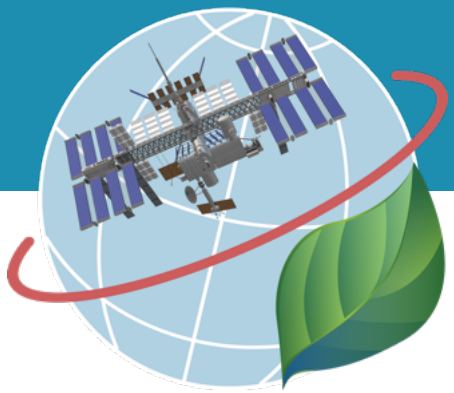


11

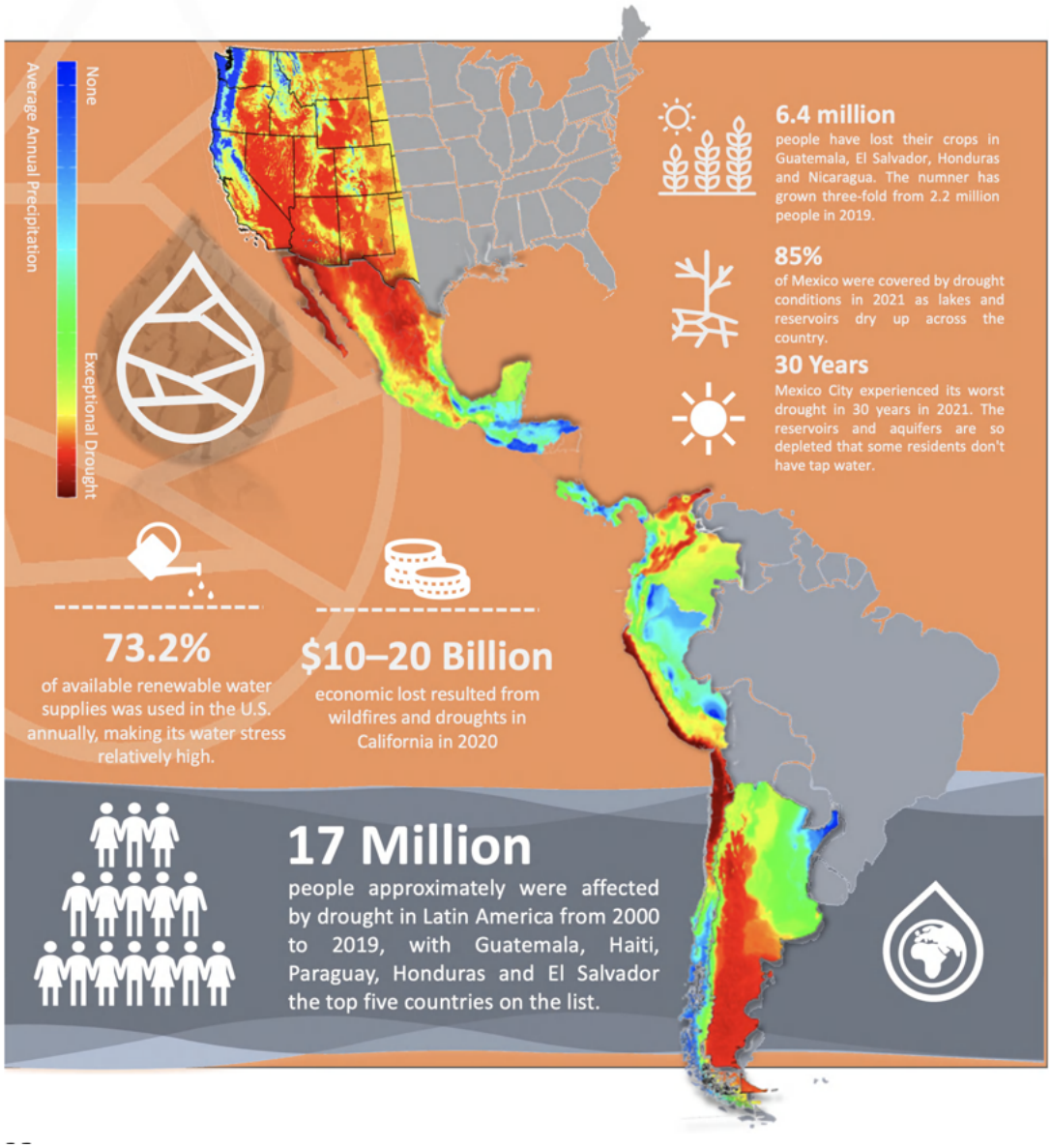
Detecting Droughts with ECOSTRESS

Quick Links To Sections

Objectives:

1. Distinguish between the two types of requests in AppEEARS: point data versus geographic area data.
2. Determine the drought status for Mexico City in 2022 and compare to the record-breaking drought in 2021.
3. Create a map that focuses on the social issues surrounding drought and water scarcity.

