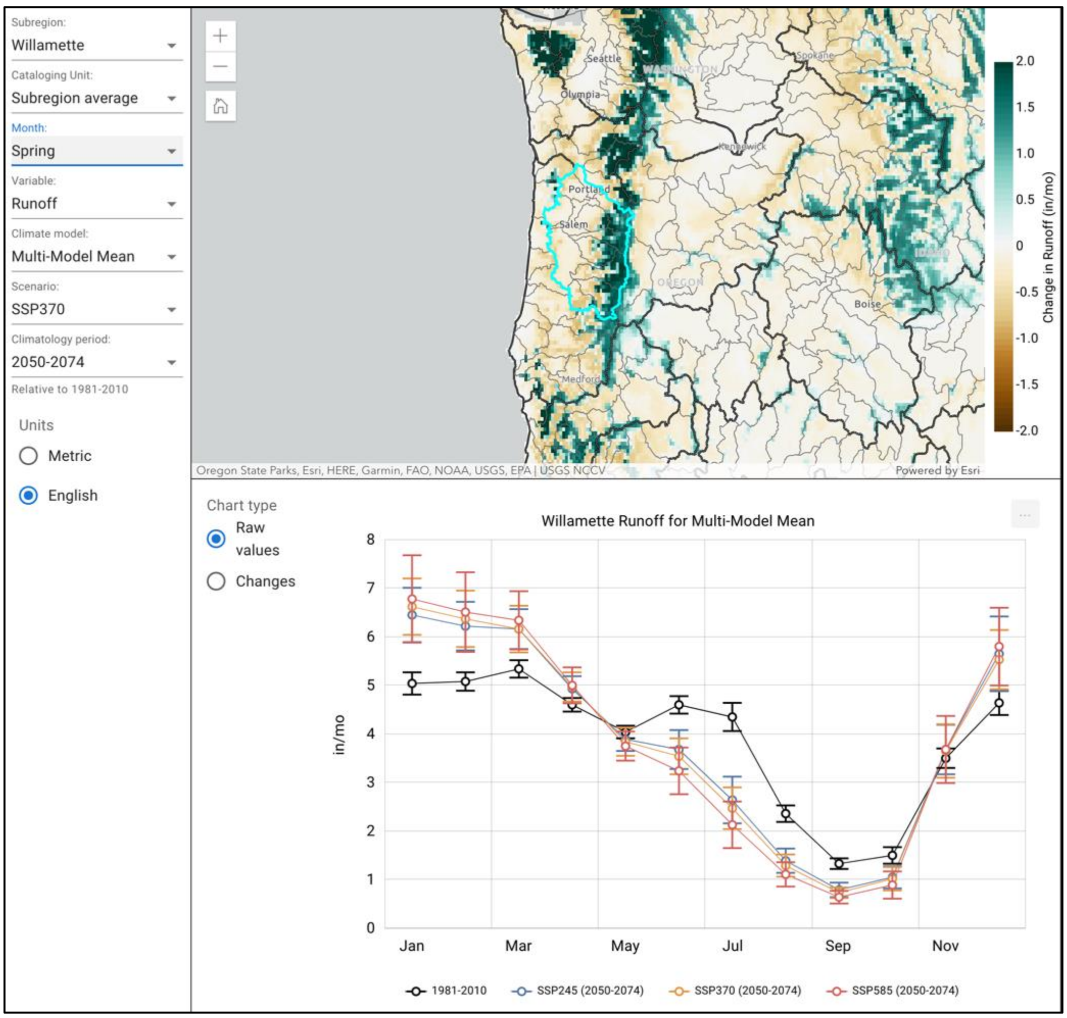

Figure 16 Seasonal cycle of runoff

Overview and limitations of the Water-Balance model

The water-balance model (WBM) was developed by USGS scientists G. McCabe and D. Wolock (1999, *J. Am. Water Resour. Assoc*. doi:10.1111/j.1752-1688.1999.tb04231.x). It has been applied to investigate the surface water-balance under climate change over the US and globally (McCabe and Wolock, 2010, *Climatic. Change*. doi:10.1007/s10584-009-9675-2; Pederson et al., 2013, *Geophysical Research Letters*. doi:10.1002/grl.50424, 2013). A detailed evaluation of the water-balance model using our specific configuration is available (Hostetler, S.W. and Alder, J.R., 2016, *Water Resources Research*. doi:10.1002/2016WR018665) and we have applied the model to assess future projections of snow over the western US (Alder, J. R., & Hostetler, S. W. (2019). The dependence of hydroclimate projections in snow-dominated regions of the western United States on the choice of statistically downscaled climate data. *Water Resources Research*, 55, 2279–2300. https://doi.org/10.1029/2018WR023458).

