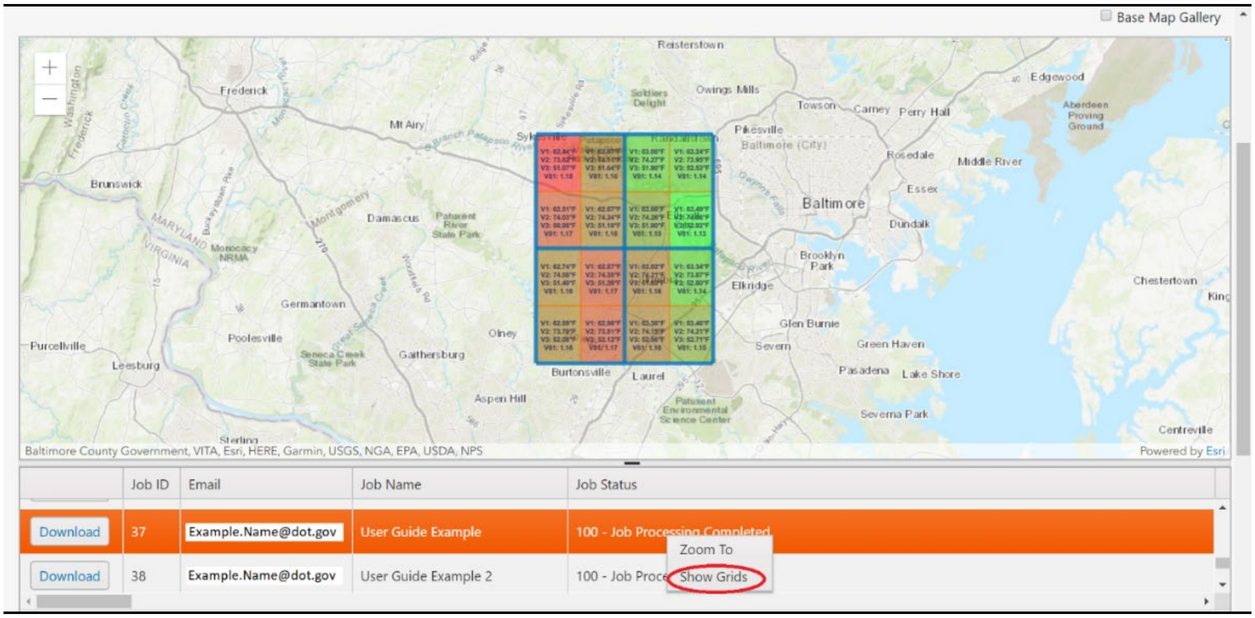
Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool 2.1

User’s Guide

March 2021



This project was carried out in support of 23 U.S.C. § 503(b)(3)(B)(viii), which directs the Department of Transportation “to carry out research and development activities … to study vulnerabilities of the transportation system to … extreme events....”

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16. Abstract This user manual provides directions and step by step processes for using the Coupled Model Intercomparison Project (CMIP) on-line software tool. The CMIP Tool takes Localized Constructed Analogs (LOCA) downscaled CMIP5 data and processes the information into statistical and other variables that can be used in planning and design with greater ease. This document includes some technical information to provide a background regarding the development of this tool and to help establish the strengths and limitations of the tool and reasoning behind the functions of the tool.		
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Acronyms

CMIP	Coupled Model Intercomparison Project
CMIP3	Coupled Model Intercomparison Project phase 3
CMIP5	Coupled Model Intercomparison Project phase 5
DCHP	Downscaled [CMIP3 and CMIP5] Climate and Hydrology Projections
FHWA	Federal Highway Administration
HEC	Hydraulic Engineering Circular
IPCC	Intergovernmental Panel on Climate Change
LOCA	Localized Constructed Analog (downscaling method)
NCHRP	National Cooperative Highway Research Program
NLDAS	North American Land-Data Assimilation System
RCP	Representative Concentration Pathways scenario set
U.S. DOT	United States Department of Transportation
WCRP	World Climate Research Programme

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1. Introduction

The purpose of the Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool, version 2.1 (CMIP Tool or Tool) is to process readily available downscaled climate data at the local level into relevant statistics for transportation planners and designers. This User's Guide provides instructions on using the Tool.

The Tool works with data from the Downscaled CMIP Climate and Hydrology Projections (DCHP) archive at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections.

This website houses downscaled climate projections from the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (WCRP 2021). The DCHP archive contains both CMIP phase 5 (CMIP5) and the earlier phase 3 (CMIP3) archive.

This updated version (2.1) of the CMIP Tool works with the statistically downscaled CMIP5 Localized Constructed Analog (LOCA) dataset; the LOCA dataset provides statistically downscaled projections to the 1/16-degree resolution. It also includes methods for calculating future return period precipitation.

The daily LOCA climate projections extend over the contiguous U.S. as well as Canadian portions of the Columbia River and Missouri River Basins. Unfortunately, this means the DCHP data (currently) excludes Alaska, Hawaii, Puerto Rico, US Virgin Islands, America Samoa, Guam and other territories of the United States. However, some of the discussions in this User Manual, particularly found in the latter portions, may help parties both there and elsewhere to apply some of the approaches and processes on their own.

This User Manual divides the process for successful application of the CMIP Tool into three stages:

1. **Downloading Data from the DCHP website** – Determining and downloading the appropriate climate data from the DCHP website, including location, global climate models, and emissions scenario(s).
2. **Applying the CMIP Tool** – Using the FHWA CMIP Climate Data Processing Tool (version 2) to process data from the DCHP website into specific temperature and precipitation variables.
3. **Interpreting Output from the CMIP Tool** – Reviewing the results from the CMIP Tool and using industry practice in applying them to decision-making and design.

This User Manual will describe each stage within a separate Chapter that "walks" the user through that portion of the application process.

To best present the process, the User Manual provides figures depicting "screen shots" of relevant portions of the software. For clarity, the User Manual may crop or otherwise edit some of these figures. In such cases, the actual software screen may appear larger (and longer) on the user's browser window.

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2. Obtaining Data from the DCHP Website

While the Tool serves to process the Downscaled CMIP5 Climate and Hydrology Projections (DCHP) data, the User must first determine and download the data. Specifically, there are two sets of data: projected and observed. The DCHP now allows collection of the projected and observed data within the same data request submission.

2.1 Requesting Data

> Note: The DCHP website has its own list of numbered steps (Step 1.1 through Step 3.10) to follow when downloading data. These instructions reference those "step" numbers. To help distinguish these, the User Manual uses **"Action N"** to indicate a user action.

2.1.1 Linking to the DCHP Main Menu

Action 1. Go to: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections.

Note: The DCHP site describes the best viewing process uses the Chrome browser; although Firefox (and Edge) function. The site describes there may be some issues when using Internet Explorer.

Action 2. **Select** (mouse click on) the ***"Projections: Subset Request"*** tab (see Figure 1).

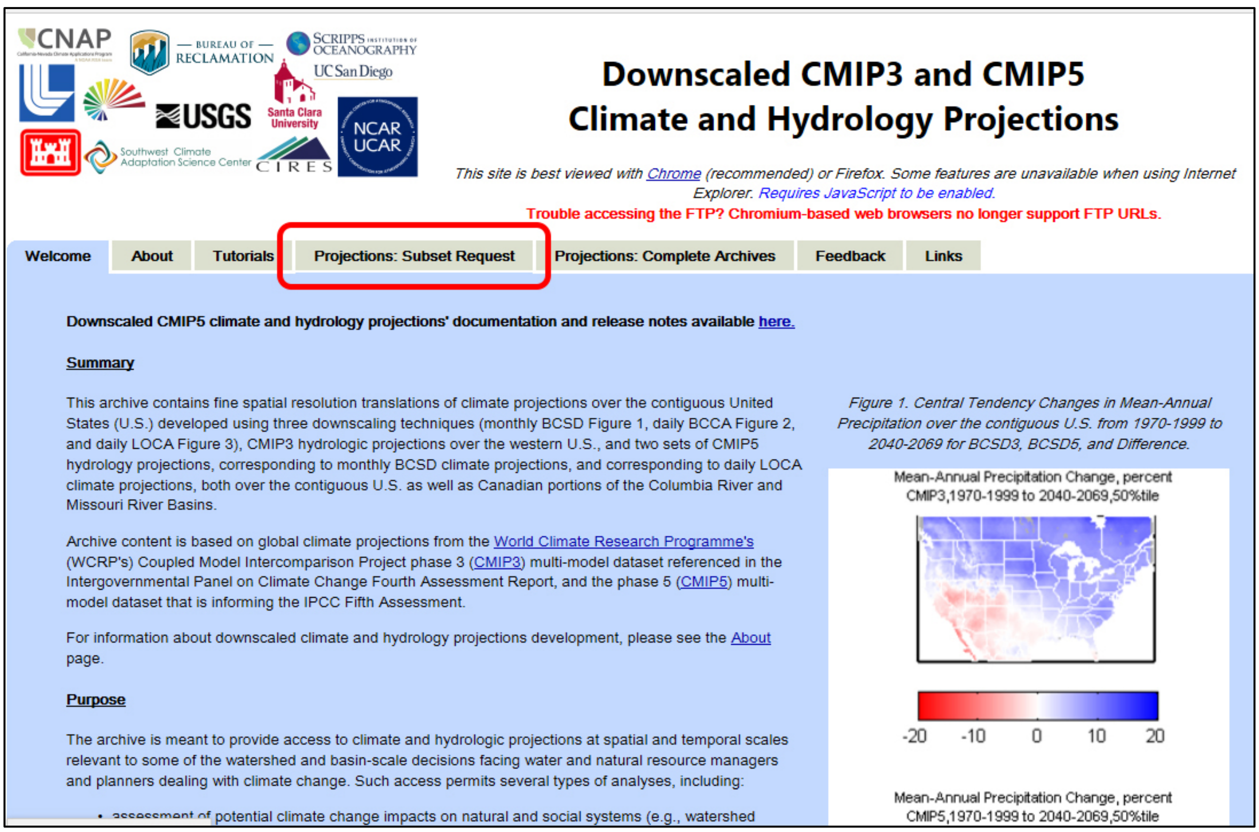

Figure 1 – Projects: Subset Request Page

2.1.2 Requesting LOCA Downscaled Data

This selection will bring up the webpage, depicted in Figure 2, where the user can request the LOCA downscaled data.

Notice that there are three “tabs” near the top of the window screen: “Page 1: Temporal & Spatial Extent,” “Page 2: Products, Variables, and Projections,” and “Page 3: Analysis, Format, & Notification.” These three “pages” represent the sequences of steps within the software product.

Starting with DCHP “Page 1: Temporal & Spatial Extent

Action 1. **Select** Tab *“Page 1: Temporal & Spatial Extent”*

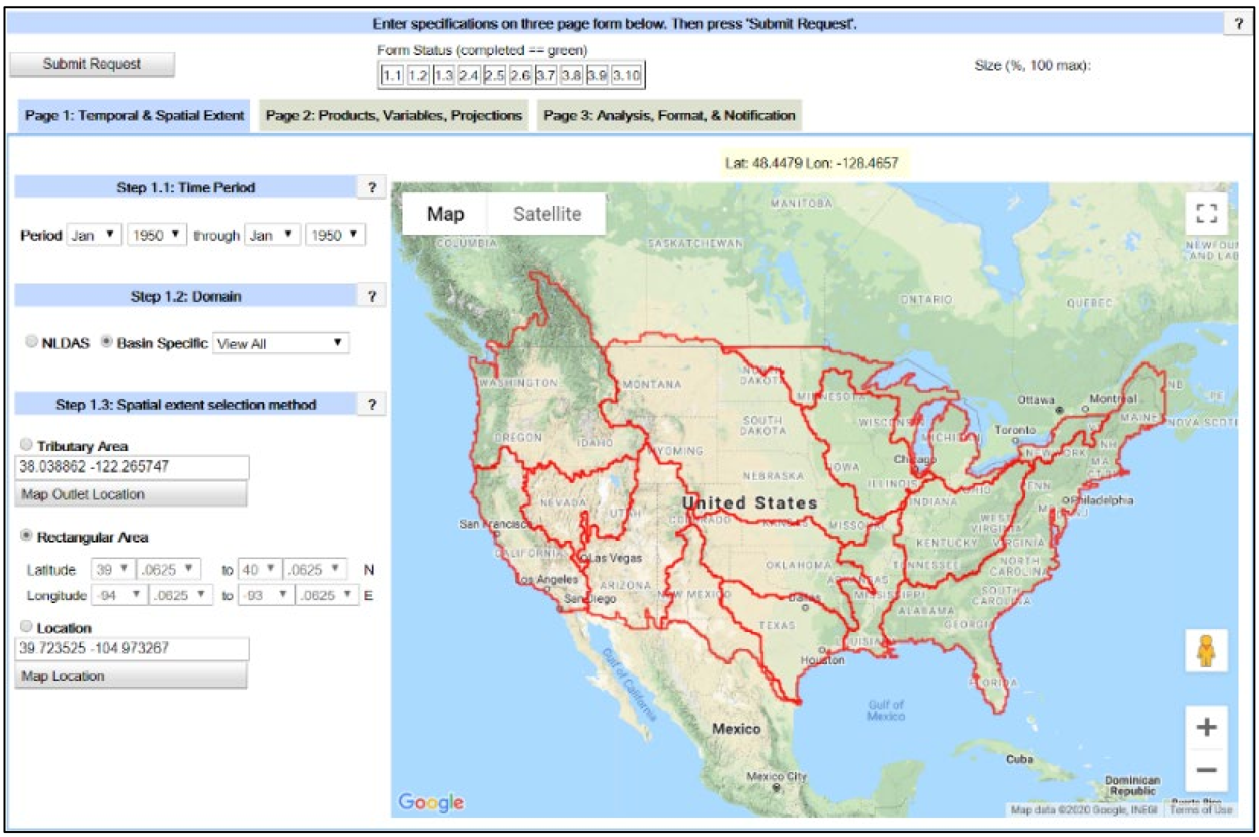

Figure 2 – Page 1 of Subset Request

Helpful Hint

Notice that the screen window (Figure 2) depicts major basin specific boundaries placed across a map of the conterminous United States (and portions of Canada). Not sure what basin you are in? Don’t worry, there are other options that we will discuss shortly…

Action 2. *Time Period (Step 1.1)* **Select** the entire time period available: January 1950 through December 2099. (see Figure 3)

Selecting the full range of data in this step provides flexibility in defining several alternative ranges within the entire period for analysis with the CMIP Tool (see Chapter 3, Applying the CMIP Tool).

Notice that the top of the window depicts the approximate status of the steps within this stage of the Tool.

For example, the User is currently at “Step 1.1” of “Page 1: Temporal & Spatial Extent” within the Stage “Obtaining Data from the DCHP Website.”

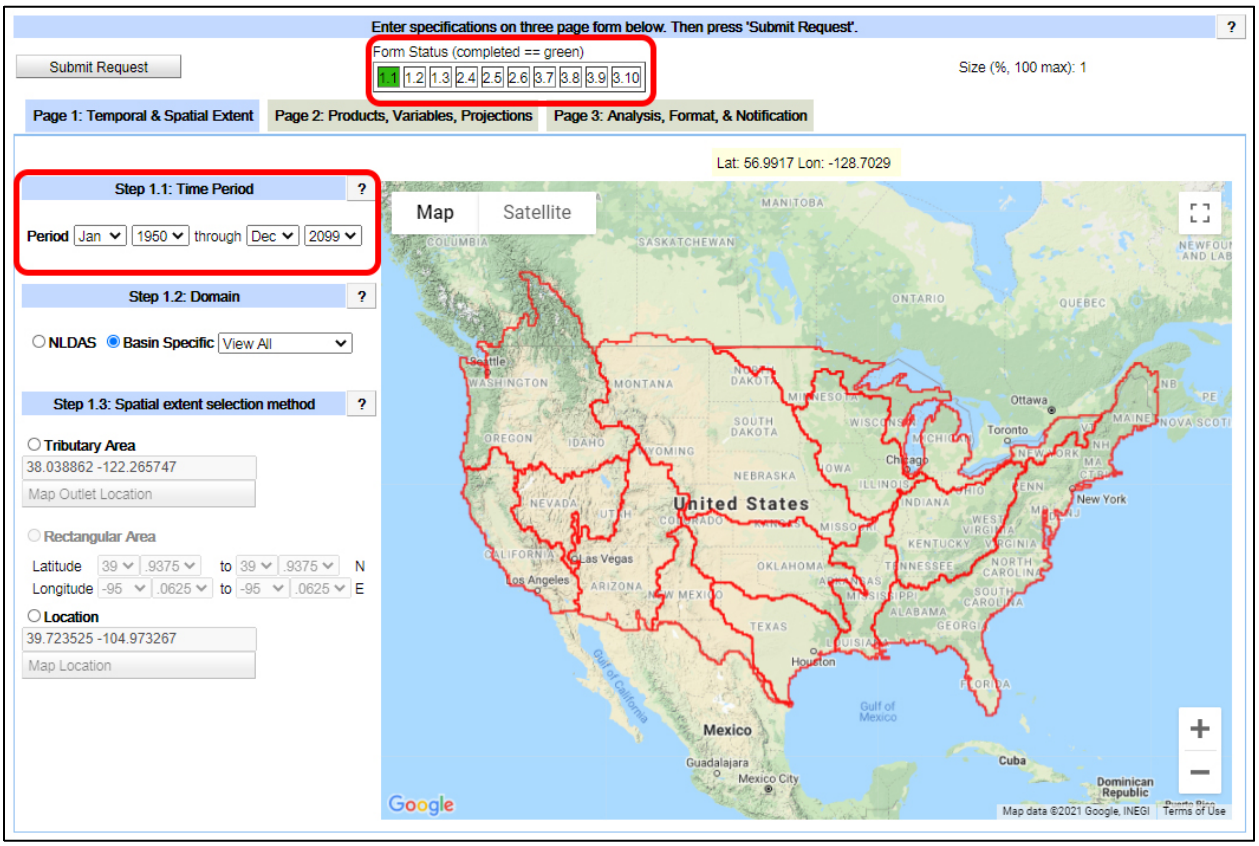

Figure 3 – Step 1.1 Screen Shot

Helpful Hint

Notice that the Form Status indicator at the top of the window of Figure 3 has turned “GREEN” for step 1.1, indicating activity (but not necessarily completion) within this step.

Action 3. *Domain (Step 1.2)*

A. **Select** *NLDAS* (referring to North American Land-Data Assimilation System).

Selecting *NLDAS* places a red boundary rectangle across the conterminous United States (the basins disappear) allows the user to "zoom in" to the location of interest (see Figure 4).

B. Alternatively, if the user knows their specific basin of interest (recall those boundaries depicted in Figure 2 and Figure 3, above), they may use the default *Basin Specific* selection.

