CMIP6 Methodology

Joseph Giguere and Andrew Pershing[1], Climate Central
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SHORT VERSION

We interpolated time series data for each of the stations that we routinely use in our Climate Matters graphics from Coupled Model Intercomparison Project 6 (CMIP6) models. We then computed monthly anomalies using the delta method: monthly averages were calculated from a reference period for each model, then subtracted from all years across the modelled period. This method reduces biases associated with specific models running slightly hot or cold. Next, we found yearly values. Finally, desired percentiles for each year for each location across all models were computed, and observed averages from the Applied Climate Information System (ACIS) were added, resulting in absolute temperature values, rather than anomalies.

LONG VERSION

The Coupled Model Intercomparison Project (CMIP) is managed by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). It was created to develop a common set of methods that the major climate modeling labs around the world would use, allowing their results to be comparable. The result is an ensemble of models that simulate the behavior of the earth's climate under a broad variety of conditions. Each model is simulated over a historical period (generally starting in 1850 and ending in 2015) using observed levels of greenhouse gases. The models are then extended into the future period (generally starting in 2015 and ending sometime after 2100) under different scenarios of future emissions.

Under the CMIP framework, models are run under certain carbon emission assumptions. CMIP6 is the latest iteration of CMIP. In conjunction with the IPCC's 6th assessment report, it introduced shared socioeconomic pathways (SSP). As we explained in our 2021 IPCC Climate Matters Release, these pathways examine different ways population, education, urbanization, economic growth, and technology may develop in the coming decades. Each pathway affects carbon dioxide and other greenhouse gas emissions over the whole 21st century. The IPCC does not attempt to pick the pathway that society is most likely to take. Instead, the pathways provide a way for people to understand the risks and benefits of alternative policy choices. Functionally, these SSPs represent different carbon emission scenarios for the 21st century.

For an overview of SSPs, see here. The 5 primary pathways used in the most recent IPCC report are:

- SSP1 ('Sustainability') - 1.9
- SSP1 ('Sustainability') - 2.6

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[1] Please send questions to apershing@climatecentral.org

- SSP2 ('Middle of the Road') - 4.5
- SSP3 ('Regional Rivalry') - 7.0
- SSP5 ('Fossil-fueled Development') - 8.5

The different SSPs each represent choices that we make about future carbon emissions. They allow us to see the risks that accumulate in a warmer, high CO2 world. The first number is the scenario being modelled (each number is associated with a short-hand definition, shown above as text at the end of each SSP). However, within each SSP, there are sub-pathways that are a function of the assumptions about the choices humans make to follow each pathway. The second number represents the maximum watts per meter squared of radiative forcing associated with each sub-pathway.

Of particular interest here, SSPs 1 -2.6 and 3 - 7.0 represent possible low and high carbon emission scenarios respectively. You can think of SSP3-7.0 as a continuation of our current emissions, while SSP1-2.6 represents an aggressive attempt to limit global warming to around 1.5°C. For our analysis, we explore how these scenarios look at a local level in the coming decades.

Data for the ensemble of models that make up CMIP6 was accessed via the Google Data Platform using the intake Earth System Model (ESM) tool. We accessed data from only those models that reported monthly data for the historical and future periods, recorded average temperatures for each of those months, and ran SSP 1 and SSP 3 scenarios. In total, 34 global climate models met these criteria.

Compared to a weather model or satellite image, the climate models in CMIP6 have low spatial resolution. That is, data points are only available for roughly every degree of latitude and longitude. Because the locations that we wanted to examine rarely fell precisely on these geographic points, it was necessary to interpolate data from the climate models to be more specific to our desired locations. To do this, we used the built-in interpolation function in the python xarray package. Using this procedure, we assembled monthly time series for each of the 247 stations that we routinely use in our Climate Matters graphics.

From this, we had unique time series data for every desired location for every model. Climate models are good at capturing the large scale features of the global climate system. They also are good at reproducing the relative rate of warming at a location. However, at any location, particular models may have a tendency to run slightly warm or slightly cool. We used a technique known as the delta method to correct this bias.

The delta method works by focusing on the relative changes in each model and then adding these changes to the observed average conditions at the location. The first step is to choose a reference period. For these calculations, the reference period used was the thirty year period from 1991-2020. The average value for each month of the year across the reference period was calculated for each model. Thus, we had an average value for January, February, etc. for each model. Next, these monthly averages for each model were subtracted from each corresponding month of the entire dataset associated with that model. For example, the average January temperature from 1991 to 2020 in one model would be subtracted from that model's value for January in 2050, resulting in a value that represents how much hotter january 2050 is projected to be relative to the average of the reference period. This calculation is done for every month for the entire modelled period. Thus, for each month in each model's data, we had the deviation from the average for that month relative to the average of the reference period for that model. These are the deltas that give the delta method its name

Next, values were averaged across each year, and desired percentiles across all models for each month were calculated (in this case, 10th, 50th, and 90th). Data before 2020 and after 2100 were dropped. This produces a time series for each location for each percentile for each scenario for each year from 2020 to 2100. The data in this time series represents the difference between the modelled reference period and the modelled year.

Finally, the observed average temperature for each location from the reference period was calculated using data from the Applied Climate Information System (ACIS). The monthly averages were then added to the time series of deltas, thus converting anomalies back to absolute temperature values.

Climate models are built to look at changes in the mean climate. In order to highlight this change, we smoothed the time series from each location using a rolling 10-year averageThis allows us to produce the change in the mean condition under high (SSP3-7.0) and low (SSP1-2.6) carbon emissions for each station. By using multiple models, we can place confidence intervals around these projections. Finally, we can compare the projections to the actual mean temperatures at the locations. In the figures provided, we applied a rolling 10 year average to the observed data from ACIS.

LIST OF MODELS USED

Model Name	**Institution**
INM-CM5-0	INM
IITM-ESM	CCCR-IITM
MIROC-ES2L	MIROC
CNRM-ESM2-1	CNRM-CERFACS
ACCESS-CM2	CSIRO-ARCCSS
CMCC-ESM2	CMCC
FGOALS-g3	CAS
CNRM-CM6-1-HR	CNRM-CERFACS

TaiESM1	AS-RCEC
NorESM2-LM	NCC
CanESM5-CanOE	CCCma
CAMS-CSM1-0	CAMS
GFDL-ESM4	NOAA-GFDL
KACE-1-0-G	NIMS-KMA
INM-CM4-8	INM
IPSL-CM6A-LR	IPSL
ACCESS-ESM1-5	CSIRO
CESM2	NCAR
MCM-UA-1-0	UA
NorESM2-MM	NCC
UKESM1-0-LL	MOHC
CESM2-WACCM	NCAR
GISS-E2-1-G	NASA-GISS
FGOALS-f3-L	CAS
CanESM5	CCCma
MPI-ESM1-2-HR	MPI-M
AWI-CM-1-1-MR	AWI
BCC-CSM2-MR	BCC
MIROC6	MIROC
CAS-ESM2-0	CAS
CNRM-CM6-1	CNRM-CERFACS
EC-Earth3-Veg-LR	EC-Earth-Consortium
MPI-ESM1-2-LR	MPI-M
MRI-ESM2-0	MRI
CMCC-CM2-SR5'	CMCC