From inputs of temperature, precipitation, and potential solar radiation, the WBM accounts for the partitioning of water through the various components of the hydrological system (**Figure 17**). Air temperature determines the portion of precipitation that falls as rain and snow, the accumulation and melting of the snowpack, and evapotranspiration (PET and AET). Rain and melting snow are partitioned into direct surface runoff (DRO), soil moisture (ST), and surplus runoff that occurs when soil moisture capacity is at 100% (RO). Potential evapotranspiration is determined from temperature and potential solar radiation by the Oudin method (Oudin et al. 2005).

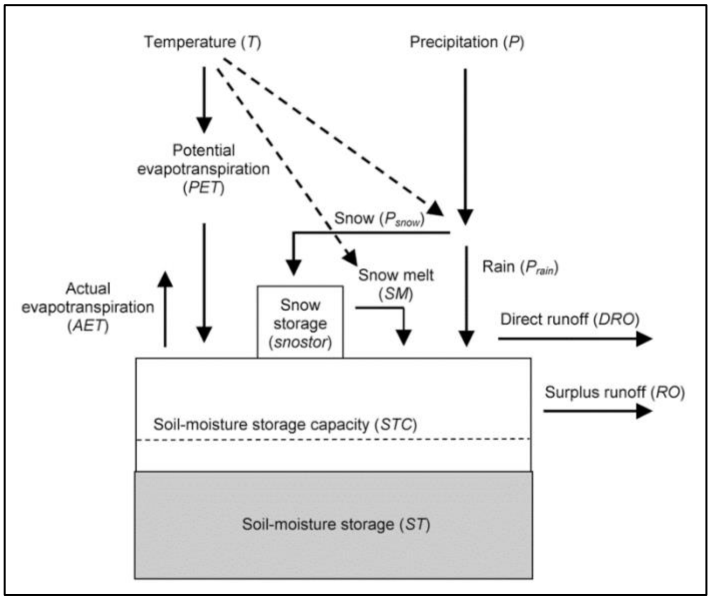

Figure 17 From McCabe and Markstrom, 2007, US Geological Survey Open-File Report 2007-1088.

We include four water balance variables in the viewer (**Figure 17**):

- Snow water equivalent (SWE), the liquid water stored in the snowpack,
- Soil water storage, the water stored in soil column,
- Evaporative deficit, the difference between potential evapotranspiration (PET), which is the amount of evapotranspiration that would occur if unlimited water were available, and actual evapotranspiration (AET) which is what occurs but can be water limited, and
- Runoff, the sum of direct runoff (DRO) that occurs from precipitation and snow melt and surplus runoff (RO) which occurs when soil moisture is at 100% capacity

The simplicity of the WBM facilitates the computational performance needed to run 144 CMIP6-LOCA2 simulations. An additional strength of the WBM is that it provides a common method for simulating change in the water balance, as driven by temperature and precipitation from the CMIP6 models, thereby producing outputs that are directly comparable across all models.

There are tradeoffs in using the simple WBM instead of more complex, calibrated watershed models that use more meteorological inputs (e.g., solar radiation, wind speed) and are adjusted to account for groundwater and water management. These limitations should be kept in mind when viewing the water balance components:

- the model is run on a monthly time step, so it does not capture day-to-day variability nor short-term extreme events such as intense precipitation and floods;
- while physically based, the model simplifies more complex energy balance detail that determines evapotranspiration and snow dynamics;
- the model simulates the runoff of a grid cell but does not route runoff among grid cells or into stream networks or groundwater;
- the parameters used in the model are independent of land use and vegetation;
- surface elevation is implicit through the CMIP6-LOCA2 temperature and precipitation data, but the model does not account for detail of slope or aspect below the resolution of the 6-km by 6-km (3.7-mile by 3.7-mile) grid cells; and
- there are no man-made diversions or reservoirs in the model.