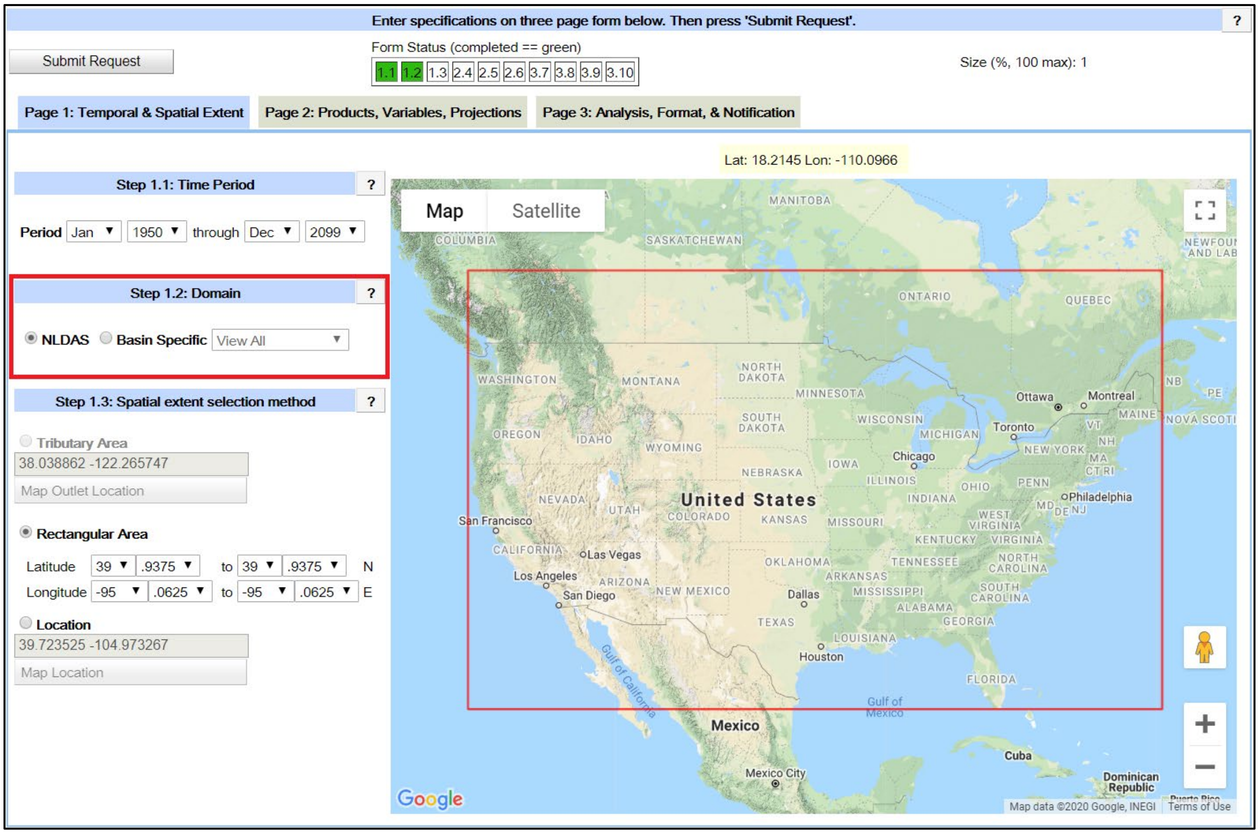

Figure 4 – Step 1.2 Domain

Making Progress!

Notice that more of the Form Status indicator at the top of the window has turned to "GREEN", indicating completion of step 1.1 and activity within step 1.2.

Action 4. *Spatial extent selection method (Step 1.3)* (see Figure 5). **Click** the *Rectangular Area* radio button (if not already selected).

Maps & Mice – A Few Pointers …

Placing the mouse cursor within the area of the window depicting the map (a "pointing hand" appears) allows the User to Zoom In or Zoom Out (usually using mouse wheel), Pan (hold down left mouse button until the hand turns into a fist and drag the map), etc.

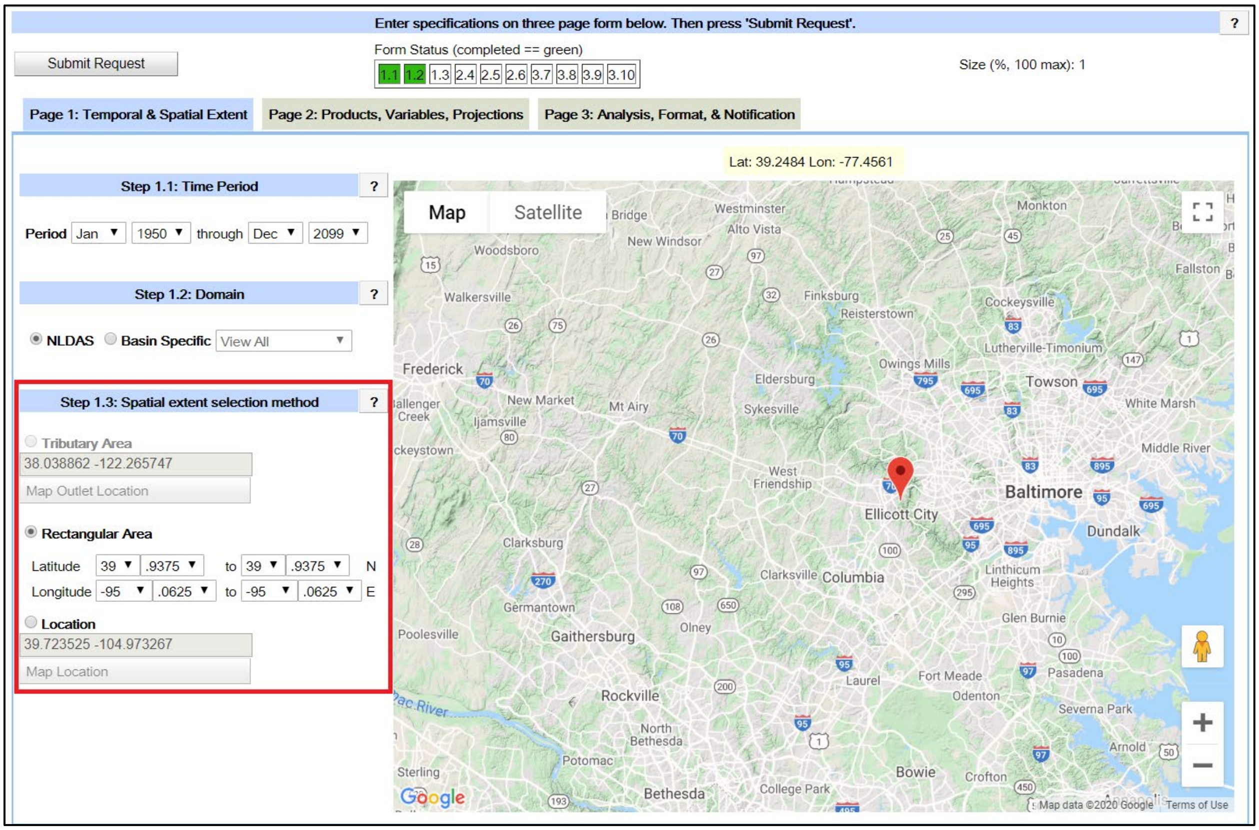

Figure 5 – Step 1.3 Spatial Extent Selection Method. Initial point selected.

Action 5. The User may proceed to any map location with mouse, **Zoom In** and select **(Mouse Click)** the area of interest.

Helpful Hint

Notice that a "red marker" will appear on the map portion of the screen (Figure 5). We will use that marker in the next action.

Action 6. Click on the red marker and drag it over the area of interest (see Figure 6).

Do not make the box too large, as the data request from the DCHP website is limited to approximately one gigabyte (as described in a note below).

Each grid cell shown on the screen will be subdivided into 4 LOCA grid cells of 1/16th degree latitude by 1/16th degree longitude (approximately 6 km by 6 km).

For example, Figure 6 (below) depicts four 1/8th degree grids. This will result in the processing of sixteen (16) 1/16th degree grids; covering the same area in the CMIP Tool[1].

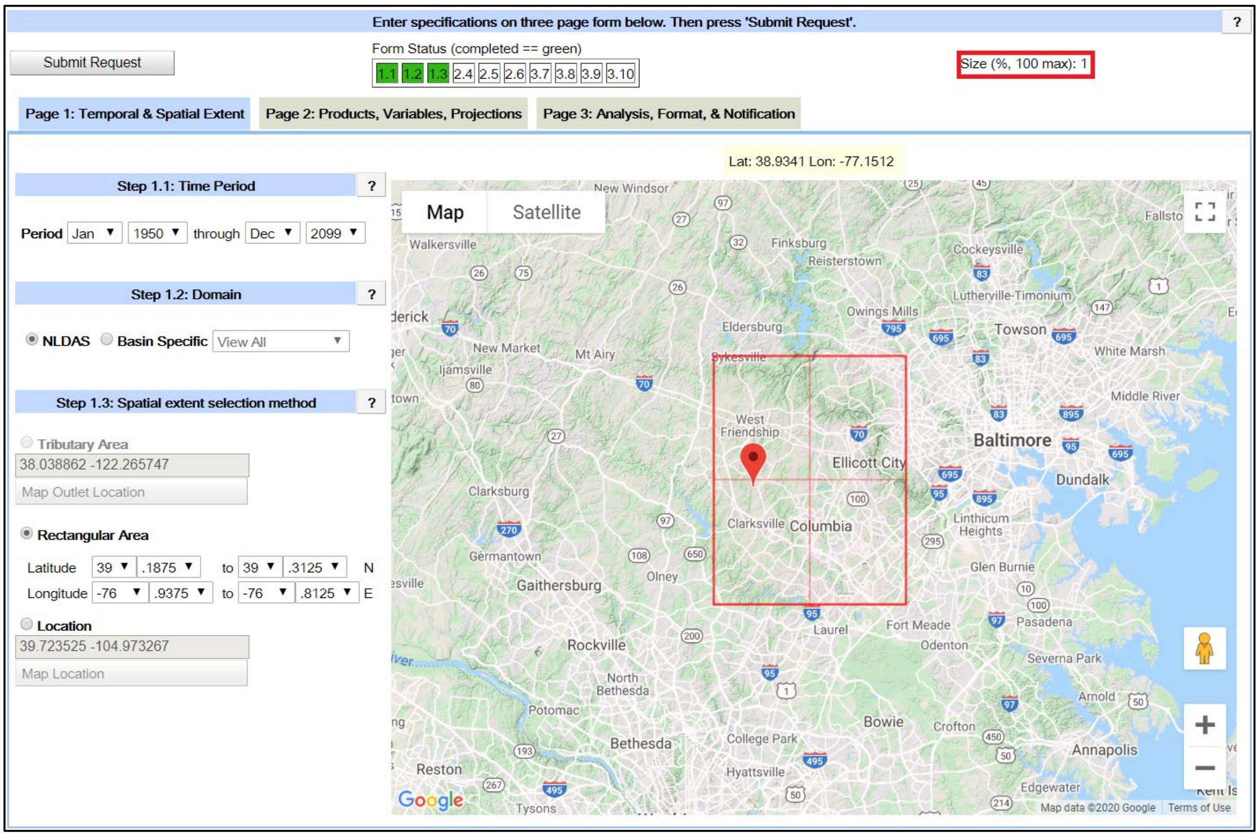

Figure 6 – Step 1.3 continued. Box selection shown.

As an approximate rule of thumb, the LOCA system can process 33 (1/8th degree) boxes at one time with just precipitation data, 16 (1/8th degree) boxes for just temperature data, and 9 (1/8th degree) boxes for both temperature and precipitation. This is because precipitation has only variable while the temperatures have 2 variables. The boxes cover large areas and it is unlikely that the maximum number of boxes will be needed for a single project.

In Figure 6, also note the "*Size (%, 100 max):1*" language in the upper right hand corner of the window. This indicates how proximity to the limit on the amount of data that can be retrieved from the dataset with any request.

[1] This User Manual will demonstrate this later when describing the CMIP Tool (Chapter 3).

Once in the model and climate scenario selections (in LOCA Steps 2.4 through 2.6), ***make sure that the size limit does not exceed 100%.*** If it does, trim back the combination of grid cells, variables requested, and number of models to run until the resultant size of the data request is acceptable (i.e., less than the 100% limit). Separate requests (and CMIP Tool runs) for precipitation and temperature data could also be processed.

> **Helpful Hint: Location, Location, Location …**
>
> A good practice is to keep track of the selected location from this stage. One way might be to take a screen shot of the map so that the User can readily refer to the location of the projections. In this approach, compare that screen shot to the CMIP Tool output screen to ensure information requested covers the correct grid cells in the area of interest.

> **Grid Cells over Water**
>
> Note that grid cells predominantly over water may not include projections. Data for these grids will appear as "NA" in the tool results.

Proceed to DCHP "Page 2: Products, Variables, Projections"

Action 7. **Select** the second tab at the top of the form, *Page 2: Products, Variables, Projections. (see* Figure 7*)*

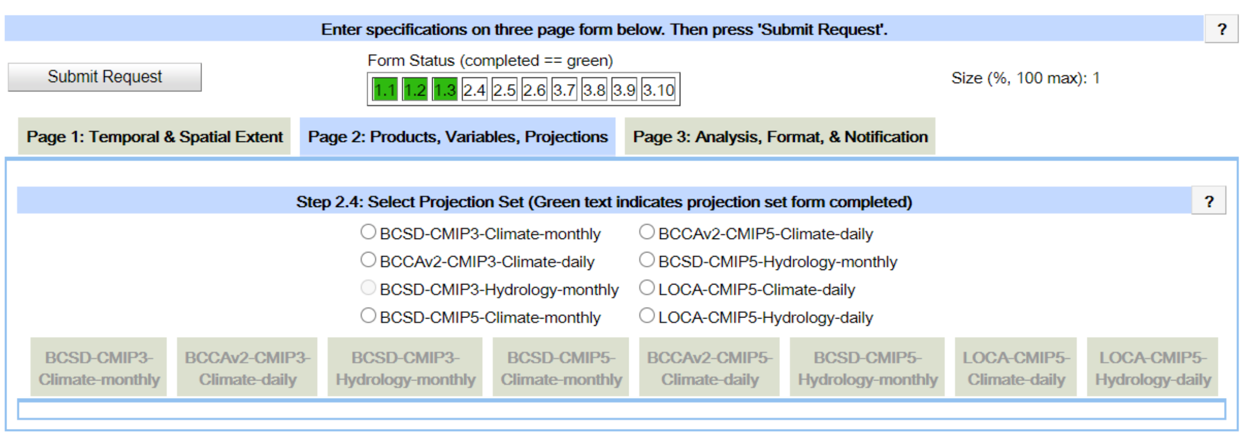

Figure 7 – Page 2 of Subset Request

Again, notice that Form Status indicator at the top of the window shown completion (i.e., turned to "green") step 1.1, step 1.2, and step 1.3).

The current "active" tab (i.e., *Page 2: Products, Variables, Projections*) is also a light blue in color, while the other two are light olive in color.

Action 8. *Select Projection Sets (Step 2.4).* **Select** *LOCA-CMIP5-Climate-daily* dataset (see Figure 8).

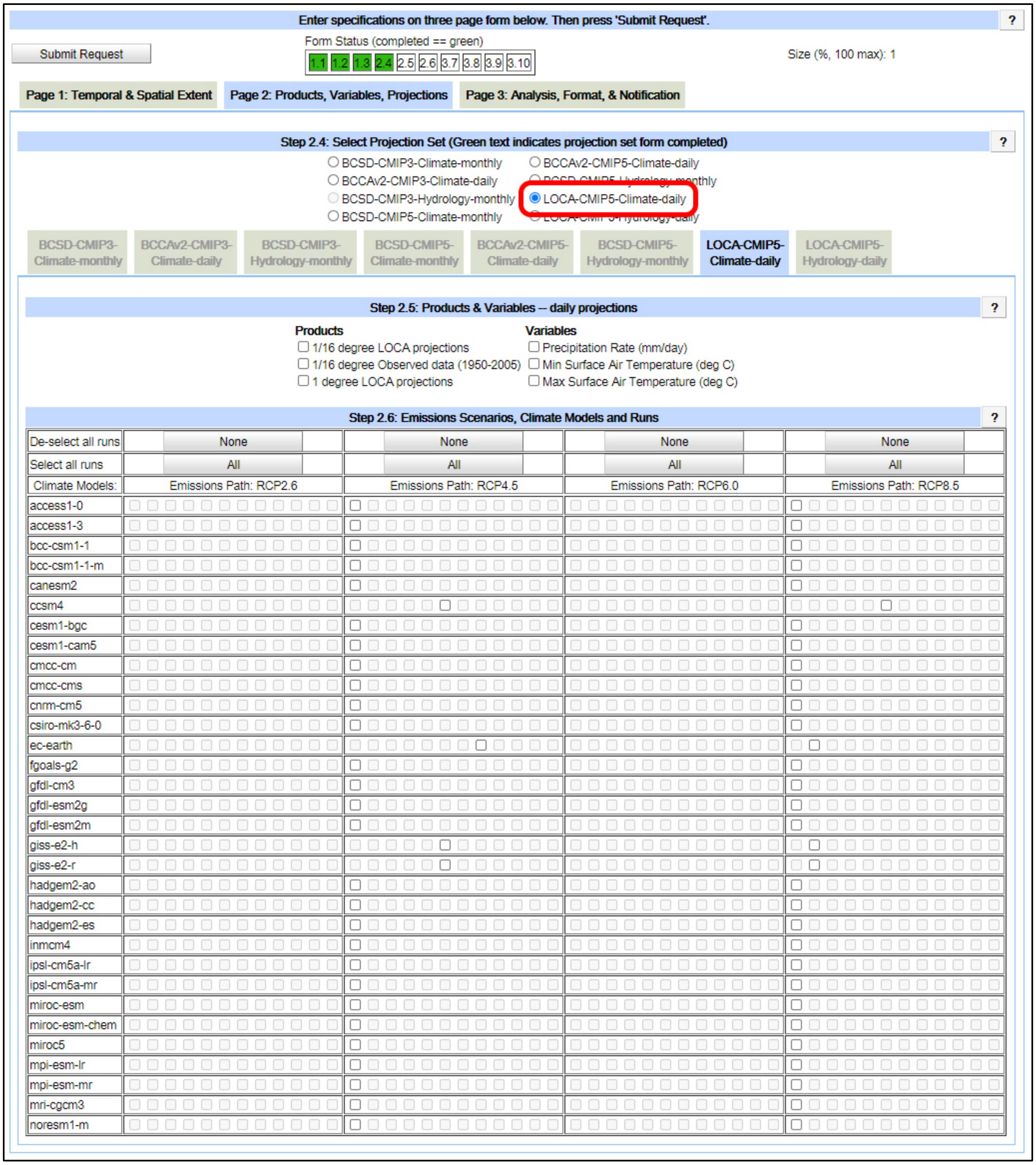

Figure 8 – Step 2.4 Select Projection Set

Notice that Figure 8 displays a series of thirty-two (32) climate models and allows selection of emission paths (i.e., RCPs) within those models. This User Manual will discuss those in more detail below.

After making the selection the page will then show further steps to take. There are 6 other data sets listed alongside LOCA, but these data sets do not function in the FHWA CMIP tool.