Motivation For Today's Tutorial : Drought & Water Scarcity



The figure above was created for the United Nations report "Drought in Numbers," calling for a global top priority commitment to drought preparedness and resilience across all regions. Drought is a complex crisis with roots not only in climate change but also in social justice and public policy.

- More than 10 million people lost their lives due to major drought events in the past century, with over 90% of these deaths occurring in developing countries (Guha-Sapir et al., 2021).
- By 2050, between 4.8 and 5.7 billion people will live in areas that are water-scarce for at least one month each year, up from 3.6 billion today (UN Water, 2021).
- Droughts can disproportionately affect women. While the majority of rural farmers around the world are women, $<$15% are the owners of agricultural lands, which means that the most affected women do not have the ability to make decisions about water scarcity and land use.

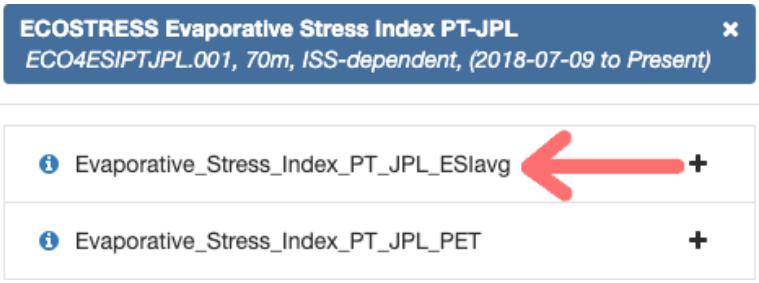
11.1 ACCESSING ECOSTRESS ESI DATA THROUGH AppEEARS

11.1.1 ECOSTRESS Evaporative Stress Index (ESI) Data

Data Product	Description	Pixel Size*	Temporal Resolution (days)
ECO1BRAD.001	Radiometric Calibration	70 x 70	Over continental United States and target areas**, every 1-7 days
ECO1BATT.001	Attitude and Ephemeris		
ECO1BMAPRAD.001	Radiometric Calibration		
ECO1BGEO.001	Geometric Calibration		
ECO2LSTE.001	Land Surface Temperature and Emissivity		
ECO2CLD.001	Cloud mask		
ECO3ETPTJPL.001	Evapotranspiration (PT-JPL model enhanced)		
ECO3ANCQA.001	Ancillary Data Quality		
ECO3ETALEXIU.001	Evapotranspiration (ALEXI model enhanced)	30 x 30***	
ECO4ESIPTJPL.001	Evaporative Stress Index derived from L3_ET_PT-JPL	70 x 70	
ECO4ESIALEXIU.001	Evaporative Stress Index derived from L3_ET_ALEXI	30 x 30***	
ECO4WUE.001	Water Use Efficiency	70 x 70	

*More accurately referred to as pixel spacing resolution (m) because of dependencies on ISS altitude, which varies.
**For more info, please visit ECOSTRESS Gmap to see where data has been acquired
***70 x 70 is resampled to 30 x 30 (meters)

In the last tutorials, we learned that ECOSTRESS uses land surface temperatures to estimate evapotranspiration (ET). A related variable is the evaporative stress index (ESI), which is a measure of potential drought conditions. It is a Level 4 (ECO4) ECOSTRESS data product that can be accessed through AppEEARS:



For ECOSTRESS, the drought stress signal is derived from the ratio of actual evapotranspiration (ET) to potential evapotranspiration (PET):

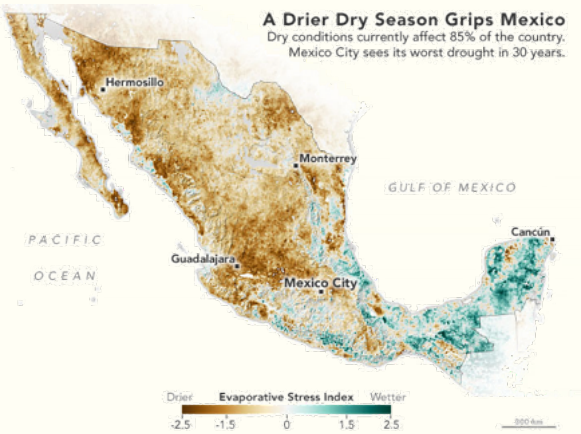
$$ESI = \frac{ET}{PET}$$

PET represents the theoretical maximum amount of ET that would occur in a location if unlimited water were available. ESI is a unitless metric (the numerator and denominator have the same units and they cancel out) that ranges from 0 to 1, with smaller proportions indicating higher water stress (minimal ET compared to PET) and higher proportions denoting no water stress (ET and PET are equal).