Appendix

Methods

The gridded, 1/16-degree (~6 km) CMIP6-LOCA2 data set was derived by statistically downscaling general circulation models with varying resolutions. The gridded temperature and precipitation data facilitated water-balance modeling over the US, and the consistent grid spacing, and fine resolution of the data sets simplified averaging the data over states, counties, and watersheds. The following steps outline an example for creating county averages. Application to states and watersheds is identical.

Step 1 A GIS shapefile for all the counties in the United States is used to assign each 6-km grid cell in the gridded data a county ID for all the cells falling within the county's boundary. The example below shows counties within Oregon. Grid cells on the boundaries are spatially weighted by the fraction of the grid cell area that lies within the county boundary (not shown).

Step 2 Changes or anomalies in temperature, precipitation, and the water balance components are calculated for the three 25-year averaging periods 2025–2049, 2050–2074 and 2075–2099 relative to the base period of 1981-2010. The 6-km anomalies are displayed as maps in the application.

Step 3 The county ID mask created in Step 1 is used to calculate area weighted spatial averages of the anomalies for every county for each month between 1950–2100. These county averages are used in climographs, histograms, timeseries and data tables.

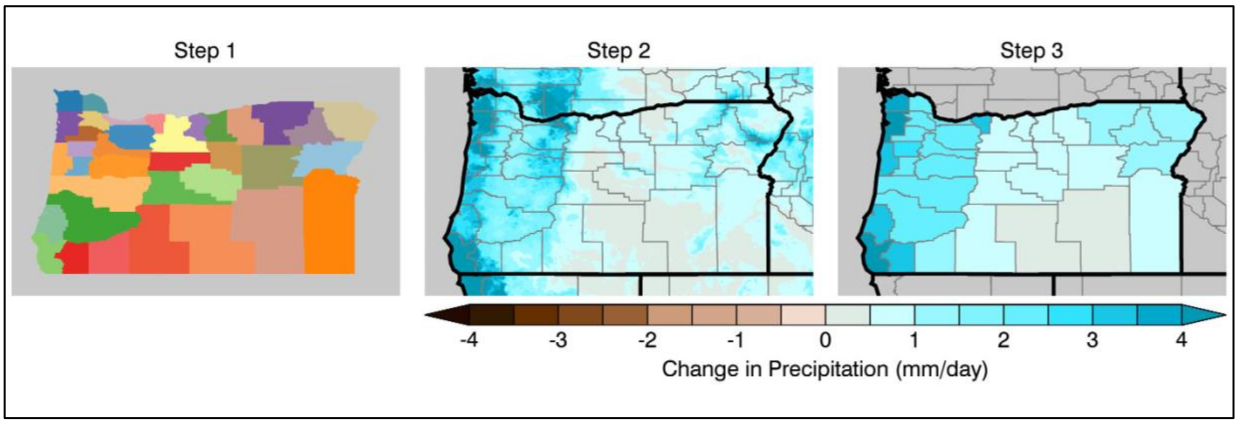

Figure 18 Example of applying region masks to gridded data to create spatial averages.

CMIP6 Models included in the CMIP6-LOCA2 Data Set

Table 1 CMIP6-LOCA2 models and realization used in the National Climate Change Viewer.