Action 9. Products & Variables -- daily projections (Step 2.5) (see Figure 9)

A. Under *Products,* **Select** *1/16 degree LOCA projections* and **Select** *1/6 degree Observed data (1950-2005).*

Why Both Projected and Observed Data?

The CMIP Tool uses BOTH projections and observed data. The Tool will allow the User to refine the actual record year intervals for each, so (typically) obtaining as much of the data here is a good idea.

B. Under *Variables,* **Select** the data of interest. The available options are: *Precipitation Rate (mm/day), Min Surface Air Temperature (deg C),* and *Max Surface Air Temperature (deg C)*. If performing a hydrologic study, select the precipitation rate.

If the User desires temperature output variables (e.g., if planning for pavements or snowmelt analysis, etc), select both air temperature options.

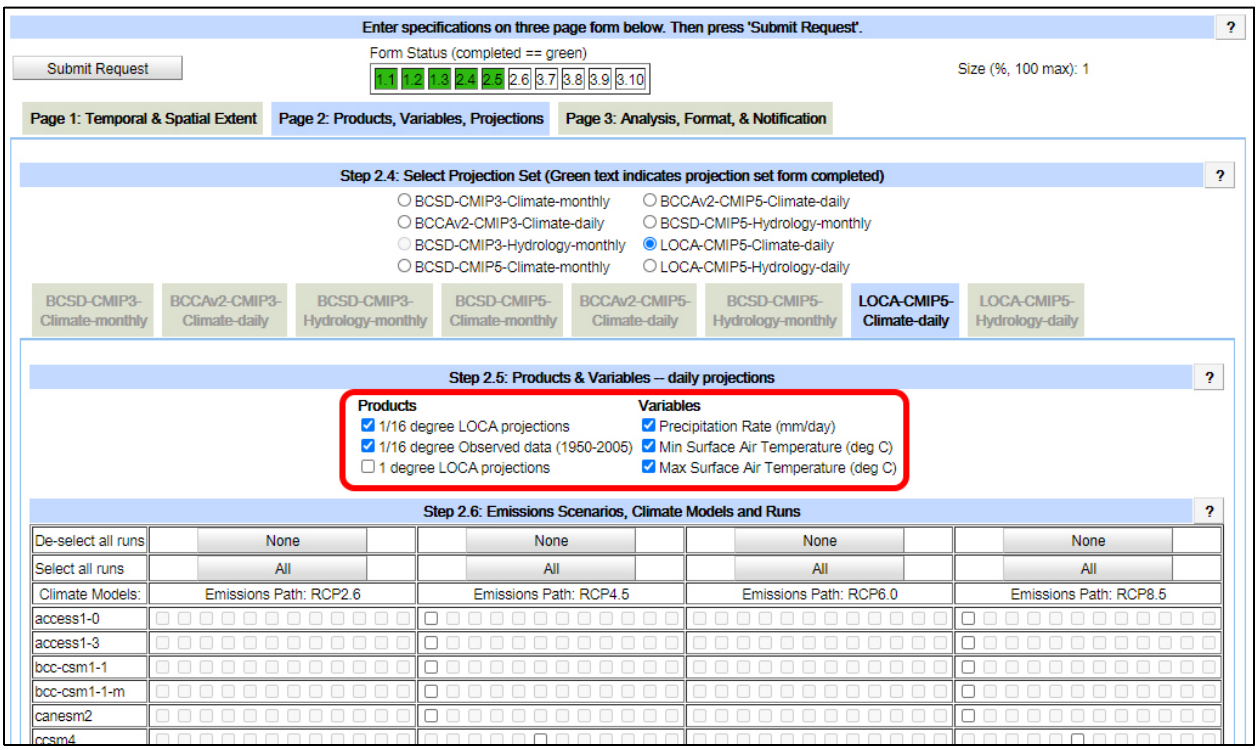

Figure 9 – Step 2.5 Products & Variables (cropped)

Action 10. Emissions Scenarios, Climate Models and Runs (Step 2.6) (see Figure 10)

A. **Check** the boxes for the emissions scenario and climate models desired. In general, a user will select either the *RCP 4.5* or *RCP 8.5* and then press the *ALL* button (see notes below). The emissions scenarios are listed in order from low to high (*RCP4.5* is the lowest available emissions path and *RCP8.5* is the highest available emissions path).

Note the Size *(%, 100 max): 36* at the top of the page. After selecting the models, a value will appear next to the size box. This value must be equal to or below 100.

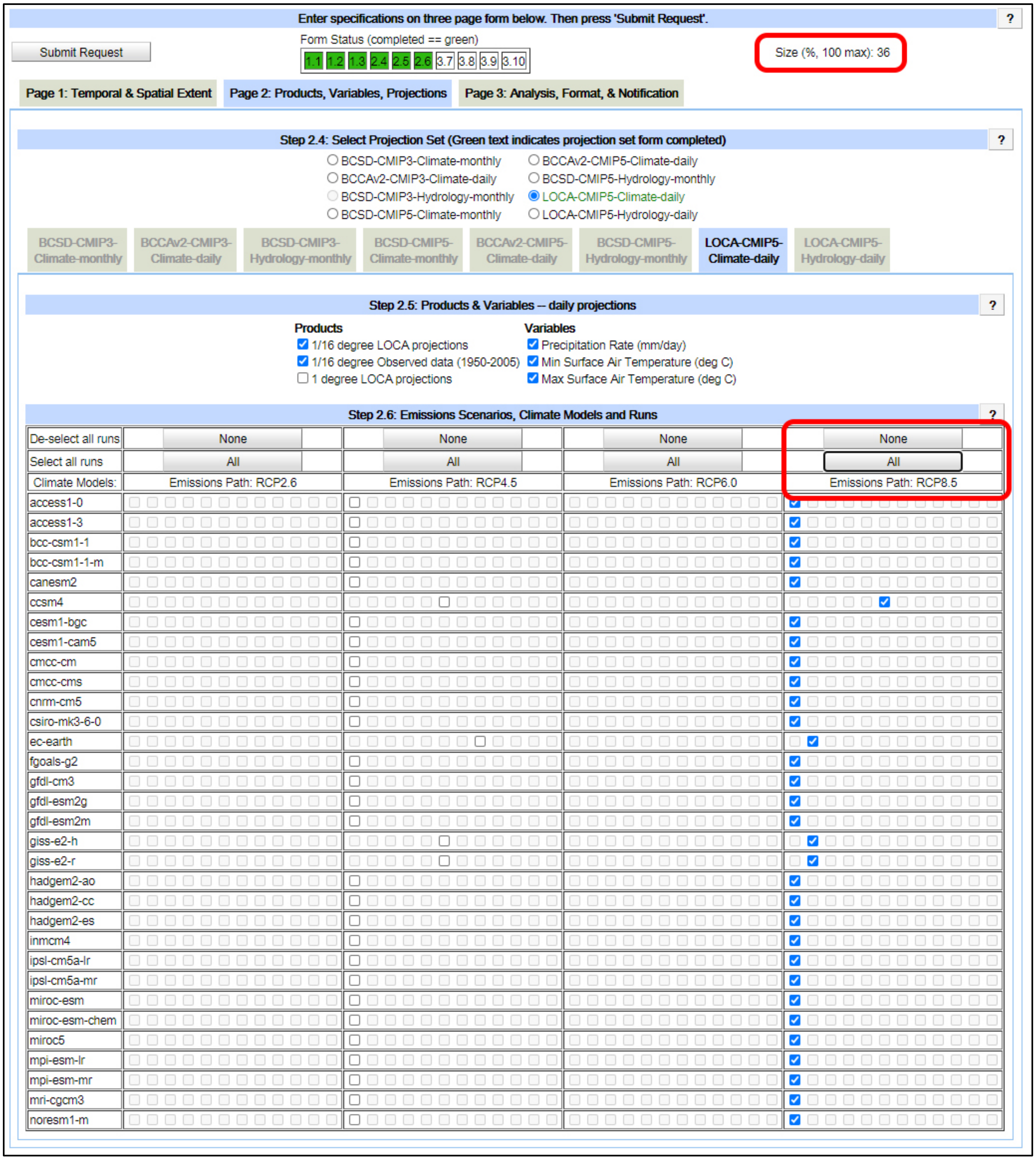

Figure 10 – Step 2.6 Emissions Scenarios, Climate Models and Runs

This completes the steps in "**Page 2: Products, Variables, Projections.**"

However, before continuing forward, this User Manual provides some information of "Choosing Emission Scenarios," "Choosing Climate Models," and "Other Resources."

Choosing Emissions Scenarios

Select models under one Emissions Scenario/Path at a time. To compare projections under different Emissions Paths, **complete a separate DCHP data request for each scenario.** Then, the user can perform a separate analysis using the CMIP Tool and compare the results for each scenario. **The CMIP Tool will not process data when multiple scenarios are selected in the same DCHP data request.**

Note that if the user is concerned with **mid-century** projections, the choice of emissions scenario(s) will not greatly affect the results. Emissions scenarios do not differ much until after mid-century. If the focus is on **end-of-century** results, choosing and comparing emissions scenarios may be more important.

The table below summarizes the emissions scenarios available from the LOCA dataset through the DCHP website. Detailed information on the emissions scenarios is available in the IPCC Fifth Assessment Report at: https://www.ipcc.ch/report/ar5/wg1/.

Representative Concentration Pathways (RCPs)

Scenario Name	Description	Concentrations (ppm CO_2 equiv.) by 2100	Global Surface Temp. Change by 2100	Global Mean Sea Level Rise by 2100
RCP4.5	Stabilization	630	2.0-4.7 °F (1.1-2.6 °C)	1.0-2.1 ft (0.32-0.63m)
RCP8.5	High emissions continue	1313	4.7-8.6 °F (2.6-4.8 °C)	1.5-2.7 ft (0.45-0.82m)

Source: UN IPCC, Climate Change 2013: The Physical Science Basis (https://www.ipcc.ch/report/ar5/wg1/)

Choosing Climate Models

A common practice among the climate science community is to select all available climate models under the chosen emissions scenario and rely on the multi-model ensemble. Selecting all models helps better account for the statistical variability and can protect against outlier results. The user may wish to consult with their NOAA Regional Integrated Sciences and Assessments (RISA) team, local universities, state climatologist, or other experts if they are considering selecting specific models.

Other Resources

Chapter 5 of the FHWA's Hydraulic Engineering Circular 17 (HEC-17) *"Highways in the River Environment — Floodplains, Extreme Events, Risk, and Resilience"*[1] provides some additional background on these models and paths.

Proceed to DCHP "Page 3: Analysis, Format, & Notification"

Action 11. **Clicking on** the third tab at the top of the form, *Page 3: Analysis, Format, & Notification* will move to the window screen depicted by Figure 11.

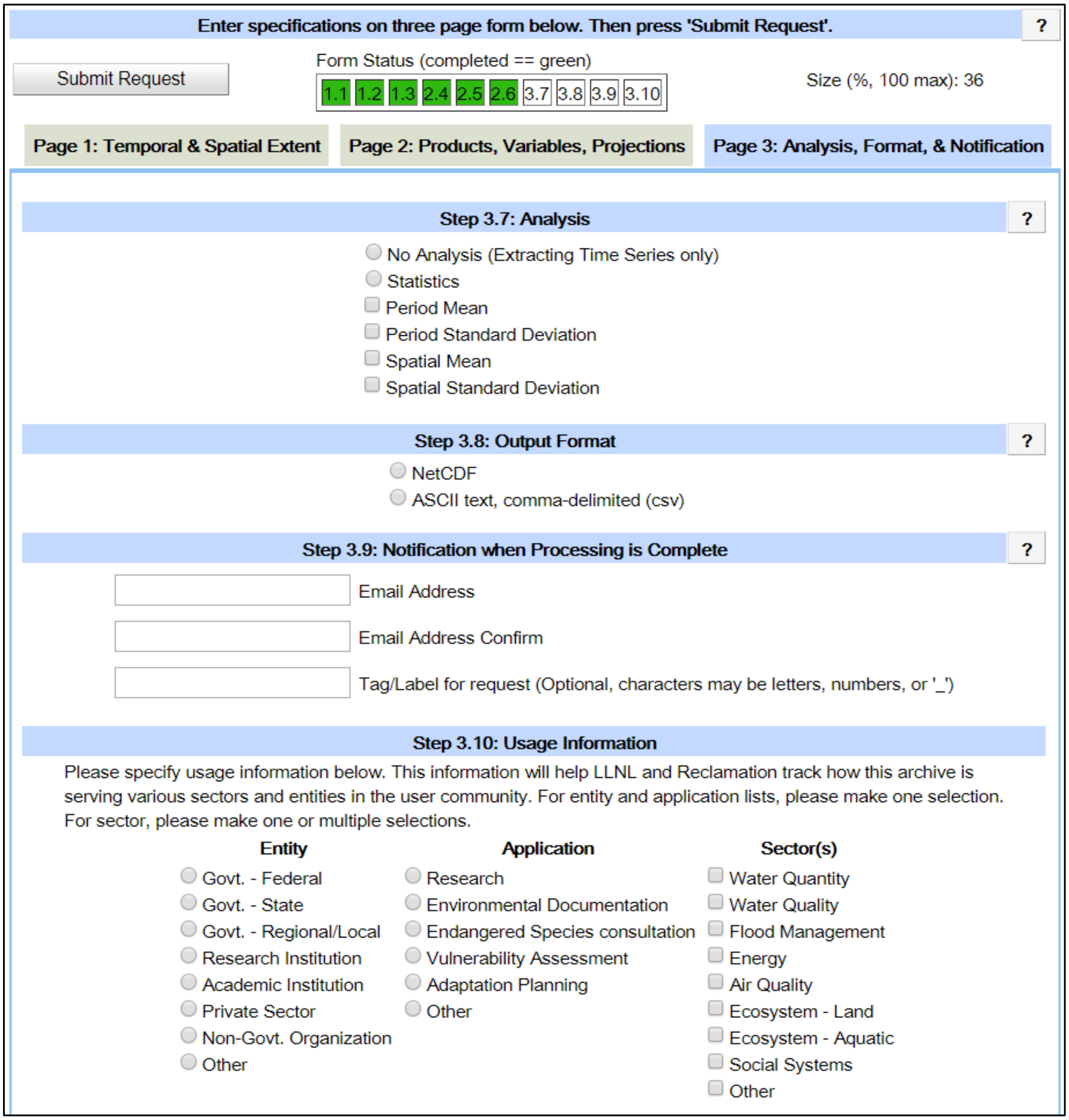

Figure 11 – Page 3 of Subset Request

In the next few pages, we will separately focus on "Step 3.7: Analysis,", "Step 3.8: Output Format," "Step 3.9: Notification when Processing is Complete," and "Step 3.10: Usage Information."

As needed, refer back to Figure 11 to see the entire window screen.

Action 12. Analysis (Step 3.7): **Select** *No Analysis (Extracting Time Series only)* (see Figure 12)

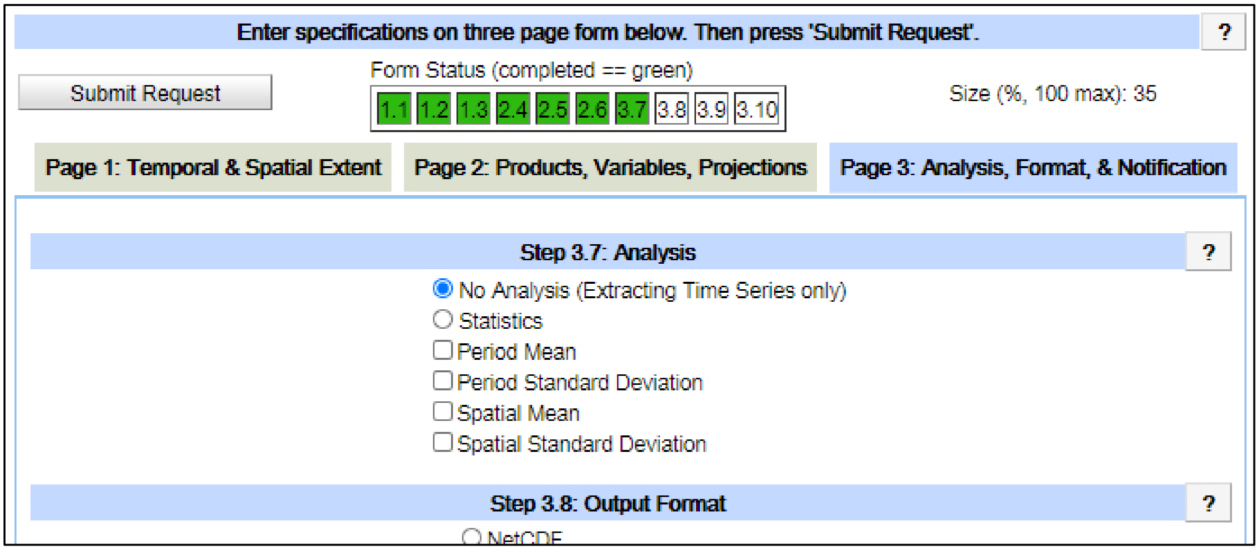

Figure 12 – Step 3.7 Analysis (cropped)

Action 13. Output Format (Step 3.8): **Select** *NetCDF* (see Figure 13).

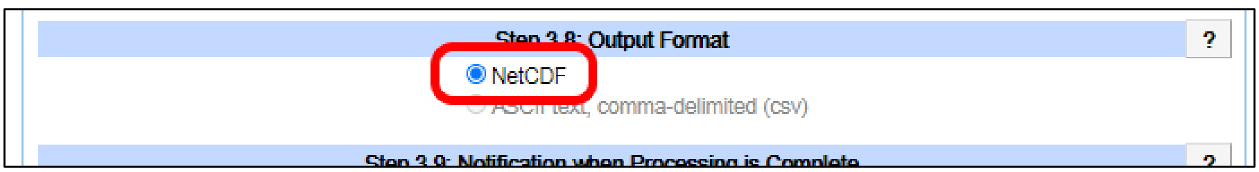

Figure 13 – Step 3.8 Output Format (cropped)

This is the data format needed by the CMIP Tool to process the LOCA data. The Tool does not process ASCII text.

Action 14. Notification when Processing is Complete (Step 3.9) (see Figure 14).

A. **Enter** the email address where the user would like to receive notification when the processing is complete.

B. **Provide** some tag or label to describe the request. This helps when making many analyses.

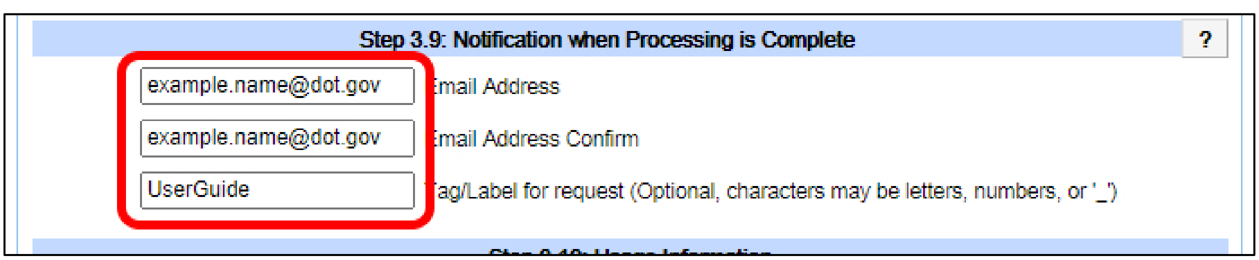

Figure 14 – Step 3.9 Notification when Processing is Complete (cropped)

Action 15. **Select** the appropriate Entity, Application, and Sector(s) (see Figure 15).

