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Projected Climate Scenarios Selected to Represent a Range of Possible Futures in California

A Document Developed by the Climate Action Team Research Working Group[1]

Introduction

This memo summarizes climate projections identified by the Climate Action Team Research Working Group with input from researchers contributing to California's Fourth Climate Change Assessment and in coordination with the Governor's Office of Planning and Research Adaptation Technical Advisory Group.[2] These climate change projections are intended to provide a manageable subset of the large number of available scenarios, while still spanning a range of possible futures that California may experience. These scenarios are intended for use as a basis for research contributing to California's Fourth Climate Change Assessment (Fourth Assessment) and also respond to the IEPR 2016 recommendation that: *Energy research and planning, respectively, should use a common set of climate scenarios as selected by the Climate Action Team Research Working Group and the Governor's Office of Planning and Research Adaptation Technical Advisory Group. Energy planning should also implement updated guidance from the Ocean Protection Council*.

Please refer to Table 1 of the section "Data Resources" for details regarding the climate and hydrological projections relevant to the Fourth Assessment.

Recommendations

These recommendations were developed to guide research contributing to California's Fourth Climate Change Assessment.

***Recommendation 1*:** Fourth Assessment research teams should prioritize use of regionally downscaled projections from these four CMIP5[3] Global Climate Models (GCMs):

- HadGEM2-ES ("warm/dry")
- CNRM-CM5 ("cool/wet")
- CanESM2 ("middle")
- MIROC5 (complement/cover range of outputs)

Based on analysis of statistically downscaled (LOCA) projections, these GCMs were systematically selected using a method involving ranks of metrics relevant to climate concerns in California. The

[1] Sub-group members of the scenario selection committee include Louise Bedsworth (OPR), Jamie Anderson (DWR), Guido Franco (CEC), Michael Anderson (DWR), Susan Wilhelm (CEC).

[2] The CAT RWG would like to extend special thanks David Pierce, Scripps Institution of Oceanography, for development and execution of key methodology for systematic selection of scenarios based on criteria on which the CAT RWG and Fourth Assessment research teams reached consensus; and to Dan Cayan, who is leading the development of a "long drought" scenario for California.

[3] The Coupled Model Intercomparison Project, Phase 5 (CMIP5) is the suite of global climate model experiments that provide the foundation for the most recent report of the Intergovernmental Panel on Climate Change (IPCC), namely the 5th Assessment Report (AR5, 2014).

metrics[4] (listed below), the time period to which they were applied (2015-2100) and relative weights (also listed below) were approved by the Climate Action Team Research Working Group, which serves as the Steering Committee for the Fourth Assessment, in consultation with Scripps Institution of Oceanography, Department of Water Resources, the California Energy Commission, the Governor's Office of Planning and Research, and California's Natural Resources Agency. This approach for selecting "priority" scenarios was also discussed in multiple meetings with Fourth Assessment research teams. Please note that the four models recommended here differ from those cited in Pierce et al (2016) due to application of the metrics to a timeline extending through 2100. However, with the exception of the extended time horizon used for the analysis, the methodology is identical to that described in Pierce et al (2016).

The metrics and weighting scheme used for the selection of the four "priority" GCMs based on results from statistical downscaling (RCP4.5, RCP8.5, 10 DWR CCTAG models) through 2100 (LOCA) scenarios are as follows:

1. Average summer daily maximum temperature (population weighted), 35%
2. Annually averaged precipitation volume (Northern California weighed), 30%
3. Average winter daily maximum temperature, 15%
4. Dry spell intensity as lowest total precipitation over a 10-year period, 10%
5. Variability of average summer daily maximum temperature (population weighted), 3.3%
6. Variability of annual average precipitation volume (Northern California weighted), 3.3%
7. Variability of average winter daily maximum temperature, 3.3%

Statistically downscaled (LOCA) projections for all four priority models, RCP4.5 and RCP8.5, and 1950-2100 are available at 1/16° and daily time steps.

Hydrological variables developed using the Variable Infiltration Capacity (VIC) model driven by LOCA projections are also available. Please see Table 1 in the next section (Data Resources) for more specifics regarding available data sets.