Model	Realization	SSP	Very likely ECS	Likely ECS	Weight	GLW1.5		GWL2		GWL3	
						start	end	start	end	start	end
ACCESS-CM2	r1i1p1f1	ssp245		yes	0.412	2019	2038	2031	2050	2062	2081
ACCESS-ESM1-5	r1i1p1f1	ssp245	yes	yes	0.581	2020	2039	2036	2055		
AWI-CM-1-1-MR	r1i1p1f1	ssp245	yes	yes		2011	2030	2030	2049		
BCC-CSM2-MR	r1i1p1f1	ssp245	yes	yes	0.723	2026	2045	2048	2067		
CanESM5	r1i1p1f1	ssp245			0.290	2004	2023	2015	2034	2040	2059
CNRM-CM6-1	r1i1p1f2	ssp245		yes		2021	2040	2039	2058	2075	2094
CNRM-ESM2-1	r1i1p1f2	ssp245		yes		2028	2047	2046	2065	2079	2098
EC-Earth3	r1i1p1f1	ssp245			0.498	2013	2032	2035	2054	2076	2095
EC-Earth3-Veg	r1i1p1f1	ssp245		yes		2001	2020	2024	2043	2058	2077
FGOALS-g3	r1i1p1f1	ssp245	yes	yes	0.716	2022	2041	2056	2075		
GFDL-CM4	r1i1p1f1	ssp245				2022	2041	2040	2059		
GFDL-ESM4	r1i1p1f1	ssp245			0.589	2037	2056	2064	2083		
HadGEM3-GC31-LL	r1i1p1f3	ssp245				2010	2029	2024	2043	2052	2071
INM-CM4-8	r1i1p1f1	ssp245			0.646	2026	2045	2054	2073		
INM-CM5-0	r1i1p1f1	ssp245			0.649	2028	2047	2063	2082		
IPSL-CM6A-LR	r1i1p1f1	ssp245		yes	0.449	2009	2028	2024	2043	2056	2075
KACE-1-0-G	r1i1p1f1	ssp245		yes		2004	2023	2014	2033	2041	2060
MIROC6	r1i1p1f1	ssp245	yes	yes	0.767	2037	2056	2064	2083		
MPI-ESM1-2-HR	r1i1p1f1	ssp245	yes	yes	0.731	2028	2047	2054	2073		
MPI-ESM1-2-LR	r1i1p1f1	ssp245	yes	yes	0.755	2027	2046	2048	2067		
MRI-ESM2-0	r1i1p1f1	ssp245	yes	yes	0.730	2021	2040	2040	2059		
NorESM2-LM	r1i1p1f1	ssp245	yes	yes	0.736	2046	2065	2076	2095		
NorESM2-MM	r1i1p1f1	ssp245	yes	yes	0.727	2037	2056	2069	2088		
TaiESM1	r1i1p1f1	ssp245		yes		2022	2041	2034	2053	2059	2078

Table 1 continued (ssp370).

Model	Realization	SSP	Very likely ECS	Likely ECS	Weight	GLW1.5		GWL2		GWL3	
						start	end	start	end	start	end
ACCESS-CM2	r1i1p1f1	ssp370		yes	0.412	2018	2037	2030	2049	2053	2072
ACCESS-ESM1-5	r1i1p1f1	ssp370	yes	yes	0.581	2024	2043	2039	2058	2060	2079
AWI-CM-1-1-MR	r1i1p1f1	ssp370	yes	yes		2013	2032	2028	2047	2055	2074
BCC-CSM2-MR	r1i1p1f1	ssp370	yes	yes	0.723	2023	2042	2037	2056	2065	2084
CanESM5	r1i1p1f1	ssp370			0.290	2004	2023	2014	2033	2034	2053
CESM2-LENS	r1i1p1f1	ssp370				2016	2035	2032	2051	2057	2076
CNRM-CM6-1	r1i1p1f2	ssp370		yes		2023	2042	2036	2055	2057	2076
CNRM-ESM2-1	r1i1p1f2	ssp370		yes		2027	2046	2043	2062	2063	2082
EC-Earth3	r1i1p1f1	ssp370			0.498	2013	2032	2029	2048	2054	2073
EC-Earth3-Veg	r1i1p1f1	ssp370		yes		2002	2021	2023	2042	2048	2067
FGOALS-g3	r1i1p1f1	ssp370	yes	yes	0.716	2018	2037	2037	2056	2075	2094
GFDL-ESM4	r1i1p1f1	ssp370			0.589	2032	2051	2048	2067	2074	2093
INM-CM4-8	r1i1p1f1	ssp370			0.646	2026	2045	2043	2062	2074	2093
INM-CM5-0	r1i1p1f1	ssp370			0.649	2023	2042	2041	2060	2075	2094
IPSL-CM6A-LR	r1i1p1f1	ssp370		yes	0.449	2010	2029	2025	2044	2046	2065
KACE-1-0-G	r1i1p1f1	ssp370		yes		2005	2024	2015	2034	2037	2056
MIROC6	r1i1p1f1	ssp370	yes	yes	0.767	2034	2053	2050	2069		
MPI-ESM1-2-HR	r1i1p1f1	ssp370	yes	yes	0.731	2025	2044	2041	2060	2072	2091
MPI-ESM1-2-LR	r1i1p1f1	ssp370	yes	yes	0.755	2026	2045	2043	2062	2069	2088
MRI-ESM2-0	r1i1p1f1	ssp370	yes	yes	0.730	2022	2041	2036	2055	2064	2083
NorESM2-LM	r1i1p1f1	ssp370	yes	yes	0.736	2042	2061	2060	2079		
NorESM2-MM	r1i1p1f1	ssp370	yes	yes	0.727	2037	2056	2053	2072	2081	2100
TaiESM1	r1i1p1f1	ssp370		yes		2024	2043	2034	2053	2052	2071

Table 1 continued (ssp585).