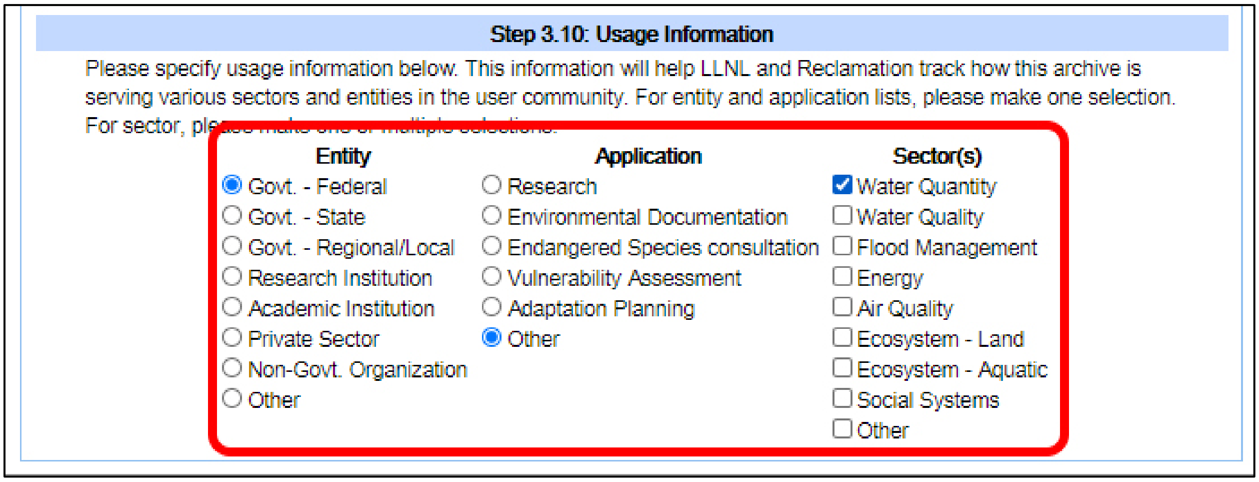

Figure 15 – Step 3.10 Usage Information (cropped)

Action 16. When complete, **scroll up the page** to make sure that all boxes for steps 1.1-3.10 are colored green (i.e., complete) (see Figure 16). If a box is white, click on that box, return to the appropriate step, and fill in the information.

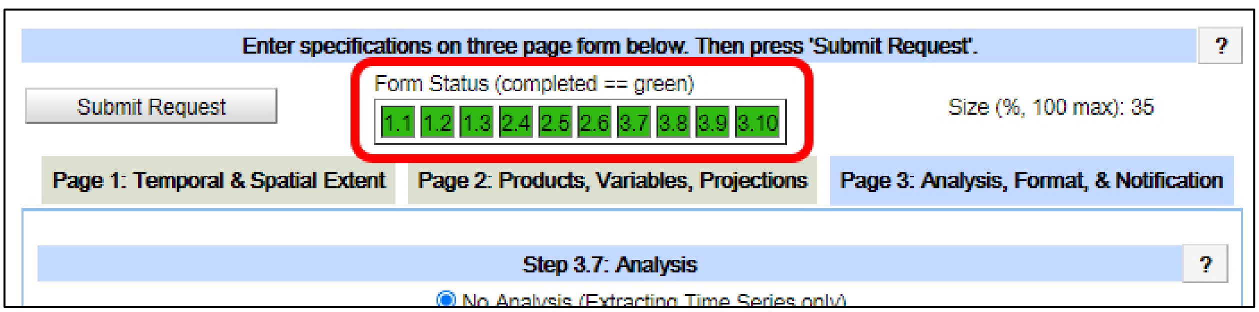

Figure 16 –Form Completion Boxes (cropped)

2.2 Submitting Request

Action 1. Once all information is entered, **Select** *Submit Request* at the top left corner of the form (Figure 17).

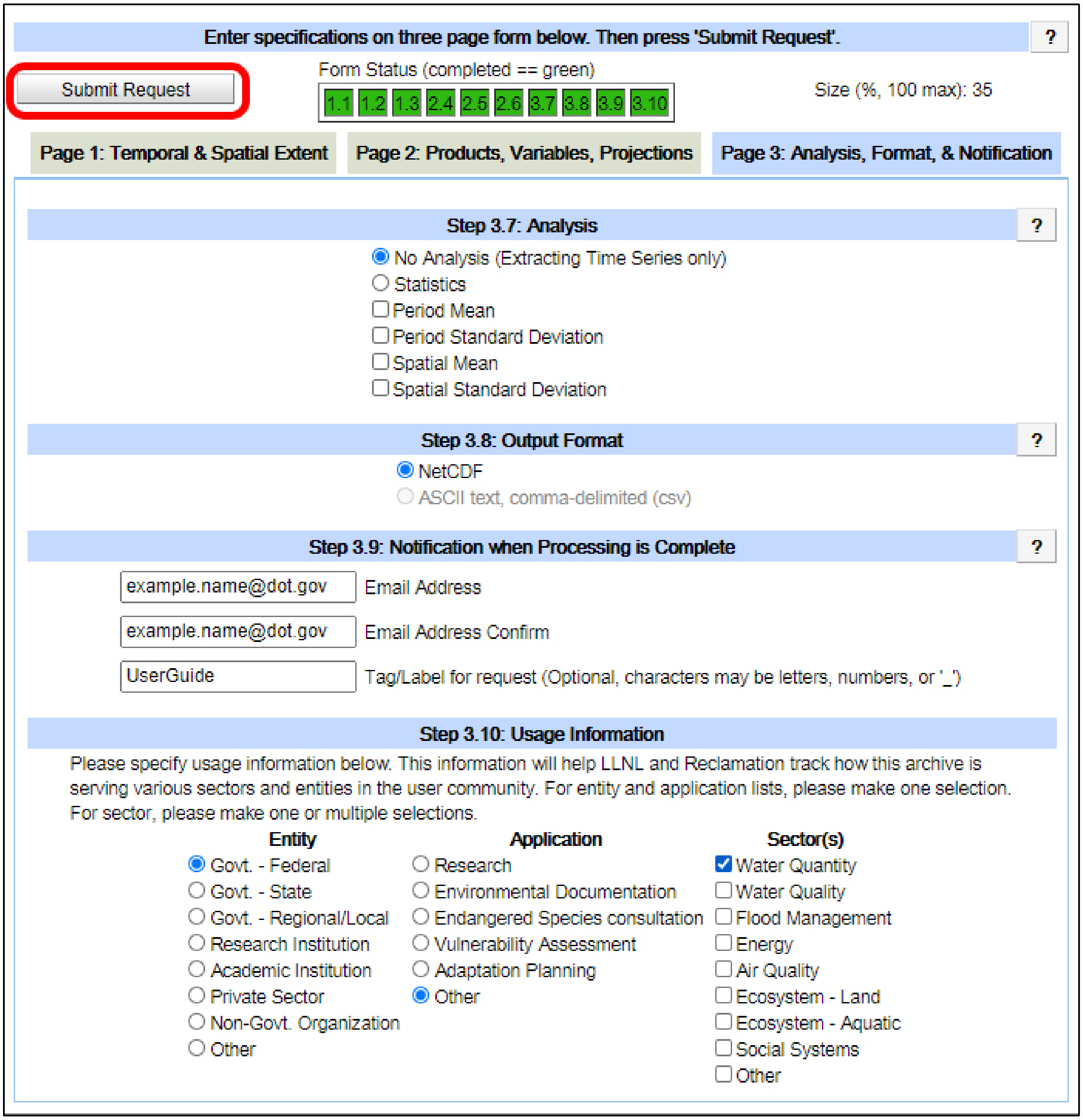

Figure 17 – Submit Request

Action 2. A "pop up" window Summary of Requested Files will appear (Figure 18). **Select** *Submit* to send the request.

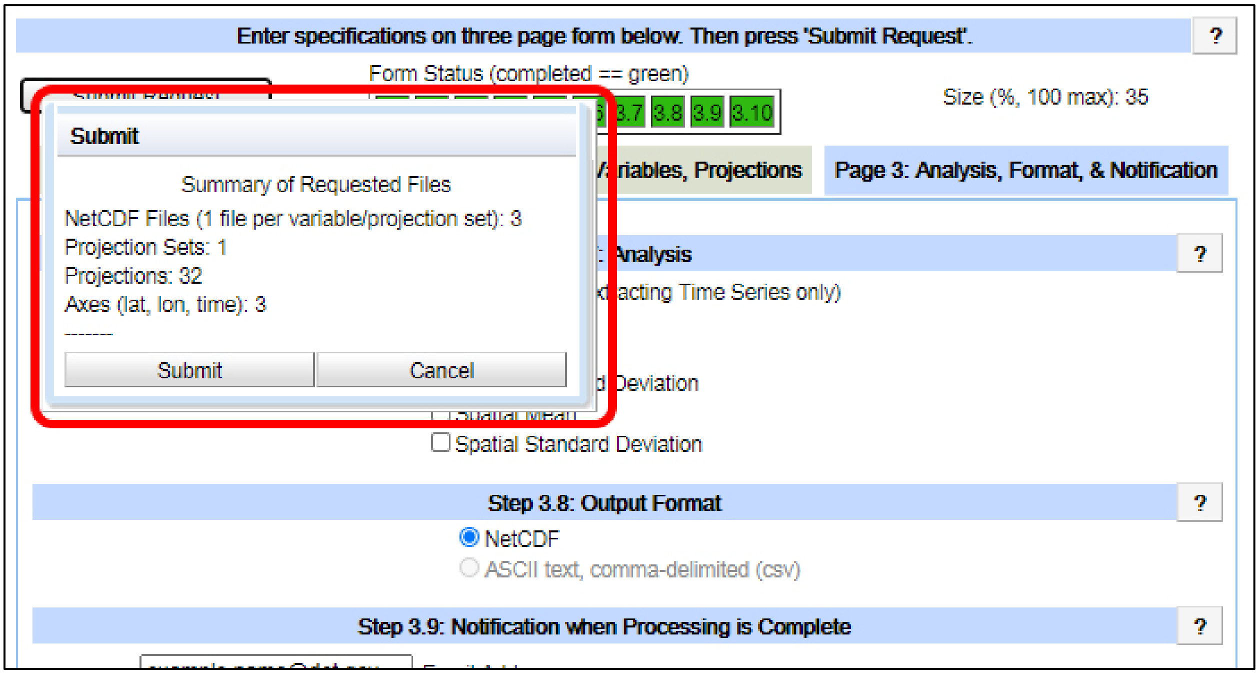

Figure 18 – Follow up Submit Request Pop-up

The system will provide a response from the request. Figure 19 depicts the appearance on browser and Figure 20 provides an enlarged view of the request response.

> **Notice**
>
> It may take from several hours to several days for DCHP to process and User to receive the requested data.

Action 3. : **Select** *OK* to initiate the process.

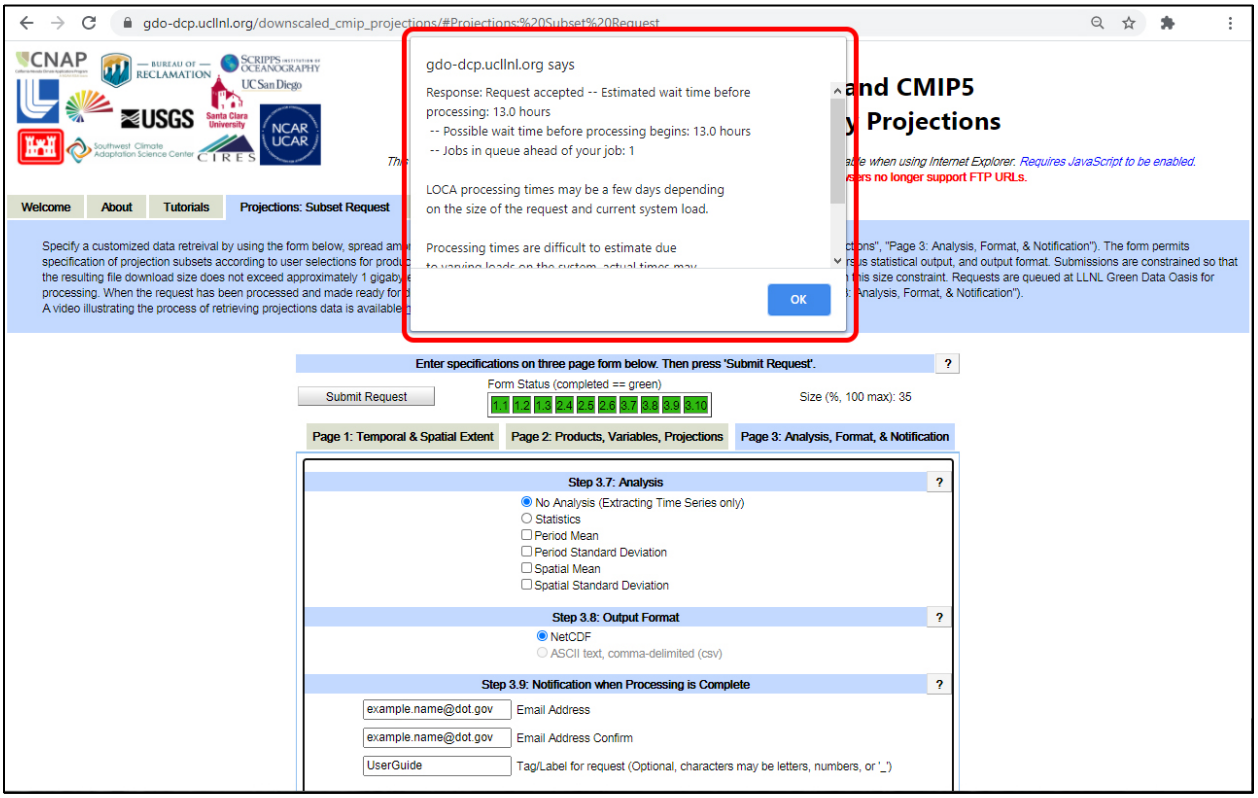

Figure 19 – Submission Notification

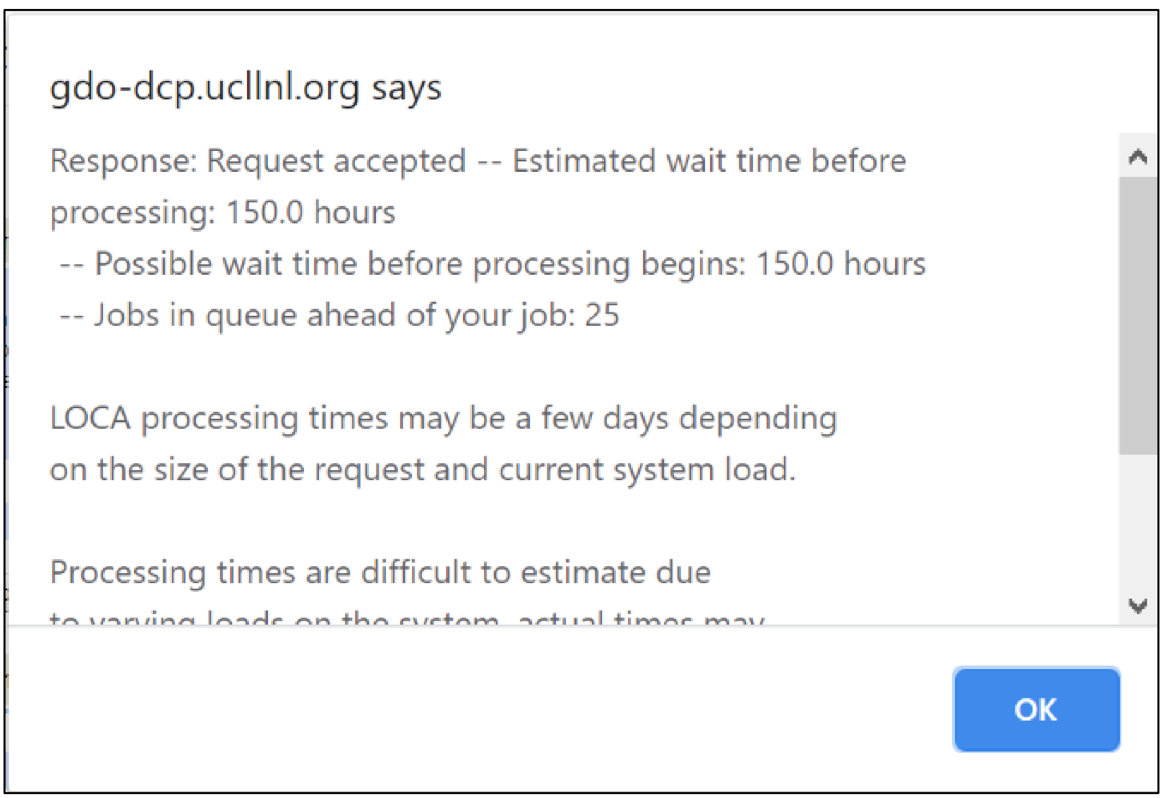

Figure 20 – Submission Pop-Up giving anticipated time to receive data

2.3 Retrieving Data

Action 1. Once the data is available, the user will receive an email. **Open the message** and **click on the link** provided.

The web pages similar to those depicted in Figure 21 and Figure 22 will appear. The DCHP website recommends to use Google Chrome or Firefox when downloading this data. For this example, the data was downloaded with Internet Explorer.

Action 2. **Select** and **download** the following 2 files: *1_16obs.tar.gz* and *loca5.tar.gz*.

Do not change the names of these files. The CMIP tool will only work with these file names. To separate and identify files from different locations, with different emissions scenarios, or other differences, a technique that can be used is to create separate folders so they can be identified by the folder name.

The ".TXT" extension files also have useful identifying information about the data (e.g., location, years, and models selected). Though they are not required to run the CMIP tool, it may be helpful to download and store them with the ".GZ" extension files for future reference.

FTP directory /pub/dcp/subset/202102191706Nr5l_n_SWzWth at gdo-dcp.ucllnl.org

To view this FTP site in File Explorer: press Alt, click **View**, and then click **Open FTP Site in File Explorer**.

Up to higher level directory

```
02/20/2021 01:58AM            0 0TAG:UserGuide
02/20/2021 01:58AM          133 202102191706Nr5l_n_SWzWth.txt
02/20/2021 01:58AM       14,019 Notes.txt
02/20/2021 05:12PM          585 Projections5.txt
02/20/2021 05:12PM    Directory loca5
02/20/2021 05:13PM  250,696,432 loca5.tar.gz
```

Figure 21 – Download link for DCHP data with LOCA data highlighted.