***Recommendation 2*:** Fourth Assessment research teams should also consider a regionally downscaled "long drought" scenario. Based on examination of historical observed as well as paleo (e.g., six centuries of tree rings) data, Dan Cayan is working on development of one or two realistic 20-year drought scenario(s) that would enable exploration of extended drought conditions. This scenario will derive from regionally downscaled (LOCA) results. Long drought scenario(s) will include daily maximum temperature, minimum temperature, precipitation, and hydrological variables developed through the application of the VIC model. Like other LOCA/VIC results, the long drought scenario(s) will be at 1/16° spatial resolution. This scenario is expected to be available in the first quarter of 2017.

***Recommendation 3*:** Studies with a time horizon of 2060 or sooner should use RCP8.5, while those with time horizons extending beyond 2060 should consider both RCP4.5 and RCP8.5. This recommendation derives from the observation that estimates of central tendency for regionally

[4] For additional discussion of these metrics and their application in selecting an abbreviated set of Global Climate Models to support the Fourth Assessment, please see p. 13 of D. Pierce, D. Cayan, and L. Dehann (2016), *Creating Climate projections to support the 4th California Climate Assessment*, submitted to the California Energy Commission on 6/14/2016, Docket Number 16-IEPR-04, TN # 211805.
http://www.energy.ca.gov/2016_energypolicy/documents/2016-06-21_workshop/2016-06-21_documents.php

downscaled temperature do not appreciably diverge between RCP4.5 and RCP8.5 until after mid-century.

***Recommendation 4*:** Fourth Assessment research teams should consider, if possible, regionally downscaled results associated with the additional six Global Climate Models (GCMs) recommended by DWR's Climate Change Technical Advisory Group. In addition to the four "priority" GCMs and the "long-drought" scenario, Fourth Assessment research teams are asked *if feasible* to consider the additional six GCMs that were recommended by DWR's Climate Change Technical Advisory Group (DWR CCTAG 2015), namely:

- ACCESS-1.0
- CCSM4
- CESM1-BGC
- GFDL-CM3
- HadGEM2-CC
- CMCC-CMS

The six GCMs listed above as well as the "priority four" models delineated in Recommendation 1 passed global, regional, and local screens imposed by the CCTAG and designed to filter from the larger CMIP5 ensemble (n=32) those GCMs that failed to adequately capture processes of importance to water resources in California.

Data Resources

Table 1 below presents data resources that are available or forthcoming to support Fourth Assessment research teams in implementing the recommendations above.

Specifically, please note that all of the priority and DWR-recommended model/scenarios combinations are included in the "LOCA" downscaling results that are available through the beta site for Cal-Adapt 2.0 (http://beta.cal-adapt.org/data/loca/) in GeoTIFF format as well as in netCDF format from other sources linked at the Cal-Adapt 2.0 data site and directly from David Pierce (UCSD, Scripps Institution of Oceanography). Hydrological results based on the Variable Infiltration Capacity (VIC) model driven by these LOCA outputs are also available (snowpack is on the Cal-Adapt site and other hydrological variables are forthcoming; the full suite of hydrological variables is available from Scripps Institution of Oceanography).

Additionally, dynamically downscaled model results with sub-daily resolution are also available from UCLA (Alex Hall) for teams who will include only end-of-century (2091-2100) projections and RCP8.5 in their analysis. Teams using Alex Hall's data are encouraged to use the two GCMs (CNRM-CM5 and GFDL-CM3) that passed DWR's screening criteria for recommended models.

References

California Department of Water Resources (DWR), Climate Change Technical Advisory Group (CCTAG), August 15, 2015. *Perspectives and Guidance for Climate Change Analysis*. http://www.water.ca.gov/climatechange/docs/2015/1_14_16_PerspectivesAndGuidanceForClimateChangeAnalysis_MasterFile_FINAL_08_14_2015_LRW.pdf

Hall, A., F. Sun, D. Walton, M. Schwarz, N. Berg, and K. Reich (2016). *Dynamically Downscaled CMIP5 Climate Projections Over California*., submitted to the California Energy Commission on 6/14/2016, Docket Number 16-IEPR-04, TN # 211804. http://www.energy.ca.gov/2016_energypolicy/documents/2016-06-21_workshop/2016-06-21_documents.php

Pierce, D., D. Cayan, and B. Thrasher (2014). Statistical Downscaling Using Localized Constructed Analogs (LOCA), *Journal of Hydrometeorology*, DOI: http://dx.doi.org/10.1175/JHM-D-14-0082.1.