Model	Realization	SSP	Very likely ECS	Likely ECS	Weight	GLW1.5		GWL2		GWL3	
						start	end	start	end	start	end
ACCESS-CM2	r1i1p1f1	ssp585		yes	0.412	2016	2035	2029	2048	2046	2065
ACCESS-ESM1-5	r1i1p1f1	ssp585	yes	yes	0.581	2018	2037	2030	2049	2051	2070
AWI-CM-1-1-MR	r1i1p1f1	ssp585	yes	yes		2010	2029	2027	2046	2050	2069
BCC-CSM2-MR	r1i1p1f1	ssp585	yes	yes	0.723	2021	2040	2034	2053	2056	2075
CanESM5	r1i1p1f1	ssp585			0.290	2003	2022	2013	2032	2031	2050
CNRM-CM6-1	r1i1p1f2	ssp585		yes		2019	2038	2031	2050	2049	2068
CNRM-CM6-1-HR	r1i1p1f2	ssp585		yes		2009	2028	2020	2039	2042	2061
CNRM-ESM2-1	r1i1p1f2	ssp585		yes		2023	2042	2036	2055	2055	2074
EC-Earth3	r1i1p1f1	ssp585			0.498	2015	2034	2026	2045	2048	2067
EC-Earth3-Veg	r1i1p1f1	ssp585		yes		2002	2021	2018	2037	2041	2060
FGOALS-g3	r1i1p1f1	ssp585	yes	yes	0.716	2020	2039	2038	2057	2065	2084
GFDL-CM4	r1i1p1f1	ssp585				2020	2039	2032	2051	2050	2069
GFDL-ESM4	r1i1p1f1	ssp585			0.589	2030	2049	2043	2062	2066	2085
HadGEM3-GC31-LL	r1i1p1f3	ssp585				2011	2030	2021	2040	2038	2057
HadGEM3-GC31-MM	r1i1p1f3	ssp585				2016	2035	2025	2044	2040	2059
INM-CM4-8	r1i1p1f1	ssp585			0.646	2021	2040	2037	2056	2060	2079
INM-CM5-0	r1i1p1f1	ssp585			0.649	2021	2040	2037	2056	2065	2084
IPSL-CM6A-LR	r1i1p1f1	ssp585		yes	0.449	2009	2028	2025	2044	2041	2060
KACE-1-0-G	r1i1p1f1	ssp585		yes		2005	2024	2014	2033	2034	2053
MIROC6	r1i1p1f1	ssp585	yes	yes	0.767	2031	2050	2044	2063	2067	2086
MPI-ESM1-2-HR	r1i1p1f1	ssp585	yes	yes	0.731	2024	2043	2040	2059	2064	2083
MPI-ESM1-2-LR	r1i1p1f1	ssp585	yes	yes	0.755	2025	2044	2039	2058	2062	2081
MRI-ESM2-0	r1i1p1f1	ssp585	yes	yes	0.730	2017	2036	2029	2048	2055	2074
NorESM2-LM	r1i1p1f1	ssp585	yes	yes	0.736	2033	2052	2047	2066	2068	2087
NorESM2-MM	r1i1p1f1	ssp585	yes	yes	0.727	2030	2049	2045	2064	2067	2086

Weighting or filtering the Multi-Model Mean

Following guidance from a recent USGS Open File Report ("Approaches for Using CMIP Projections in Climate Model Ensembles to Address the 'Hot Model' Problem"), we apply multiple strategies to summarize the ensemble mean. In previous CMIP assessments, a simple arithmetic mean of all models with equal weights was used to create the Multi-Model Mean. Numerous models from CMIP6 have been found to have a climate sensitivity outside the range established in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6). These models —so called 'hot models'— simulate 21st century global warming that may be implausibly warm.