FTP directory /pub/dcp/subset/202102191706Nr5l_n_lDp99p at gdo-dcp.ucllnl.org

To view this FTP site in File Explorer: press Alt, click **View**, and then click **Open FTP Site in File Explorer**.

Up to higher level directory

```
02/20/2021 02:17AM            0 0TAG:Observations
02/20/2021 02:37AM    Directory 1_16obs
02/20/2021 02:37AM    2,142,935 1_16obs.tar.gz
02/20/2021 02:17AM          136 202102191706Nr5l_n_lDp99p.txt
02/20/2021 02:17AM       14,019 Notes.txt
```

Figure 22 – Download link for DCHP data with Observed data highlighted.

This completes the first stage of the CMIP Tool process.

3. Applying the CMIP Tool

The CMIP Tool is housed on the FHWA's website. The previous Chapter explained how to specify and download the LOCA dataset from the DCHP website. This section details the step by step process of using the tool to process the LOCA data from the DCHP website obtained in the previous section.

3.1 Uploading Data and Initiating a Job

The CMIP Climate Data Processing Tool (version 2.1) is hosted on FHWA's website at https://fhwaapps.fhwa.dot.gov/cmip.

Action 1. **Go to** https://fhwaapps.fhwa.dot.gov/cmip. Figure 23 depicts the initial screen.

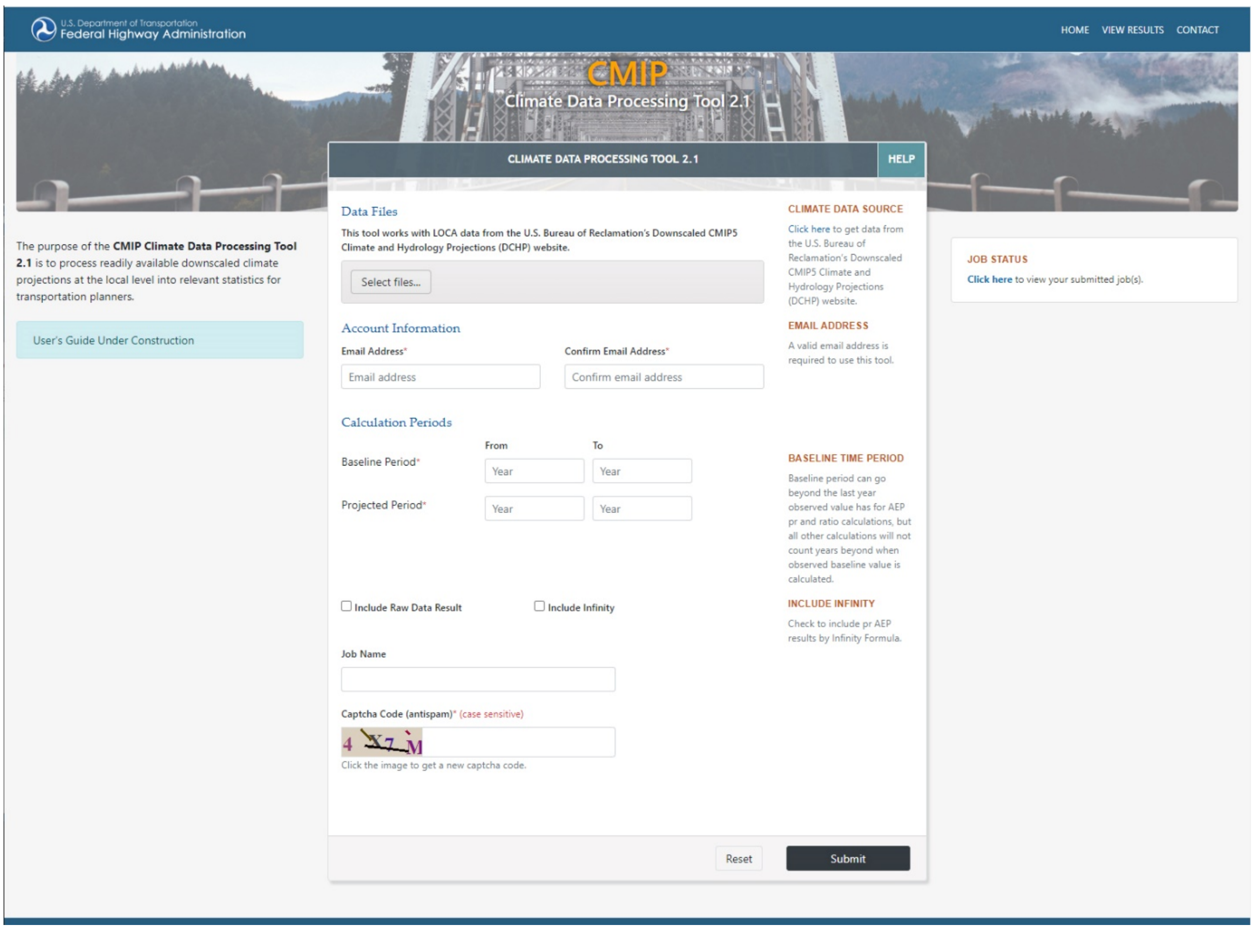

Figure 23 – CMIP Tool Data Processing Request Page

Action 2. Upload the files saved from the DCHP download (see Figure 24). **Click** the *Select files…* button.

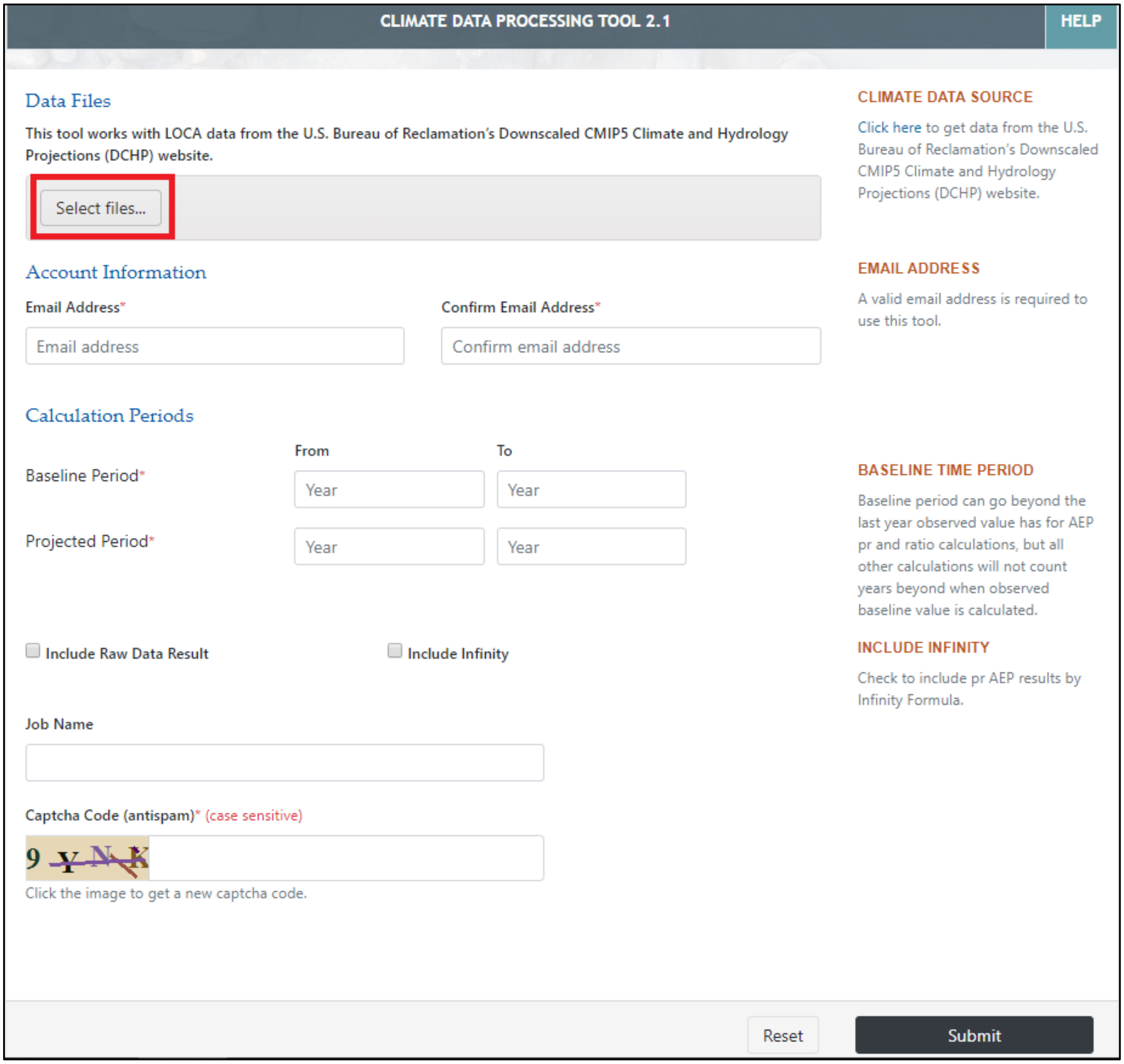

Figure 24 – Select Files step highlighted

Once the files have finished uploading, the Data Files part of the screen should look as depicted in Figure 25 below.

Action 3. **Select** the files for the appropriate location with the original file names (i.e., *1_16obs.tar.gz* and *loca5.tar.gz.*)

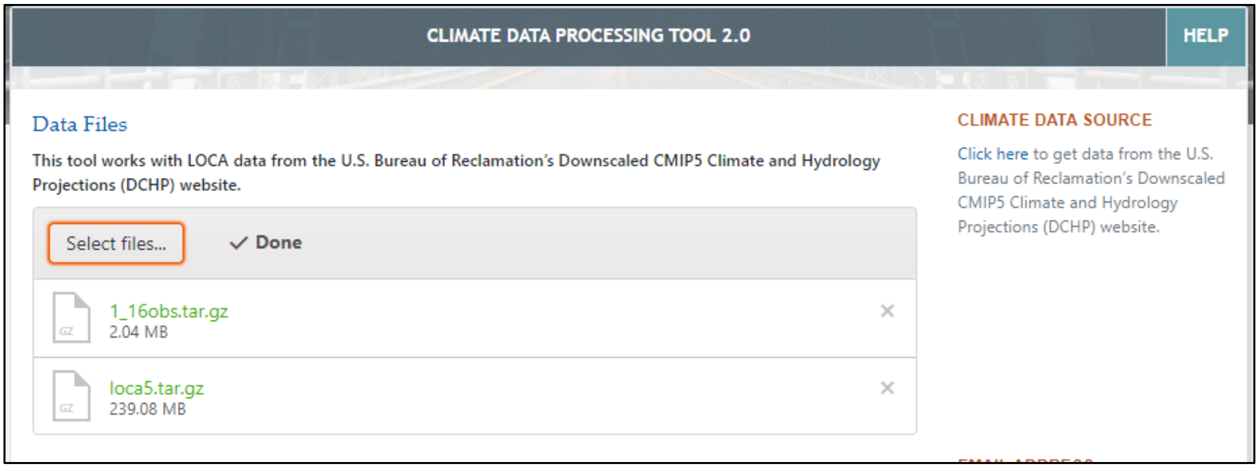

Figure 25 – Select Files step with LOCA and Observation data uploaded.

Action 4. **Enter** the preferred email address in the *Email Address* and in the *Confirm Email Address* boxes (see Figure 26).

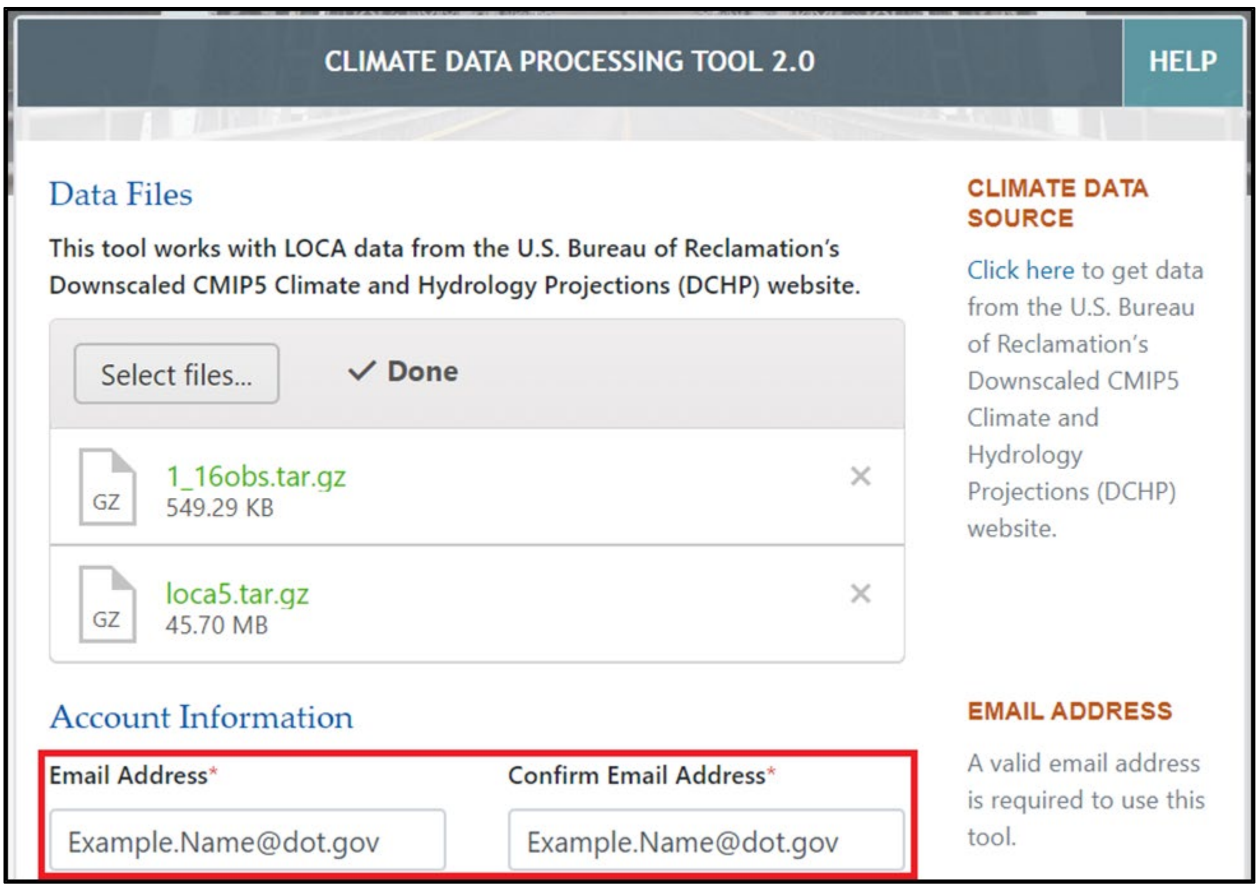

Figure 26 – Enter Email Address Step

Action 5. Enter the information for the Calculation Periods (see Figure 27).

A. **Enter** the **starting year value** in the *From* column and the **ending year value** in the *To* column for the *Baseline Period*.

B. **Repeat** entering those years in the *Projected Period*.

Note that observed data ends at 2005. If users are interested in projected temperature variables, selecting a baseline period within 1950-2005 that spans at least 30 years will allow for an "apples to apples" comparison of baseline and future data to the observed data. This comparison is used for projected results as discussed later in the User Manual.

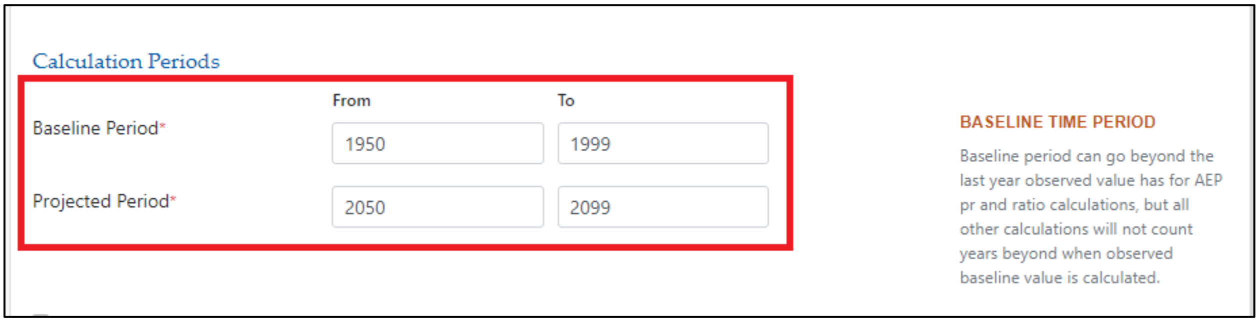

Figure 27 – Enter Calculations Period Step

Choosing Baseline and Projected Periods

Use a minimum of 30 years to define the baseline and projected periods to avoid potentially misleading results that may occur in shorter time periods. For example, if the interest is in the present time compared with the end of the century, a minimum baseline period could be 1990 to 2019 with a future period of 2070 to 2099. **The CMIP tool will not process a data request with less than a 30-year period.**

Observed data are only available through the year 2005. If the baseline period selected starts after 2005, no observational data will be used in the calculations. If the baseline period includes years after 2005, the observational record will be reduced to the years up to 2005 and the results will be based on the shorter period.

The end of the baseline period must end before the beginning of the future period. For example, if the baseline period is from 2000 to 2029 then the projected period must start from 2030 or later.

Action 6. Leave the *Include Raw Data Result* box **unchecked** (see Figure 24 above) unless there is a specific need for it. If checked, the resulting information will include the data from the original DCHP download in .xls format resulting in large files. There may be some cases where the user would like to examine the raw data.

Action 7. Leave the *Include Infinity* box **unchecked** (see Figure 24 above) unless there is a specific need for it. The checkbox is only applicable for the computation of the precipitation annual exceedance probability (AEP) quantiles and ratios (see Section 3.1). As described in Section 3.2.3, the default computations use the actual samples sizes for computation of the quantiles using a Gumbel distribution. If checking the *Include Infinity* box, the CMIP Tool also computes the quantiles and ratios assuming an infinitely large sample size for the Gumbel distribution. Unless the user has a specific reason to use the infinite sample size option, it is suggested that leave the box unchecked to avoid confusion. If both boxes are checked, the normal distribution items will have a *("Table 4.12") tag* at the end of every label while the infinity distributions will have no modifier to the label.

Action 8. **Enter** a *Job Name* (see Figure 28).

Action 9. **Enter** the *Captcha Code* (it is case sensitive) (see Figure 28).

Action 10. **Select** *Submit* at the bottom right corner (see Figure 28).

The *Captcha Code* can time out if the screen has been idle for too long, in which case the page will refresh the *Captcha Code*. If this happens, the data files must be uploaded again.

