Data Adoption Justification Memo (for California's Fifth Climate Change Assessment)

LOCA version 2 Hybrid Downscaling

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Methods and Prior Relevant Work

The Localized Constructed Analogs (LOCA) statistical downscaling method (Pierce et al. 2014; Pierce et al. 2015a; Pierce et al. 2015b) is an analog based method that is used to downscale relatively coarse scale global climate model projections to finer scale regional projections. In conducting this global to regional downscaling, LOCA uses observationally-based training data over the regional domain for two purposes: 1) bias correction; 2) to provide a library of observed weather patterns that, after spatial coarsening, are matched to the global climate model (GCM) day being downscaled. We call the latter the "pattern library".

The LOCA downscaling method proceeds in two steps: 1) from the original GCM grid (which varies by GCM) to a common 0.5x0.5 degree grid. 2) from the common 0.5 degree grid to the final, fine scale 3 km grid. These two steps are used so that all models can be bias corrected using information from the same 0.5 degree grid, even though the GCMs have different grid resolutions (Pierce et al. 2014). Other schemes sometimes interpolate the different GCM grids to a common grid before downscaling, but our analysis has found that the interpolation can lead to a poorer representation of spatial variability in the final downscaled result.

In previous versions of LOCA, such as that used for California's Fourth Climate Assessment (Pierce et al. 2018), the pattern library was generally obtained from observed meteorological station data gridded using a nearest neighbor algorithm. (The exception to this is the surface downward solar radiation training data, which was obtained from GOES satellite observations.) Using gridded historical observations for the pattern library is a reasonable approach and also a necessary one given that future observed weather patterns are not available. However, it does lead to some concerns. In particular, the warmer future climate will have less snow, possibly leading to altered surface temperature patterns in locations where snow is systematically lost in coming decades.

To address this concern, in the LOCA version 2 (LOCA2 hereafter) California domain we used a hybrid downscaling scheme with a pattern library obtained from dynamically downscaled GCM-Weather Research Forecasting (WRF) runs that were bias corrected to the ERA5-WRF-BC[1]

[1] ERA5-WRF-BC refers to the bias corrected (BC) dataset produced from application of WRF to downscale the ERA5 reanalysis. ERA5 is the fifth generation European Center for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis of the global climate covering the period from January 1940 to the present.

training data (Pierce et al. 2023a). The period covered by the GCM-WRF runs extends to the year 2100, so a model estimate of future weather patterns can be obtained by this approach. This method is a form of hybrid downscaling since it couples the statistical downscaling approach of LOCA with a pattern library obtained from a dynamically downscaled model containing information about the historical and future climate. Other approaches to hybrid downscaling exist as well, but are not included in this effort.

We implement the hybrid approach using UCLA's[2] WRF downscaled runs CESM2 r11i1p1f1 and EC-Earth3-Veg r1i1p1f1. These were run (like all the UCLA WRF simulations for this project) under emissions scenario SSP 370. These particular GCM-WRF runs were selected because Krantz et al. 2021 show that these two GCMs perform well in simulating historical climate variables over the California domain of interest here. In addition, the smaller memory requirements of the common 0.5 degree grid used in the first step of the LOCA process allow us to use an additional two models in the first half of the downscaling; we used CNRM-ESM2-1 r1i1p1f2 and FGOALS-g2 r1i1p1f1 for that purpose.

LOCA2 downscaling is split into 3 future periods so that the process can fit into the memory of the NASA Pleiades supercomputer where the runs were performed. In LOCA2 we used the standard CMIP6 historical period ending year of 2014, and three future periods of 2015-2044, 2045-2074, and 2075-2100. The pattern library for each of these three periods was obtained from the contemporaneous GCM-WRF downscaled (and bias corrected) run. I.e., when LOCA2 was processing years 2075-2100 the pattern library was taken from WRF years 2075-2100, and similarly for the other periods. This means that end-of-century GCM days were downscaled by LOCA2 using a pattern library from WRF simulations also at the end of the century, and therefore will include any WRF-simulated changes in weather patterns in that time frame.