To address the issue of hot models in the NCCV we include two methods for computing Multi-Model Means. The first method is based on IPCC Equilibrium Climate Sensitivity (ECS): the Multi-Model Mean with *likely* ECS (warming range of 2.5°C to 4°C) and the Multi- Mean with *very likely* ECS (warming range of 2°C to 5°C). These means include only models with simulated warming within the respective ECS ranges (*see Table 1 for model listing*).

The second method is the Weighted Multi-Model Mean in which included models are weighted based on model skill or independence. The weights are determined through Bayesian Model Averaging (BMA) and are estimated by evaluating the model ECS values against our knowledge of the true state of the climate system. This approach effectively down-weights models outside the likely ECS range but does not exclude those models entirely. BMA weighting is used in the Fifth National Climate Assessment and is limited to models used in the assessment (see Massoud et al., 2023, *Nature Communications Earth and Environment*).

Global Warming Levels

Global Warming Levels (GWLs) offer an indirect way to address hot models and variably among scenarios by focusing on the climate response at the year when the global average temperature in a model simulation reaches a specified temperature (e.g., 2°C) above the average preindustrial temperature (the year varies by model and scenario, *see Table 1 for year ranges*). When using GWLs, all models and all scenarios can be combined, as they are individually anchored to the 20-year window that reaches the GWL. By viewing climate projections through a lens of GWL, users can focus on the *what* (local climate impacts) as opposed to the *when* (**Figure 19**). We provide summaries for GWL 1.5°C, 2.0°C, and 3.0°C in the NCCV which can be viewed for an individual model or one of the four approaches to the Multi-Model Mean as described above. GWLs can also be combined with the Scatter plot tool to visualize the response-space of all the models, regardless of scenario (**Figure 20**).

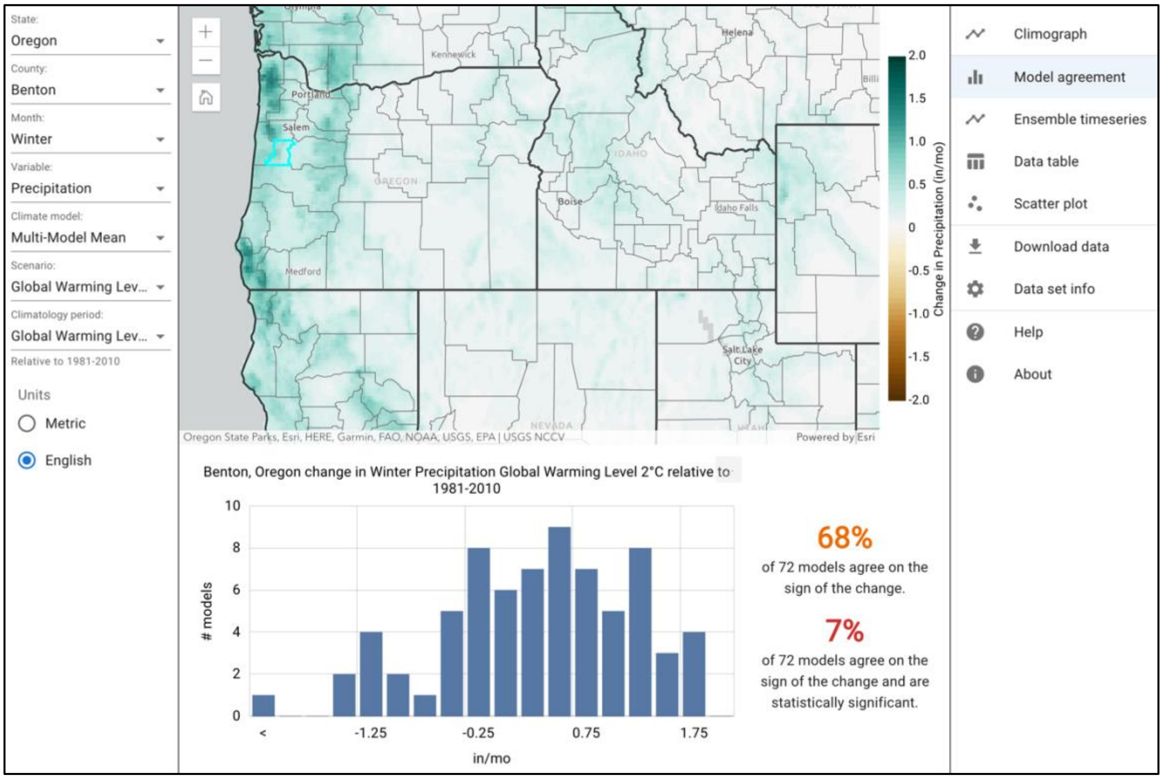

Figure 19 Example of Global Warming Levels displaying model agreement chart for all models (n=72).