NOTE: The range for ESI may be confusing, as a large number (nearing 1) indicates the absence of drought conditions, and a small number (nearing 0) suggests drought.

NOTE: Confusingly, evaporative stress index can have different definitions from study to study. For example, the Mexico City map in the box below has a scale of -2.5 to 2.5, because it is estimated with a different formula. Keep an eye out for this!

Mexico City

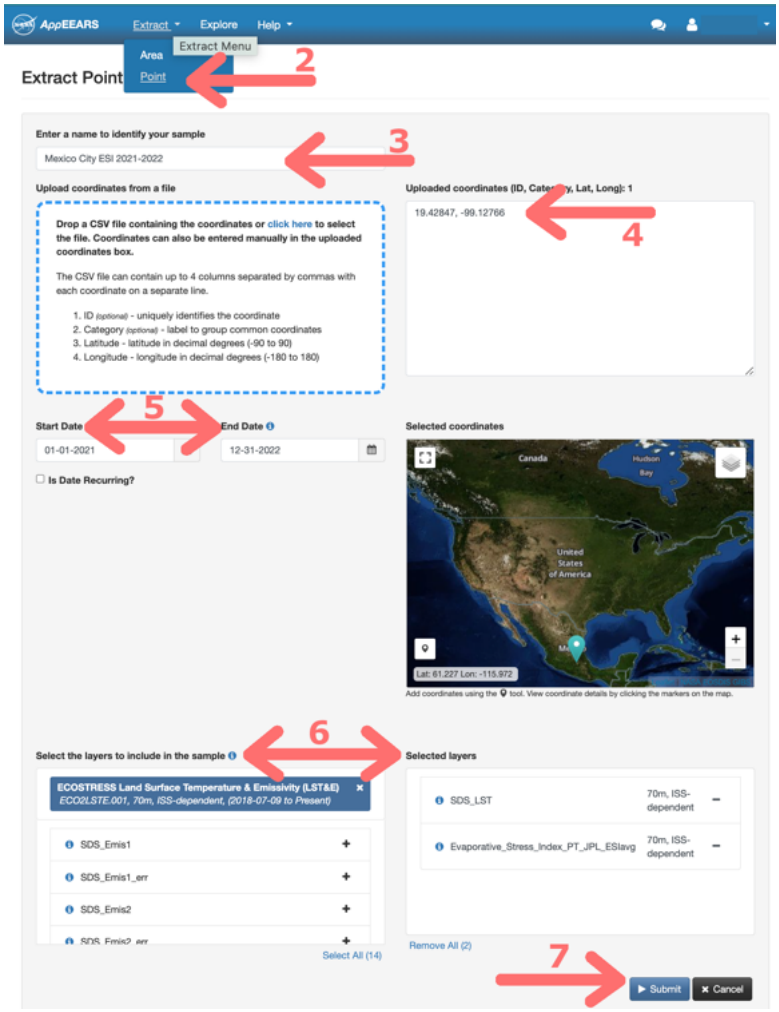


- Most populous city in North America with $>$ 9.2 million people in the city center and $>$ 21.8 million people in the greater metropolitan area.
- Northern Mexico's system of $>$ 60 reservoirs is currently $>$ 75% drained, leading to water scarcity (the lack of available water for human use) for $>$ 30% urban residents who do not have daily access to water.
- Mexico City sometimes has too little and sometimes too much water. In the dry season (October - April), droughts dry the land and deplete the water table. In the wet season (May - September), floods wash through its working-class neighborhoods.
- The year 2021 saw the worst drought conditions in more than three decades for Mexico City and brought predictions that 2022 might be worse. Today, we are using ECOSTRESS to compare the drought conditions of 2022 with the extreme conditions of 2021.