QA/QC and Uncertainty

Being a hybrid product, the LOCA2 hybrid downscaling incorporates uncertainties in the original GCM-WRF data (Rahimi-Esfarjani 2022a and 2022b), since LOCA2 assumes that the pattern library is a faithful depiction of the spatial patterns of weather variability seen in reality. We bias correct the GCM-WRF runs before use in the pattern library since WRF (like all models) has biases it its output, so the attendant uncertainties that apply when bias correction is used apply here as well. These issues are described in the Bias Correction data memo (Pierce et al. 2023b). The standard LOCA bias correction scheme is used, which preserves GCM-predicted trends in variables by quantile (Pierce et al. 2015a).

Note that because surface downward solar radiation uses GOES satellite-based training data rather than data from a WRF run that extends to 2100, solar radiation cannot be downscaled in a hybrid approach. However, our analysis of projected solar radiation changes in the Fourth

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[2] The IPCC Sixth Assessment Report (2021) defines global emissions scenarios in terms of an SSP (Shared Socio-Economic Pathways) framework. Each SSP represents a scenario corresponding to projected socioeconomic global changes through 2100.

California Climate Assessment (Pierce et al. 2018) found that these changes were small, on the order of a few percent, so we do not consider this a significant limitation.

Fundamentally, by assuming that the WRF downscaled runs faithfully represent future weather patterns, the LOCA2 hybrid approach produces results with the same kinds of weather patterns as depicted in the WRF dynamically downscaled runs. This provides a unifying element between the LOCA2 and WRF downscaling runs that would be absent if the previous historical analogue approach was employed.

Guidance or Caveats on Best Practices for Use of Data Products

There were a considerable number of data products produced for EPC-20-006 and for use by California's Fifth Climate Assessment, including the LOCA2 hybrid downscaled runs described here, the WRF downscaled runs, and hourly time series of temperature at individual stations derived from the LOCA2 results. Considerations that may be helpful in choosing between these different data products include:

1) How wide a sample of models is desired. LOCA2 has data from 15 GCMs[3]; WRF has data from 9 GCMs (with differing states of bias correction).
2) Whether gridded hourly data are required. WRF has gridded hourly data for at least 21 different meteorological variables (some simulations also contain wind and solar variables). LOCA2 has hourly data for temperature at selected stations (Yao et al. 2024), while the LOCA2 gridded Tmin, Tmax, precipitation, windspeed, meridional wind, zonal wind, specific humidity, relative humidity daily min and max, and surface downward solar data are daily.
3) Whether different SSPs are needed. LOCA2 includes SSP-245, -370, and -585 (roughly, medium-low, medium, and high) emissions scenarios. WRF has data from SSP 370.
4) Whether data from different ensemble members are needed, for instance, for evaluating the role of natural variability versus the anthropogenically forced signal. LOCA2 has up to 10 ensemble members per GCM for those GCMs that saved the data. WRF has one ensemble member per GCM.
5) Whether dynamically consistent data is needed. WRF produces dynamically consistent data (at least, before any bias correction is performed), while LOCA does not, since bias correction does not honor the original conservation equations in the models.
6) Whether bias correction is needed. The flip side of bias correction producing data that is not consistent with the original conservation equations is that WRF data can have significant biases. Some stakeholders have application models that do not produce correct or useful results when run with biased input data. Four WRF runs are available with a final bias correction step applied at a daily temporal

[3] 27 GCMs are available in the wider North American domain from Southern Canada through Central Mexico.

resolution. All LOCA2 GCMs and ensemble members have had bias correction applied.

Because of the complexity of these questions, there is no one size fits all answer to which data should be used. Every stakeholder must determine where their needs fall on the spectrum of desired time resolution, model coverage, ensemble member access, SSP coverage, dynamical consistency, and bias correction.

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