Pierce, D., D. Cayan, and L. Dehann (2016). *Creating Climate projections to support the 4th California Climate Assessment*, submitted to the California Energy Commission on 6/14/2016, Docket Number 16-IEPR-04, TN # 211805. http://www.energy.ca.gov/2016_energypolicy/documents/2016-06-21_workshop/2016-06-21_documents.php

Table 1. Climate projections and derived variables available to support California's Fourth Climate Change Assessment.

data set	*source*	*temporal scope*	*resolution*	*parameters*	*RCP/GCM*	*access*
LOCA projections[5]	David Pierce (Scripps Institution of Oceanography)	1950-2005 hindcast; 2006-2100 projections based on RCPs and CMIP5	1/16 degree (ca. 6 km), daily	maximum temperature, minimum temperature, precipitation	RCP4.5, RCP8.5, CMIP5	http://beta.cal-adapt.org/data/loca
Dynamically downscaled projections[6]	Alex Hall (UCLA)	1981-2014 for "baseline" historical simulation; October 2091-September 2101 for future projections	6-hourly for all except temperature at 30-minute resolution; 3-km resolution over Sierra Nevada, 9-km resolution elsewhere in CA	complete WRF model output, including temperature, precip., humidity, snow water equivalent, surface run-off[7]	RCP8.5, CNRM-CM5, GFDL-CM3, inmcm4, IPSL-CM5A-LR, MPI-ESM-LR	Contact Alex Hall, alexhall@atmos.ucla.edu
Variable Infiltration Capacity (VIC) model (driven by LOCA projections)	David Pierce (Scripps Institution of Oceanography)	1950-2100	1/16 degree (ca. 6 km), daily	evapotranspiration, runoff, soil moisture, snow water equivalent, daily change in SWE, snowfall rate, snow melt rate, humidity, albedo, *and more*[8]	RCP4.5, RCP8.5, CMIP5	Scripps Institution of Oceanography

[5] Detailed in Pierce et al (2016), Pierce et al (2014), and at this site: http://loca.ucsd.edu/.
[6] Detailed in Hall et al (2016).
[7] See p. 2 of Hall et al (2016) for a more detailed variable list as well as link to the entire list of WRF outputs available.
[8] For complete list of variables available from VIC model driven by LOCA projections, please see Appendix 2 on p. 20 of Pierce et al (2016).

data set	*source*	*temporal scope*	*resolution*	*parameters*	*RCP/GCM*	*access*
Routed streamflow (driven by VIC output, bias-corrected, unimpaired)	Noah Knowles (USGS): routing; Scripps Inst. of Oceanography: bias correction	1950-2100	59 locations in California, daily unimpaired flows	daily average flow rate (m^3/s)	RCP4.5, RCP8.5; 10 GCMs selected by DWR's CCTAG	Forthcoming on Cal-Adapt and internal website (Q1, 2017) http://ccca4.org/
Long drought derived from LOCA projections	Dan Cayan (Scripps Institution of Oceanography)	20-year time period near mid-century (and possibly near end-of-century)	1/16 degree (ca. 6 km), daily	maximum temperature, minimum temperature, precipitation	*tbd*	Contact Dan Cayan at dcayan@ucsd.edu
Fine-scaled projections derived from LOCA and coupled to USGS Basin Characterization Model	Lorrie Flint (USGS)	1980-2099	270 m, daily and monthly	maximum temperature, minimum temperature, precipitation (daily); hydrological parameters (monthly)	LOCA scenarios (n=10) associated with: RCP4.5, RCP8.5; 10 DWR CCTAG GCM's	Contact Lorrie Flint at lflint@usgs.gov