11.1.2 Requesting Timeseries Point ESI Data in A$\rho\rho$EEARS

So far, we have been using ECOSTRESS area data to create maps that visualize our variable of interest, but A$\rho\rho$EEARS also has another type of data output from a *Point* request. Instead of providing a shapefile or GeoJSON to define a set polygon area, we can provide A$\rho\rho$EEARS GPS coordinates (latitude, longitude), and it will return a timeseries of our variable of interest for the single pixel that encompasses our coordinates. Today, we are going to study ESI, but it can return this for any of the ECOSTRESS variables.

1. To begin, go to https://appeears.earthdatacloud.nasa.gov/ and login with your credentials.
2. Use the *Extract* drop-down menu, but this time select *Point*. Next, select *Start a new request*.
3. Enter a useful name for the request you are going to submit, maybe something like "Mexico City ESI 2021-2022".
4. In the *Uploaded coordinates (ID, Category, Lat, Long):* section enter the GPS coordinates for Mexico City as 19.42847, -99.12766.
5. Update the *Start* and *End* Date Fields for our dates of interest: 01/01/2021 to 12/31/2022.



6. Under *Select the layers to include in the sample*, type the words “ECOSTRESS” and “ESI” Select *ECOSTRESS Evaporative Stress Index PT-JPL*. Click on the “+” signs to add the following layers to your cart:

- Evaporative_Stress_Index_PT_JPL_ESIavg

Next, clear the selection of the current category using the small “x” to the right of the *ECOSTRESS Evaporative Stress Index PT-JPL* box.
Then, under *Select the layers to include in the sample* type the words “ECOSTRESS” and “LST,” select *ECOSTRESS Land Surface Temperature & Emissivity (LST&E)*. Click on the “+” signs to add the following layers to your cart:

- SDS_LST

Clear the selection of the current category using the small “x” to the right of the *ECOSTRESS Land Surface Temperature & Emissivity (LST&E)* box.
7. Click *Submit* to complete the data request. At the top, you should see a green banner:

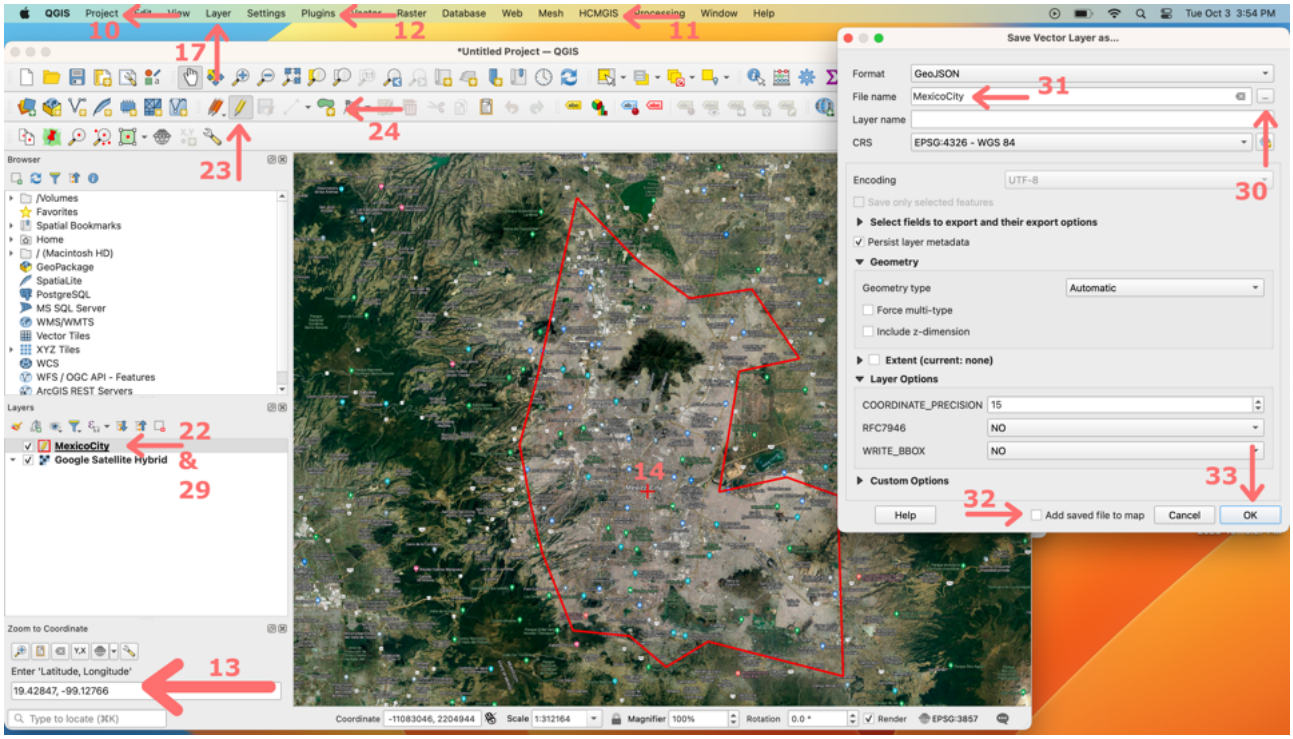
8. Use the *Explore* drop-down at the top to monitor the status of your request. Point requests typically process faster than area requests because the system only needs to pull a single pixel from each scene.