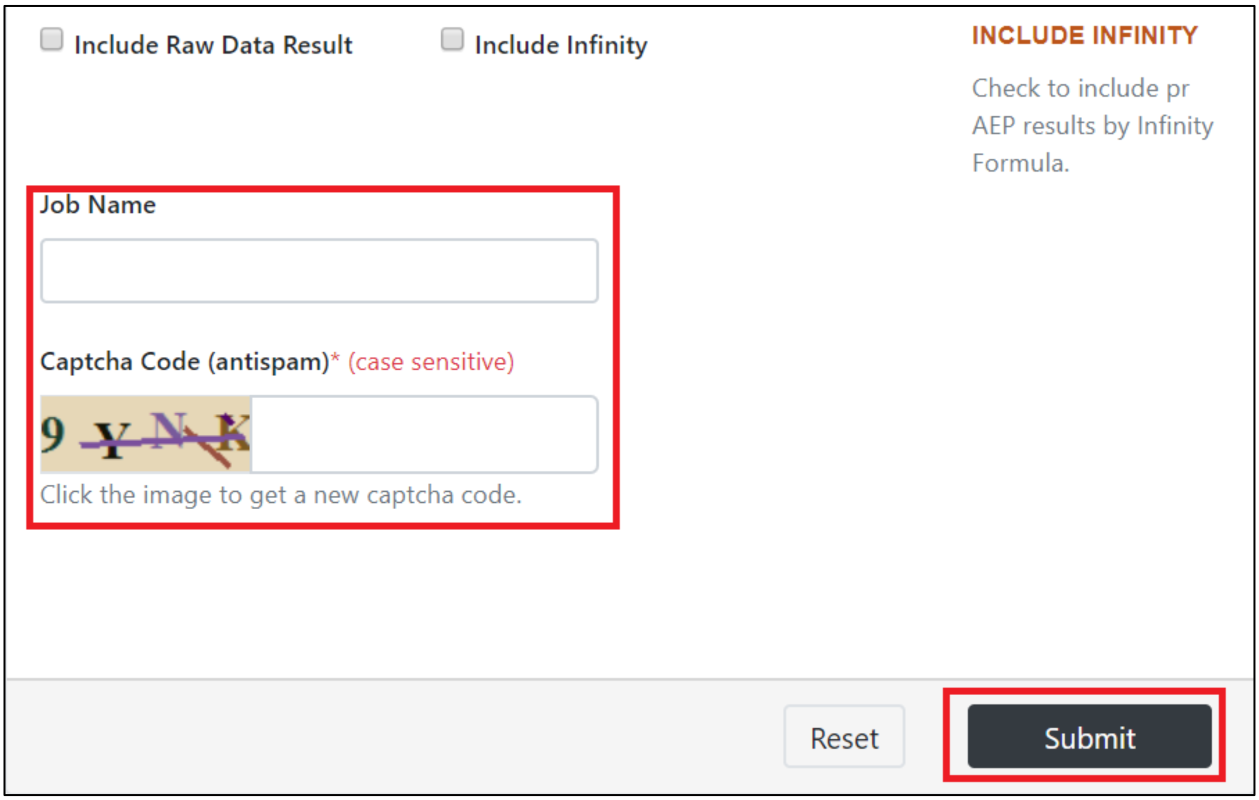

Figure 28 – Enter Job Name and Captcha Code Step

After clicking the submit button, the user will receive a message that "Your job has been successfully submitted. You will receive an email notification once your job has been processed."

Shortly after submitting, an email will be sent to the provided email address confirming that the job is being processed. Processing times can take anywhere from a few minutes to a few hours.

3.2 Retrieving a Job and Exploring the Results

Action 1. Once the job is completed, a second email is sent to the user. The body of this email contains an access code as shown in Figure 29 below.

> CMIP Calculation Job:37 Completed on 02/06/2020 3:14:00 PM. Please visit CMIP web site to review or to download results. Your access code is ED52

Figure 29 – Email clip showing access code.

Action 2. **Return** to the CMIP Tool website (https://fhwaapps.fhwa.dot.gov/cmip)

Action 3. **Click on** the *VIEW RESULTS* button in the upper right hand corner of the page or select the link under *JOB STATUS*. (See Figure 23).

3.2.1 Logging into CMIP Tool

The user will be sent to the login screen depicted in Figure 30.

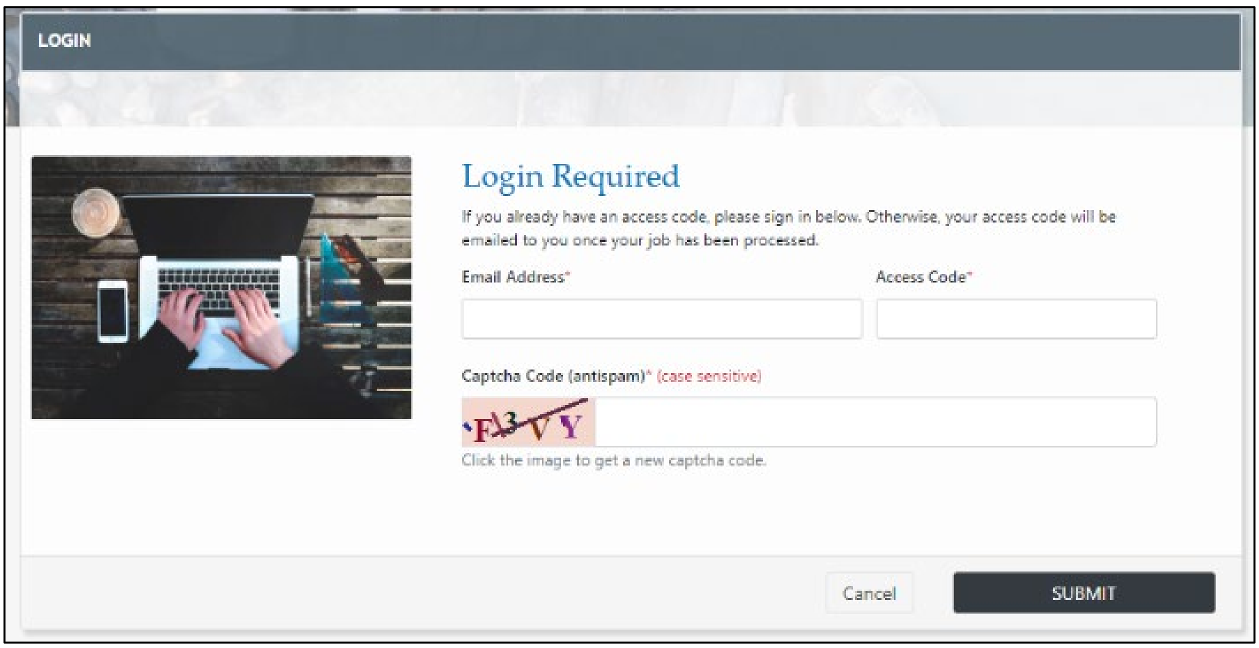

Figure 30 – CMIP Tool Login Page

Action 4. **Enter** the email address previously used (i.e., from Figure 26).

Action 5. **Enter** the 4-character access code from the Job Completion email (Figure 29).

> **Which Access Code?**
>
> When multiple jobs have been submitted to the CMIP Tool from the same email address, the user should use the access code from the last job that was completed.

Action 6. **Enter** the Captcha Code at the bottom of the screen.

Action 7. **Select** *Submit* once entering all the information above.

3.2.2 Application of the Tool

After logging in, the screen depicted in Figure 31 will appear:

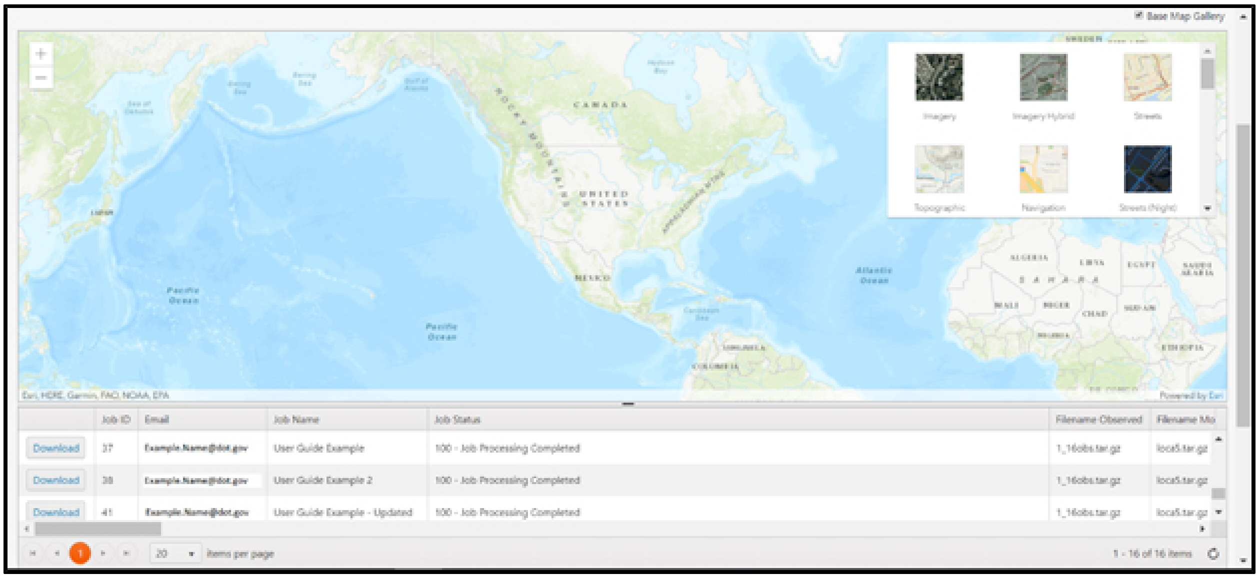

Figure 31 – CMIP Tool Download Page

The base map options appear in the upper right corner (see Figure 32).

Figure 32 – CMIP Tool Download Page Base Map Gallery

Action 8. The user can **select** from multiple different background maps in the top right corner including street views, topographic, imagery, etc.

To turn off the base map gallery, **click** the box in the upper right corner named Base Map Gallery.

Action 9. Below the map view depicted in Figure 33 is a list of jobs submitted within the past three months. (Older jobs are deleted.) Find the desired job and **right click on it**.

By right clicking on the requested job, an option will appear with *Zoom To* and *Show Grids*.

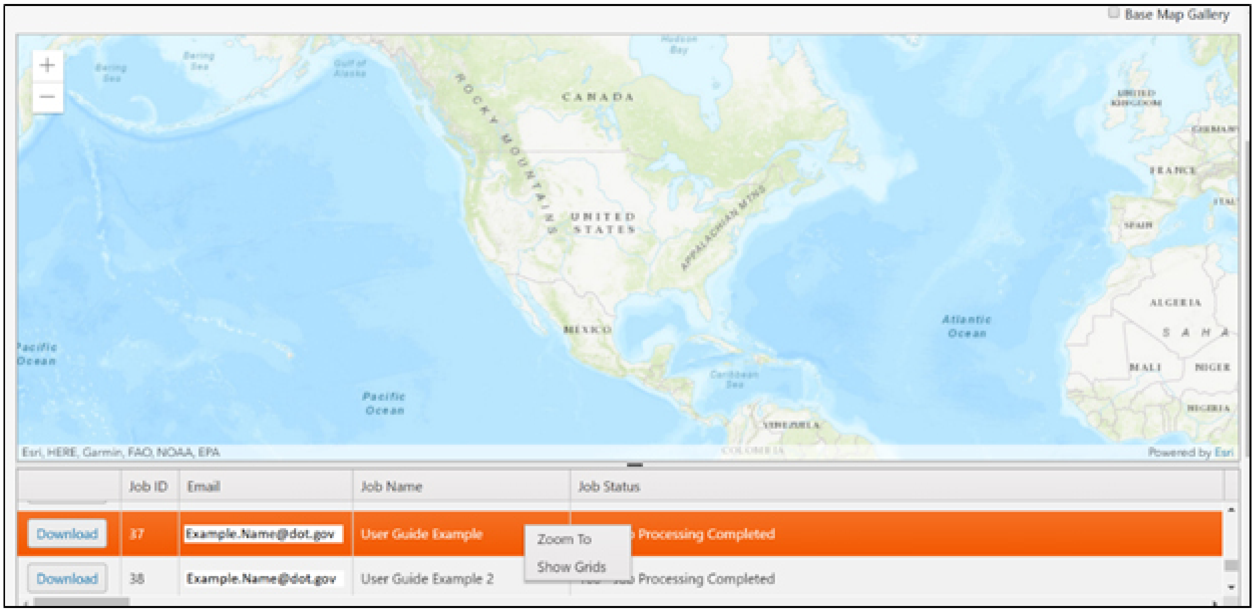

Figure 33 – CMIP Tool Download Selection

Action 10. When **clicking** on *Zoom To,* the CMIP Tool will zoom in to the grid locations included in the job. This is useful to confirm that the information that has been processed is at the expected location.

Action 11. When **clicking** on *Show Grids,* the CMIP Tool will display the LOCA grid cells (1/16th degree by 1/16th degree) with a series of numbers within each grid.

As depicted in Figure 34, the larger 1/8th degree by 1/8th degree cells defined by the data retrieval from the DCHP website are indicated by thick blue lines.

For each grid selected in the DCHP website, four grids (separated by thin red lines) appear in the CMIP Tool.

In the Figure 34, the map window depicts the four 1/8th degree grid cells selected in the DCHP website and sixteen (16) 1/16th degree LOCA grid cells.

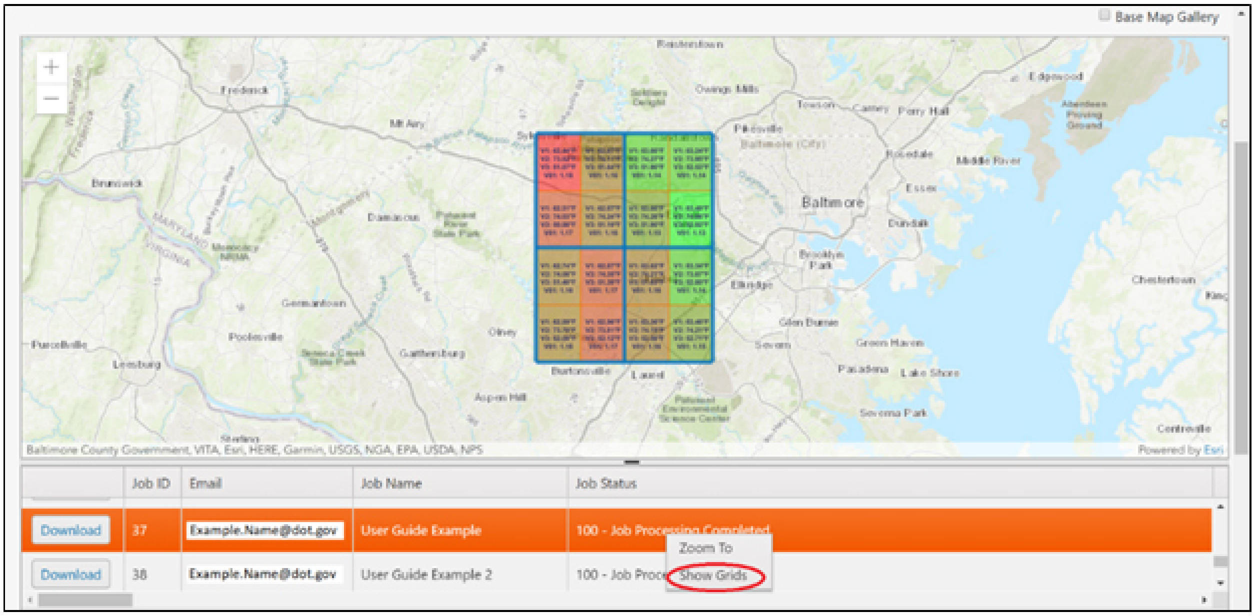

Figure 34 – CMIP Tool Show Grids Option

What are those numbers in the grid cells?

The grid cells have numbers and a color assigned to each cell. The numbers are values from a subset of the parameters computed by the CMIP Tool (temperatures are in degrees Fahrenheit):

V1 = Average Annual Mean Temperature

V2 = Average Annual Maximum Temperature

V3 = Average Annual Minimum Temperature

V81 = Ratio of 24-hr Precipitation with an Annual Exceedance Probability (AEP) of 10.0% (a 1 in 10-yr event)

The grid cells are color-coded based on V81, with a heat ramp ranging from a bright red for higher values (i.e., larger change from baseline to future) to a bright green for lower values.

These numbers and colors provide the user a quick overview of information in the cells, which may assist in identifying cells that may exhibit anomalous behavior.

3.2.3 Downloading CMIP Tool Calculation Results

The final step for the CMIP Tool is downloading the calculation results

Action 12. **Select** the *Download* button for the selected job (see Figure 33 and Figure 34).

This will initiate a download of a zipped file that contains some or all of the files in Figure 35 (shown after unzipping).

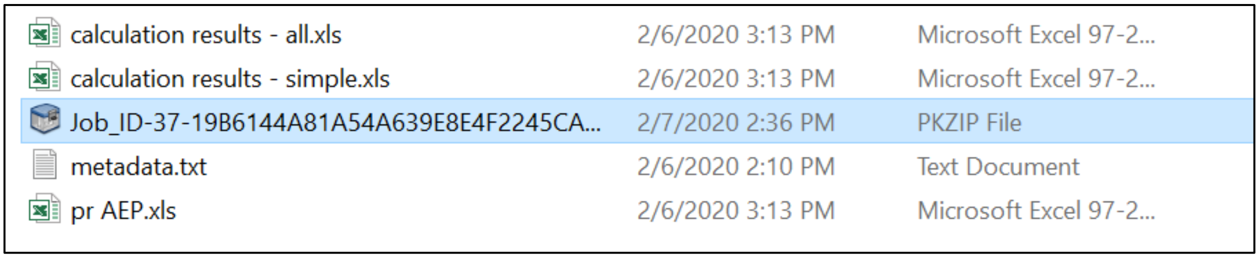

Figure 35 – CMIP Tool Download Materials

The next Chapter, **Interpreting Data,** provides a more extensive description of the information contained in these files and how to use the data

4. Interpreting CMIP Tool Output

Projected temperature and precipitation values merit careful use as the future is unknown. It is important to understand what each of the numbers represents before applying them in assessments or decision-making.

The results of the CMIP Tool operations may be useful for providing information on the potential magnitude and range of changes in the location of interest, which in turn can inform vulnerability assessments, adaptation, and long-term planning. This also may be useful in some design contexts.

Please review the DCHP website for information on the underlying climate data and review the information below for details on how specific variables were calculated and what each value represents.

4.1 Overview

The CMIP Tool provides four output files within the job zip file.

- **metadata.txt**
- **calculation results – all.xls**
- **calculation results – simple.xls**
- **pr AEP.xls**

Users may find it easiest to start with the 'simple' calculation results file, and refer to the other files subsequently as needed.

The ***metadata.txt*** file contains information about the LOCA data that was downloaded from the DCHP website. This includes information on the grids (grid size, latitude, and longitude), periods of information for observed and modeled data, the source of the modeled data, and the global climate models and emission scenarios included in the modeled data. The user should verify that this information is consistent with user's intent.