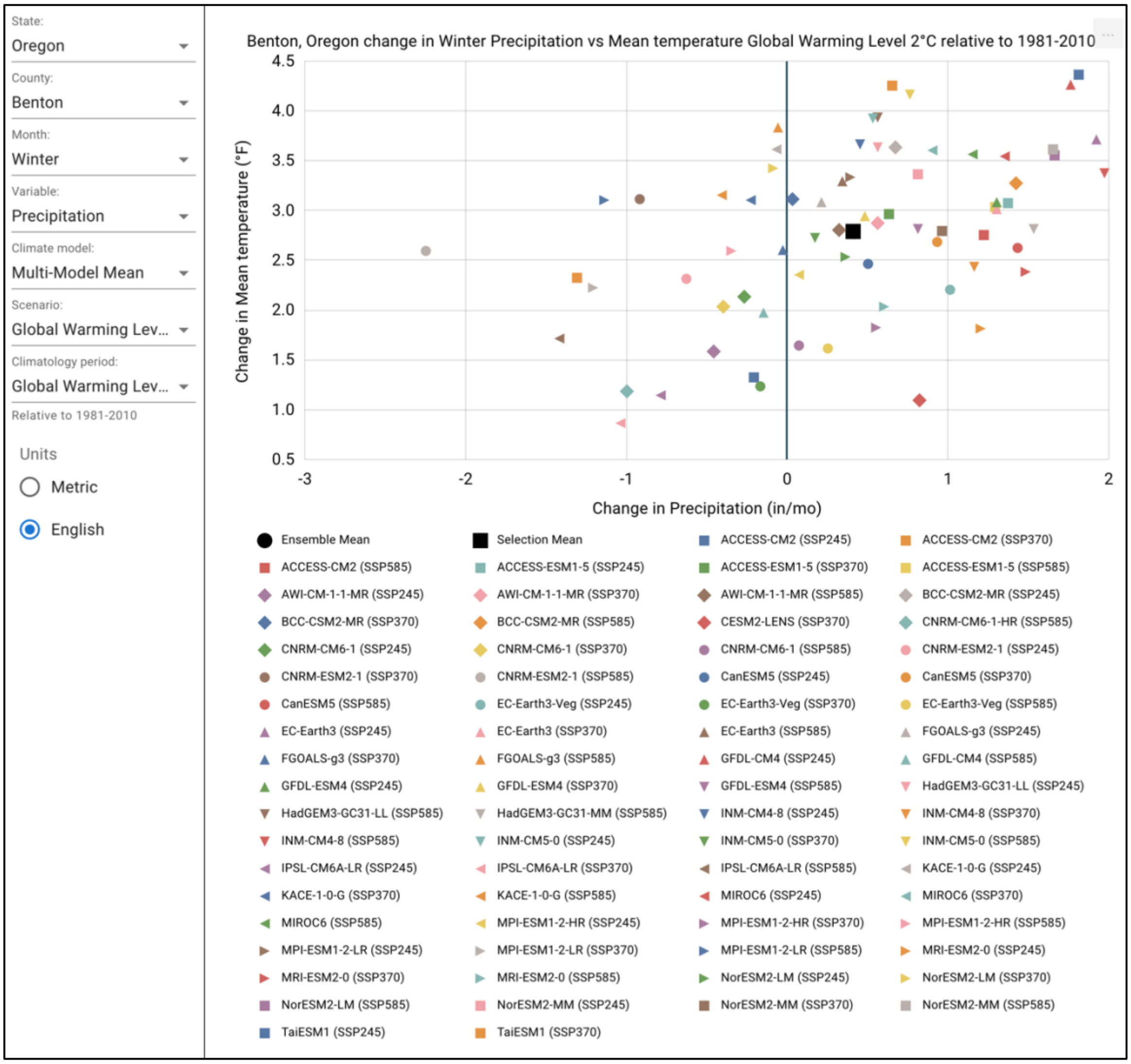

Figure 20 Example of Global Warming Levels displaying scatter plot chart for all models (n=72).

Citation Information

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