The ***calculation results – all.xls*** spreadsheet file provides a listing of computational results for 127 temperature and precipitation variables, including the observed, modeled baseline, modeled future, and projected future values for each variable. The spreadsheet contains a tabbed sheet for each LOCA grid included in the job. For each grid, the sheet contains the following data:

- Column A: Root variable. This indicates whether the variable was calculated based on the daily maximum temperature (tasmax), daily minimum temperature (tasmin), or daily precipitation (pr) data.
- Column B: Whether the value is observed, modeled, or projected (see box).
- Column C: Time period (e.g., baseline or projection period)

Definitions

Observed Value – Value calculated for the baseline time period based on the observed data from the DCHP website.*

Modeled Value – Values for the baseline and future time period calculated based on the LOCA climate model data from the DCHP website.

Projected Value – Value estimated to represent the future time period, where:

Projected value = (Modeled Future – Modeled Baseline) + Observed Baseline

*The observed data come from Livneh, B., E. A. Rosenberg, C. Y. Lin, B. Nijssen, V. Mishra, K. M. Andreadis, E. P. Maurer, and D. P. Lettenmaier 2013. "A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions," Journal of Climate, 26(23), pp. 9384-9392.

- Column D: Variable name. See Section 4.2.2 below for a description of each variable.
- Column E: Unit (e.g., degrees Fahrenheit, days, inches)
- Column F: Value

The ***calculation results – simple.xls*** spreadsheet file provides a summary of the observed and projected values for 98 temperature and precipitation variables based on the results summarized in the ***calculation results – all.xls*** spreadsheet file. The spreadsheet contains a tabbed sheet for each LOCA grid included in the job.

Finally, the ***pr AEP.xls*** spreadsheet file provides the supporting information for the computation of the annual exceedance probability (AEP) precipitation quantiles for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2 percent AEPs included the other two spreadsheets.

- Rows 1-26 (1-47 if *include infinity box* is selected) provide computations of the AEP precipitation *quantiles* and the associated *projected to baseline* ratios for each model.
- Rows 28+ (49+ if *include infinity box* is selected) provide the annual maximum series extracted for the observed dataset and for each model. This is the annual maximum 24-hour precipitation value for each year, for each model.

As with the other spreadsheets, this spreadsheet contains a tabbed sheet for each LOCA grid included in the job.

4.2 Processing Methodology

The LOCA datasets from the DCHP website contain daily maximum temperature (Tmax), minimum temperature (Tmin), and precipitation (Precip) values for each climate model and for a given emissions scenario. The DCHP website also provides observed daily maximum temperature, minimum temperature, and precipitation values for the same grid locations. The CMIP Tool uses that data to compute various temperature and precipitation statistics and estimates of projected values using the processes described below.

Additional information on the observation or model data is available through the DCHP website.[2]

Definitions

Tmax – The maximum surface air temperature on a given day.

Tmin – The minimum surface air temperature on a given day.

Precip – The amount of precipitation on a given day (24-hour period).

Seasons – In the CMIP Tool, the seasons are defined as follows:

Winter – December, January, February

Spring – March, April, May

Summer – June, July, August

Fall – September, October, November

4.2.1 General Processes

The ***observed*** and ***modeled values*** for all variables are calculated using the same general process:

1. Assemble the subject variable **for each model and each day.**
2. **Average across years for each model.**
3. Average within the **baseline** and **projected time periods** for each model.
4. Calculate **multi-model ensemble average** variables for each time period.

[2] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Welcome.

Figure 36 illustrates the process for the *Average Annual Maximum Temperature* variable. The CMIP Tool starts with the Tmax for each model, each day. Then, it calculates across each day in the year to get the average Tmax for each model, each year.[3] Next, it averages across the years in each time period (1961-2000 and 2060-2099) to determine the average annual Tmax for each model in each time period. Finally, it averages across models to get a single value for each time period.

To compute ***projected values*** for the projected time period, the Tool does not directly use modeled projected values because of the potential for biases in the models, even though the LOCA downscaling removes some of the bias. Instead, the basis of the projected values uses an observed value and some relationship between the values derived from the modeled baseline and future periods. Temperature and many precipitation variables use the difference between the baseline and future. For some computations, the Tool applies the ratio of future to baseline values to the observed value to estimate a projected value. When using a difference, the procedure is:

1. Calculate the change from baseline (modeled future value minus modeled baseline value) using the multi-model ensemble means for the variable.
2. Add the modeled change to the baseline observed value to derive the "projected value" for each variable.

It is important to note the observed data is only available up to 2005. If the baseline period overlaps with the 2005 year, observed data from only up to and including 2005 will be used. For example, if a baseline period of 2000 to 2029 is selected, all observed and projected calculations will be based off the six-year period of 2000-2005. This would mean the observed and projected variables would be calculated based on only 6 years of observed data (which is not suggested) instead of the 30 initially selected as the baseline period. If the baseline starts beyond 2005, observed and projected data will not be processed and will be shown as N/A, and the Tool will only calculate the precipitation AEP ratios.

4.2.2 Variable-Specific Processes

Listed below are variable-specific processing steps that depart from or add to the general process. These steps focus on how the CMIP Tool computes Step 1 (a value for each model, each day) and Step 2 (a value for each model, each year) as described above. From the annual values, the Tool calculates an average for the time period selected. The discussion below describes the specific process for each variable.

[3] For the example shown, the CMIP Tool averages across all days in the year to get the average annual Tmax. However, for some variables, the tool calculates the sum, maximum, or minimum value across all days in each year. Any variables that do not represent annual averages are specified later in this guide.

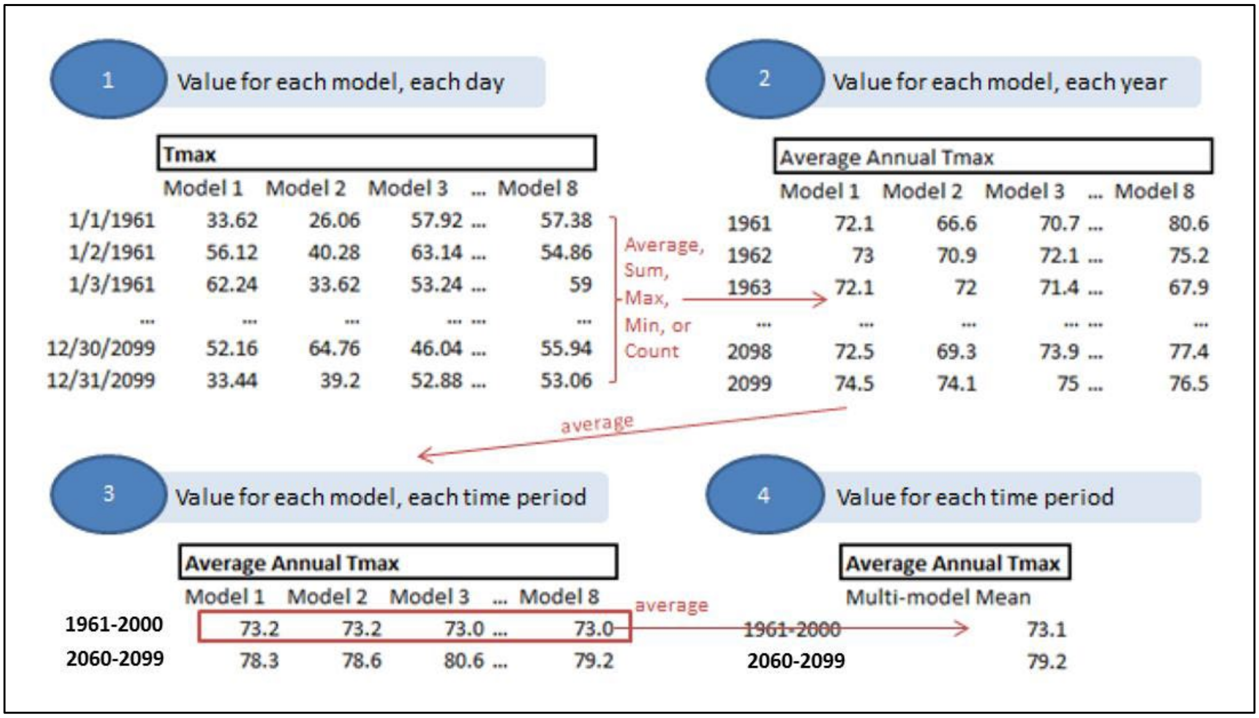

Figure 36 – Average Annual Maximum Temperature Calculation Example

4.2.3 Temperature Outputs

Annual Averages

Average Annual Mean Temperature

- For each day, calculate the average of the Tmax and Tmin values.
- Calculate average value across all days in each year.

Average Annual Maximum Temperature

- Calculate average daily Tmax value across all days in each year.

Average Annual Minimum Temperature

- Calculate average daily Tmin value across all days in each year.

Annual Extreme Heat

Hottest Temperature of the Year

- For each year, find the maximum Tmax value.

"Very Hot" Day Temperature

- For each time period, calculate the 95th percentile Tmax value (i.e., the threshold at which 95% of Tmax values for the entire time period are cooler). This variable is an exception to the general process and is calculated based on all the daily values across the time period. This is the only step necessary to calculate the value for this variable for each time period.

"Extremely Hot" Day Temperature

- Similar to "Very Hot" above, but with the 99th percentile (i.e., the threshold at which 99% of Tmax values for the entire time period are cooler).

Average Number of Days per Year above Baseline “Very Hot” Temperature

- Count the number of days per year with Tmax greater than or equal to the observed baseline (e.g., 1976-2005) 95th percentile Tmax value.

Average Number of Days per Year above Baseline “Extremely Hot” Temperature

- Count the number of days per year with Tmax greater than or equal to the observed baseline (e.g., 1976-2005) 99th percentile Tmax value.

Average Number of Days above 95°F, 100°F, 105°F, 110°F per Year

- Count the number of days per year with Tmax greater than or equal to 95°F, 100°F, 105°F, and 110°F.

Maximum Number of Consecutive Days per Year above Baseline "Very Hot" Temperature

- For each day, check whether that day is greater than or equal to the observed baseline (e.g., 1976-2005) 95th percentile Tmax value; if so, count how many consecutive days have been above that value. (See example in Table 1 below, where the “Very Hot” temperature is 92°F.)
- Calculate the maximum number of consecutive days above the threshold for each year.

Table 1. Consecutive Days above Maximum Temperatures

Date	Tmax (°F)	Consecutive Days > 92°F
7/1/1961	90.0	0
7/2/1961	92.5	1
7/3/1961	92.0	2
7/4/1961	97.0	3
7/5/1961	91.7	0

Maximum Number of Consecutive Days per Year above Baseline “Extremely Hot" Temperature

- Similar to above. Find the maximum number of consecutive days in each year with Tmax greater than or equal to the observed baseline (e.g., 1976-2005) 99th percentile Tmax value.

Maximum Number of Consecutive Days per Year above 95°F, 100°F, 105°F, 110°F

- Similar to above. Find the maximum number of consecutive days in each year with Tmax greater than or equal to 95°F, 100°F, 105°F, and 110°F.

Seasonal Extreme Heat

Average Summer Temperatures

- For each day, calculate the average across the Tmax and Tmin values.

Highest 4-Day Average Summer High Temperatures

- For each day, calculate the running average Tmax across a four-day period consisting of that day and the three previous days (e.g., the 4-day average maximum temperature on July 4, 1976 equals the average of the Tmax values on July 1, 2, 3, and 4, 1976).

- Find the maximum value of these four-day averages within the summer of each year.

Highest 7-Day Average Summer High Temperatures

- Same as above, except first step takes the average across 7 days.

Number of Days per Season above 95°F, 100°F, 105°F, 110°F

- For each season, count the number of days with Tmax values greater than or equal to 95°F, 100°F, 105°F, and 110°F.

Extreme Cold

Coldest Temperature of the Year

- Find the minimum Tmin value for each year.

"Very Cold" Day Temperature

- Calculate the 5th percentile Tmin value (i.e., the threshold at which 5% of Tmin values for the entire year are cooler). Note that this variable is an exception to the general process, and is calculated based on all the daily values across the time period. This is the only step necessary to calculate the value for this variable for each time period.

"Extremely Cold" Day Temperature

- Similar to above, calculate the 1st percentile Tmin value (i.e., the threshold at which 1% of Tmin values for the entire year are cooler).

Average Number of Days per Year Below Freezing

- Count the number of days per year that have Tmin values less than or equal to 32°F.

Average Number of Times per Year Low Temperatures Fluctuate around Freezing

- For each year, count the number of times Tmin values drop below and go above freezing temperatures. For example, as shown in Table 2 below, if the Tmin on January 1 is 30°F and the Tmin on January 2, is 35°F, then that is considered one fluctuation around freezing. If on January 3, Tmin goes back down to 30°F, then that is considered another fluctuation. This variable is intended to be a *rough proxy* for changes in freeze-thaw cycles.

Table 2. Average Number of Freezing Temperatures

Date	Tmin (°F)	Fluctuation?
1/1/1961	30.0	
1/2/1961	35.0	Yes
1/3/1961	30.0	Yes
1/4/1961	27.0	No

Average Winter Temperatures

- For each day, calculate the average across the Tmax and Tmin values.

Lowest 4-Day Average Winter Low Temperatures

- For each day, calculate the running average Tmin across a four-day period consisting of that day and the three previous days (e.g., the 4-day average minimum temperature on January 4, 1976 equals the average of the Tmin values on January 1, 2, 3, and 4, 1961).
- Find the minimum value of these four-day averages within the winter of each year.

Lowest 7-Day Average Winter Low Temperatures

- Same as 4-day average above, except first step takes the average across 7 days.

4.2.4 Precipitation Outputs

Average Precipitation Calculations

Average Total Annual Precipitation

- For each year, calculate the sum of all Precip values.

Average Total Monthly Precipitation

- For each year, calculate the sum of all Precip values in each month.

Average Total Seasonal Precipitation

- For each year, calculate the sum of all Precip values in each season.

"Heavy" Precipitation Calculations

"Very Heavy" 24-hour Precipitation Amount

- For each time period, calculate the 95th percentile Precip value for days with nonzero precipitation (i.e., the threshold at which 95% of nonzero Precip values for the entire time period are less). This variable is an exception to the general process, and is calculated based on all the daily values across the time period. This is the only step necessary to calculate the value for this variable *for each time period.*

Daily Percentiles vs. Return Period

Very Heavy and Extremely Heavy Precipitation values are based on the 95th and 99th percentile largest daily values, respectively, in the time period. For the Extremely Heavy threshold, that means that on any given day that has nonzero precipitation, there is a 1 percent chance that the daily total precipitation will exceed that threshold.

This should NOT be confused with the 1 percent AEP (annual exceedance probability) precipitation for a 24-hour (daily) storm, otherwise known as the 100-year (return period) 24-hour precipitation. The 100-yr precipitation is calculated based on only the highest precipitation value in each year and is generally much larger than the Extremely Heavy amount.

"Extremely Heavy" 24-hour Precipitation Amount

- Similar to above, for each time period, calculate the 99th percentile Precip value within days with nonzero precipitation (i.e., the threshold at which 99% of nonzero Precip values for the entire time period are less).

Average Number of Baseline "Very Heavy" Precipitation Events per Year

- Count the number of days per year that have Precip values greater than or equal to the model's baseline (e.g., 1976-2005) 95th percentile Precip value.

Average Number of Baseline "Extremely Heavy" Precipitation Events per Year

- Count the number of days per year that have Precip values greater than or equal to the model's baseline (e.g., 1976-2005) 99th percentile Precip value.

Other Precipitation Values & Calculations

Largest 3-Day Precipitation Event per Season

- For each day, calculate the running total Precip across a three-day period consisting of that day and the two previous days (e.g., the 3-day total precipitation on January 3, 1976 equals the sum of Precip values on January 1, 2, and 3, 1976).
- For each year, find the maximum value of these three-day averages within each season.

Ratio of 24-hr Precipitation Quantiles

- These variables represent the ratio of modeled future to modeled baseline 24-hour precipitation amounts for each recurrence interval (the "quantile ratio").
- For each 24-hour precipitation quantile for each model, compute the quantile ratio of the modeled future period quantile to the modeled baseline period quantile. **See detailed method in Section 4.3 below.**
  - Ratios labeled "(Table 4.12)" represent quantile ratios computed using the Gumbel distribution (see Section 4.3 below for more information).
  - Ratios without a "(Table 4.12)" label represent quantile ratios computed using the Infinity distribution (see Section 4.3 below for more information).
- For each quantile, average the quantile ratios from each model for the ensemble average.
- For each quantile, compute the 90 percent confidence interval of the model ratios around the ensemble average ratio.

24-hr Precipitation with various AEPs (in *calculation results-all* and *pr AEP* output files)[4]

- Compute the daily (24-hour) precipitation depths for various quantiles (50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent AEPs) for each model for each grid cell. Compute these for the baseline and future period. **See detailed method in Section 4.3 below**.
- For each quantile, average the quantile precipitation depth from each model for the ensemble average for each grid cell for the baseline and future period.

4.2.5 Precipitation Annual Maximum Series

In the ***pr AEP.xls*** spreadsheet, the CMIP Tool provides a summary of the 24-hour precipitation annual maximum time series from the observed dataset as well as from each climate model. For each year in the dataset, the tool calculates the highest daily (24-hour) precipitation amount in that year.

4.3 NCHRP 15-61 and 10 Step Method for 24-hour precipitation AEPs

The provisional National Cooperative Highway Research Project (NCHRP) 15-61 Guide titled *Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure* provides multiple methods of using climate data (such as the LOCA data discussed in this guide) to make adjustments to hydrologic and coastal design to account for

[4] These precipitation quantiles are computed to calculate the quantile ratios. Because these are derived from the LOCA dataset, they are spatially-averaged constrained daily (midnight to midnight) values, not point 24-hour values typically used by engineers. However, since the quantile ratios are the relevant output, these adjustments are not needed for the ratios. See FHWA HEC-17 (Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience. Federal Highway Administration, FHWA-HIF-16-018.) for discussion of spatial-average and constrained daily precipitation values.

future climate conditions. The CMIP Tool allows for easy access to variables necessary in one of the techniques outlined in the report, called the "10-step method." This method, which is not required under FHWA regulations, takes ratios of modeled baseline to future precipitation depths and applies those ratios to historic rainfall to project future rainfall. Applying this ratio to historic rainfall values will give a rainfall value that accounts for future potential change determined by climate models. More information about the variables provided by the CMIP tool used in the 10-step method is detailed below.

4.3.1 Precipitation Quantiles, Ratios, and Confidence Intervals

The CMIP Tool provides seven precipitation quantiles for the user-specified baseline and future time periods for each model: 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities (AEPs). These correspond to the 2-. 5-, 10-, 25-, 50-, 100-, and 500-year return period events, respectively. The CMIP Tool computes the quantiles by fitting the annual maximum series (AMS) for the given time period and model to the Gumbel distribution[5] using the mean and standard deviation of the respective AMS.

Two alternative computations of the quantiles are made by fitting the Gumbel distribution: 1) using the actual sample size (number of years in the time period)[6] and 2) assuming a very large sample size approaching infinity (which will only appear if selecting the *Include Infinity* box). The Tool denotes the former in the spreadsheets by referencing "Table 4.12," which refers to a source of sample length dependent frequency factors for performing the computations (FHWA 2009).

After computing the quantiles for the baseline and future periods, the CMIP Tool computes a **ratio of the quantiles** for each model and each grid. This gives the user information on the sense of projected change for each quantile:

$$R_q = \frac{PF_q}{PB_q}$$

where:

R_q = Ratio of the future to baseline 24-hour precipitation quantile (q).

PF_q = Future modeled 24-hour precipitation quantile (q).

PB_q = Baseline modeled 24-hour precipitation quantile (q).

The subscript (*q*) indicates the quantile including the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities (AEPs). The ***pr AEP.xls*** spreadsheet summarizes the computed quantiles and ratios for each model and each grid cell. Ratios averaged across all models for each grid can be found in the ***calculations results – simple.xls.***

The CMIP Tool also computes the 90 percent **confidence interval** based on the 5 percent and 95 percent confidence limits. These confidence limits are NOT to estimate our confidence in the

[5] Other probability distributions could have been applied, such as the Generalized Extreme Value distribution. The Gumbel distribution was selected to simplify the computations and because the Gumbel distribution is not as sensitive to high outliers compared with 3-parameter distributions because the skew is fixed.

[6] Although the two approaches will result in different quantile estimates, these are used to compute ratios of projected to baseline quantiles. The ratios are less sensitive to the computational method than the quantiles themselves.

estimate of the ensemble average quantile ratio. Rather, the user wants to estimate the degree of uncertainty about the future recognizing that each model provides a different representation of the future. The CMIP Tool assumes that the model outputs represent independent, normally distributed observations,[7] and uses the following formulas to estimate the confidence interval:

$$CI_{90} = CL_{95} - CL_5$$

where:

CI_{90} = 90 percent confidence interval.

CL_{95} = 95 percent confidence limit.

CL_5 = 5 percent confidence limit.

The CMIP Tool computes the 95 percent and 5 percent confidence limits for each quantile and each grid as follows:

$$CL_{95} = \overline{R_q} + 1.645\left(\sigma_{RFB_q}\right)$$

$$CL_5 = \overline{R_q} - 1.645\left(\sigma_{RFB_q}\right)$$

where:

$\overline{R_q}$ = mean value of the quantile (q) ratios from each model.

σ_{RFB_q} = standard deviation of the quantile (q) ratios from each model.

1.645 = standard normal deviate (z) corresponding to the 90 percent confidence interval.

4.3.2 Projection of Precipitation Quantiles

The purpose of calculating the quantiles and the ratios is to estimate the percent change projected by the models, which can be applied to historic data to estimate future precipitation values, as noted in NCHRP 15-61. The CMIP Tool computes projected precipitation quantiles only for calculating ratios; the numerator and denominator are both modeled values, and the LOCA observations are not part of the analysis. (The user then can apply the ratios to the user-supplied historic precipitation data.). The CMIP Tool provides modeled quantiles for a future period, but these should not be used directly as they may be biased. However, the quantile ratios computed by the CMIP Tool can be used with historical (observed) AEP quantiles taken from established sources of observed precipitation data such as NOAA Atlas 14 or other locally accepted sources.[8] To estimate the projected 24-hour precipitation quantile(s), the user multiplies the historical precipitation quantile by the ratio of future to baseline model quantiles as follows:

$$P_{q,p}=P_{q,h}\left(R_q\right)$$

where:

$P_{q,p}$ = Projected 24-hour precipitation quantile (q).

$P_{q,h}$ = Historical 24-hour precipitation quantile (q).

[7] Although these assumptions are not completely true, they provide a useful context from which to begin to quantify uncertainty.

[8] Observed precipitation from the DCHP datasets that are included in the CMIP Tool output should not be used for estimating future quantiles.

As described above, the historical 24-hour precipitation quantile comes from an accepted source, such as NOAA Atlas 14. The quantile ratio comes from the CMIP Tool.

The above equation is not suggested for quantiles more extreme than the 10-percent AEP (10-yr event) quantile, because the current ability of high-resolution climate datasets to represent precipitation extremes (in the engineering hydrology sense) is limited.[9] Therefore, the following equation is suggested for more extreme quantiles, including the 4-, 2-, 1-, and 0.2-percent AEP quantiles.

$$P_{q,p} = P_{q,h}(R_{10})$$

where:

R_{10} = Ratio of the model future to model baseline for the 24-hour precipitation 10-percent AEP quantile.

In this equation, the ratio associated with the 10-percent AEP quantile is substituted for the ratios estimated for the more extreme quantiles.

The user is encouraged to consider the uncertainty in the estimate(s) of the projected 24-hour precipitation quantile(s) by using the upper and lower confidence limits of the ratios. This will provide insight into the potential variation in these estimates resulting from scientific uncertainty based on the ensemble of models.

4.4 Example Application

The following is a hypothetic example that applies the CMIP Tool. The example assumes that the User has correctly followed the process and obtained the correct datasets.

4.4.1 Scenario

A State Department of Transportation (SDOT) wishes to design and construct a best management practice (BMP) feature for water quantity and water quality purposes. The SDOT has a design standard that requires consideration of the 50-year precipitation event. In doing so, they wish to consider the resilience of the asset for the anticipated service life, including projected future precipitation.

4.4.2 Solution

Estimate a projected 50-yr precipitation quantile for a watershed draining to a Pond near Sykesville, Maryland. Figure 37 depicts a view of the example output.

The drainage area for this BMP lies entirely within the upper left most grid. If the watershed extended into multiple grids, information from the multiple grids is entered. In this example, the baseline period is 1991-2020 and the future period is 2070-2099.

[9] NCHRP study

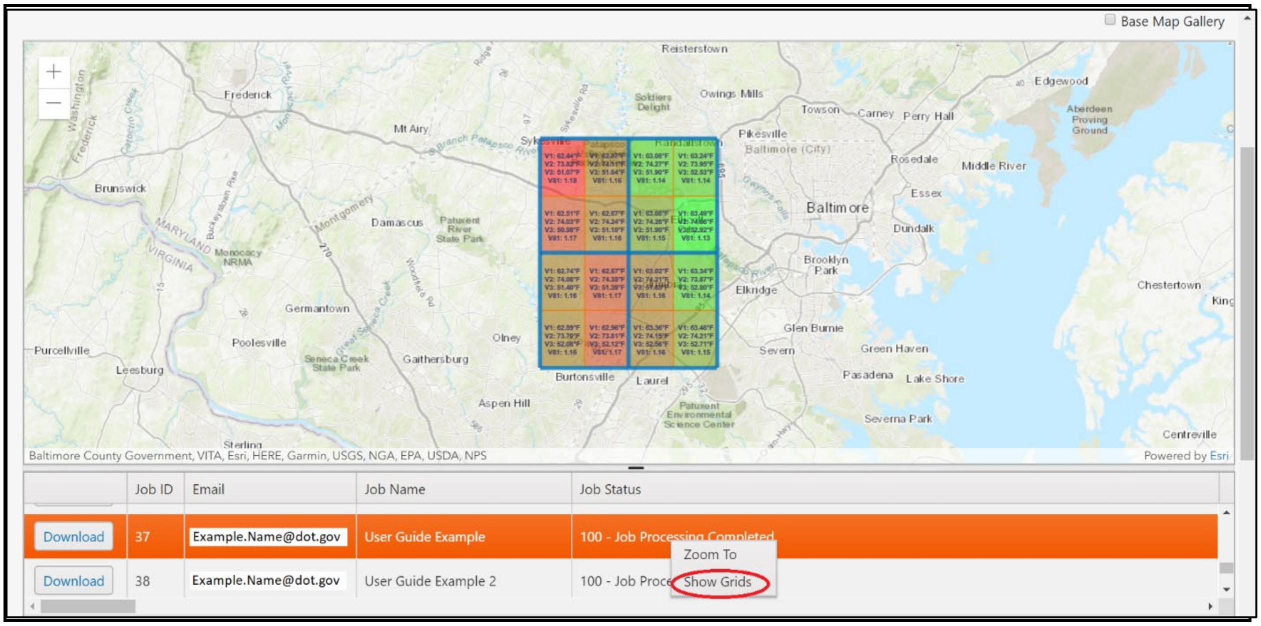

Figure 37 – CMIP Tool Show Grids function for Example Project

As shown in Figure 38, using the CMIP spreadsheet and locating grid 13, the R_{10} is 1.17. It is suggested to inspect that ratios for the neighboring grids to reduce the risk that a single value is an outlier. If the user decides it is an outlier, a more representative value, based on the neighboring grids, may be used as an alternative.

	Ratio of 24-hr Precipitation			
71	Ratio of 24-hr Precipitation With an AEP of 50.0% (Table 4.12)	N/A	N/A	1.16
72	Ratio of 24-hr Precipitation With an AEP of 50.0% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.29
73	Ratio of 24-hr Precipitation With an AEP of 20.0% (Table 4.12)	N/A	N/A	1.16
74	Ratio of 24-hr Precipitation With an AEP of 20.0% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.34
75	Ratio of 24-hr Precipitation With an AEP of 10.0% (Table 4.12)	N/A	N/A	1.17
76	Ratio of 24-hr Precipitation With an AEP of 10.0% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.39
77	Ratio of 24-hr Precipitation With an AEP of 4.0% (Table 4.12)	N/A	N/A	1.17
78	Ratio of 24-hr Precipitation With an AEP of 4.0% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.45
79	Ratio of 24-hr Precipitation With an AEP of 2.0% (Table 4.12)	N/A	N/A	1.17
80	Ratio of 24-hr Precipitation With an AEP of 2.0% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.49
81	Ratio of 24-hr Precipitation With an AEP of 1.0% (Table 4.12)	N/A	N/A	1.17
82	Ratio of 24-hr Precipitation With an AEP of 1.0% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.52
83	Ratio of 24-hr Precipitation With an AEP of 0.2% (Table 4.12)	N/A	N/A	1.17
84	Ratio of 24-hr Precipitation With an AEP of 0.2% (Table 4.12) - Confidence Interval (90%)	N/A	N/A	0.56

Figure 38 – Calculation Results – simple.xls for Example Project

Obtaining Historical Precipitation Information

Next, find the historical 50-year 24-hour precipitation from a locally acceptable source. In this case, the example uses NOAA Atlas 14.

Going to the NOAA Atlas 14 website, locate the BMP Watershed (see Figure 39). For this example, we decided to use the Partial Duration Series (PDS) approach, available within NOAA Atlas 14. However, NOAA Atlas 14 also allows the user to consider the Annual Maximum Series (AMS) as an alternative.

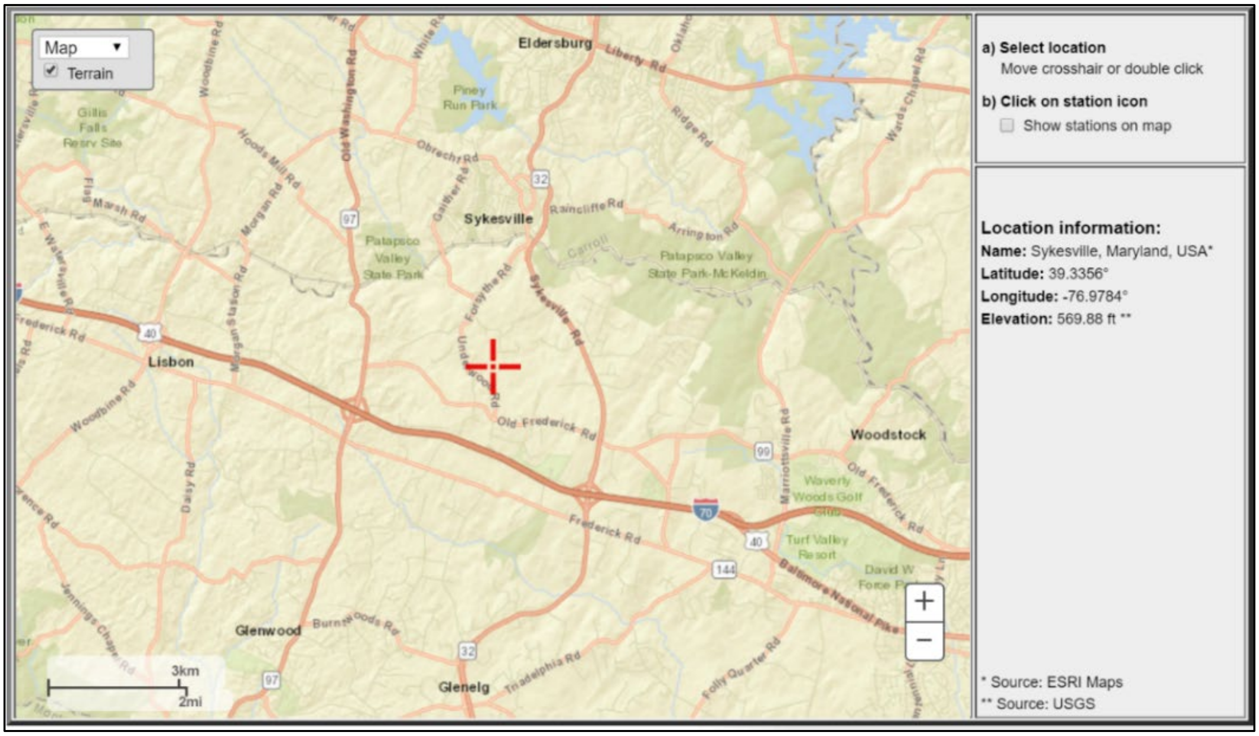

Figure 39 – NOAA Atlas 14 Website Selection for Example Project

Once selecting the location, look on the NOAA Atlas 14 PDS table for the appropriate rainfall value. In this case, the variable of interest is the 50-year storm event for the 24-hour storm duration. This P_{50h} value is 7.22 inches.

PF tabular | PF graphical | Supplementary information | Print page

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.343 (0.311-0.378)	0.410 (0.372-0.451)	0.486 (0.440-0.535)	0.544 (0.491-0.598)	0.614 (0.551-0.676)	0.666 (0.595-0.734)	0.718 (0.639-0.792)	0.768 (0.679-0.850)	0.831 (0.728-0.923)	0.880 (0.766-0.982)
10-min	0.549 (0.498-0.605)	0.657 (0.596-0.724)	0.780 (0.706-0.859)	0.868 (0.784-0.956)	0.977 (0.877-1.08)	1.06 (0.947-1.17)	1.14 (1.01-1.26)	1.22 (1.07-1.35)	1.31 (1.15-1.46)	1.38 (1.20-1.54)
15-min	0.684 (0.621-0.754)	0.825 (0.748-0.908)	0.984 (0.891-1.08)	1.10 (0.991-1.21)	1.24 (1.11-1.36)	1.34 (1.20-1.48)	1.44 (1.28-1.59)	1.53 (1.36-1.70)	1.65 (1.45-1.83)	1.74 (1.51-1.94)
30-min	0.938 (0.852-1.03)	1.14 (1.03-1.25)	1.40 (1.27-1.54)	1.59 (1.43-1.75)	1.83 (1.64-2.01)	2.02 (1.80-2.22)	2.20 (1.96-2.43)	2.38 (2.10-2.63)	2.62 (2.30-2.91)	2.80 (2.44-3.13)
60-min	1.17 (1.06-1.29)	1.43 (1.30-1.57)	1.79 (1.62-1.98)	2.07 (1.87-2.28)	2.44 (2.19-2.68)	2.73 (2.44-3.01)	3.03 (2.70-3.34)	3.34 (2.95-3.69)	3.76 (3.29-4.18)	4.09 (3.56-4.57)
2-hr	1.39 (1.26-1.54)	1.70 (1.54-1.88)	2.15 (1.94-2.37)	2.50 (2.25-2.76)	3.00 (2.69-3.31)	3.42 (3.04-3.77)	3.86 (3.41-4.26)	4.33 (3.80-4.79)	5.02 (4.34-5.58)	5.59 (4.79-6.23)
3-hr	1.50 (1.35-1.67)	1.82 (1.65-2.02)	2.31 (2.08-2.56)	2.69 (2.41-2.98)	3.24 (2.89-3.59)	3.70 (3.28-4.10)	4.20 (3.69-4.65)	4.72 (4.12-5.25)	5.50 (4.73-6.13)	6.14 (5.22-6.88)
6-hr	1.87 (1.69-2.08)	2.26 (2.05-2.52)	2.85 (2.57-3.18)	3.34 (3.00-3.72)	4.07 (3.62-4.53)	4.70 (4.14-5.22)	5.38 (4.70-5.99)	6.14 (5.30-6.84)	7.26 (6.18-8.14)	8.23 (6.91-9.26)
12-hr	2.29 (2.05-2.60)	2.77 (2.48-3.14)	3.52 (3.14-3.98)	4.16 (3.69-4.70)	5.14 (4.51-5.79)	6.00 (5.22-6.76)	6.98 (6.00-7.87)	8.08 (6.85-9.12)	9.77 (8.11-11.1)	11.3 (9.18-12.8)
24-hr	2.64 (2.41-2.93)	3.19 (2.91-3.55)	4.10 (3.73-4.56)	4.90 (4.44-5.43)	6.13 (5.51-6.76)	$\boxed{7.22 (6.44-7.93)}$	8.46 (7.48-9.25)	9.87 (8.62-10.8)	12.0 (10.3-13.1)	14.0 (11.8-15.2)
2-day	3.06 (2.78-3.41)	3.70 (3.36-4.12)	4.74 (4.30-5.28)	5.63 (5.09-6.27)	6.98 (6.27-7.76)	8.15 (7.28-9.05)	9.46 (8.38-10.5)	10.9 (9.57-12.1)	13.1 (11.3-14.5)	15.0 (12.8-16.7)
3-day	3.23 (2.93-3.60)	3.91 (3.54-4.36)	5.00 (4.53-5.57)	5.93 (5.36-6.61)	7.35 (6.59-8.16)	8.58 (7.65-9.51)	9.94 (8.79-11.0)	11.5 (10.0-12.7)	13.8 (11.9-15.2)	15.8 (13.4-17.5)
4-day	3.40 (3.08-3.79)	4.11 (3.73-4.59)	5.25 (4.76-5.86)	6.23 (5.63-6.94)	7.71 (6.91-8.56)	9.00 (8.01-9.97)	10.4 (9.20-11.5)	12.0 (10.5-13.3)	14.4 (12.4-16.0)	16.5 (14.0-18.3)

Figure 40 – NOAA 14 Rainfall Table for Example Project

Applying the Equations and Information

Finally, apply the equation in the previous section applicable to the 50-year quantile.

$P_{50p} = P_{50h} \, (R_{10})$

$P_{50p} = 7.22 \text{ inches} \times 1.17$

$P_{50p} = 8.45 \text{ inches}$

4.4.3 Results

The projected 50-yr (2% AEP) precipitation depth for the future period (2051-2080) is 8.45 inches.

The design team could apply these values into their design process hydrologic computations to capture insights, sensitivity, and other relevant design outcomes.

Thank You!

We hope you enjoy using the CMIP Tool. Please see our website to ask any questions or provide any comments.

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