11.1.3 Requesting Area ESI Data in AρρEEARS

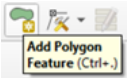
While we wait for the point request, we are also going to create an area request so we can examine how the drought affects different parts of Mexico City. The procedure to download area ESI data through the AρρEEARS interface is the same as in previous tutorials on land surface temperature, evapotranspiration, and water use efficiency.

Drawing and Exporting A GeoJSON File with QGIS

9. First, we will begin by drawing an outline of the metropolitan region surrounding Mexico City and export it as a GeoJSON that we can load into AρρEEARS.



10. Open QGIS and start a new project by selecting the *Project* menu, then *New*.
11. Then to add a basemap, find the *HCMGIS* menu bar, select *Basemap*, then pick your preferred map. Since we are outlining an urban area, I suggest we use *Google Satellite Hybrid*, which overlays streets and other Google maps data on satellite imagery. Note that clicking on a basemap type automatically adds a new layer to your map, as seen in the layer browser window.
12. Open the Lat Lon Tools window by selecting the *Plugins* menu → *Lat Lon Tools* → *Zoom To Coordinate*.
13. Enter in the following GPS coordinates of Mexico City (formatted as latitude, longitude): 19.42847, -99.12766.
14. The *Lat Lon Tools* plugin has found the GPS coordinates for Mexico City and marked them with a "+" on the map.

15. Next, we want to draw a polygon (i.e., a line that forms the perimeter of the area of interest) that encompasses Mexico City, so that we can pull the request and download the data from AρρEEARS.
16. Zoom in to the GPS coordinates that we entered and marked with a "+" on the basemap using the *zoom in*, *zoom out*, and *pan* buttons in the toolbar. If you are on a laptop, you could use the trackpad to do the same.
17. Next, we are going to create a new layer on the map by selecting the following menus: *Layer* → *Create Layer* → *New Shapefile Layer...*
18. Select the "..." option next to the *Filename* input window. Navigate somewhere you can remember (as always, we suggest creating a folder for each tutorial) and save it with a worthy filename. "Mexico City Perimeter" would be an appropriate name.
19. Select *UTF-8* for *File encoding*.
20. Select *Polygon* for geometry type.
21. Leave the remaining options as their defaults and click *OK*.
22. Now, it is time to draw the polygon. First, make sure that your new "Mexico City Perimeter" layer is highlighted in the *Layers* window.
23. Select the *Toggle Editing* button on the toolbar to start editing the layer.
24. Then select the *Add Polygon Feature* 

button to begin drawing.
25. Draw a polygon that encompasses Mexico City. Don't worry too much about being perfect or strictly aligning to the city's borders; getting the basic shape is fine. Right-click on Windows or Linux and Ctrl-click on Mac to stop drawing when your shape is complete.

NOTE: Drawing a polygon in QGIS is both straightforward and nuanced. You use successive clicks with your mouse to create your desired shape. Simple forms such as squares or rectangles are easily achievable, whereas complex designs take some practice to master. It may take a couple of attempts to get it to look like what you are envisioning. You can always hit the "ESC" key to clear the polygon and start over.

26. After you finish drawing, QGIS will prompt you for a feature ID. This is an arbitrary designation for our purposes today, so simply using the number 1 is my recommendation.
27. Click *OK*.
28. Select the *Toggle Editing* button from the toolbar to toggle off editing the layer. QGIS will prompt you to confirm saving the layer. Select *Yes*.
29. To export your layer as a GeoJSON file: right-click (Windows or Linux) or ctrl-click (Mac) on the layer in your layer browser window. Then select *Export*, then *Save Feature As...*. In the next window make sure "GeoJSON" is the selected format.

NOTE: Make sure "GeoJSON" is the selected format. The default for QGIS is "GeoPackage", which isn't a format that AρρEEARS can read as an input. Also, there is a similar filetype "GeoJSON Newline Delimited" that AρρEEARS can also not read.

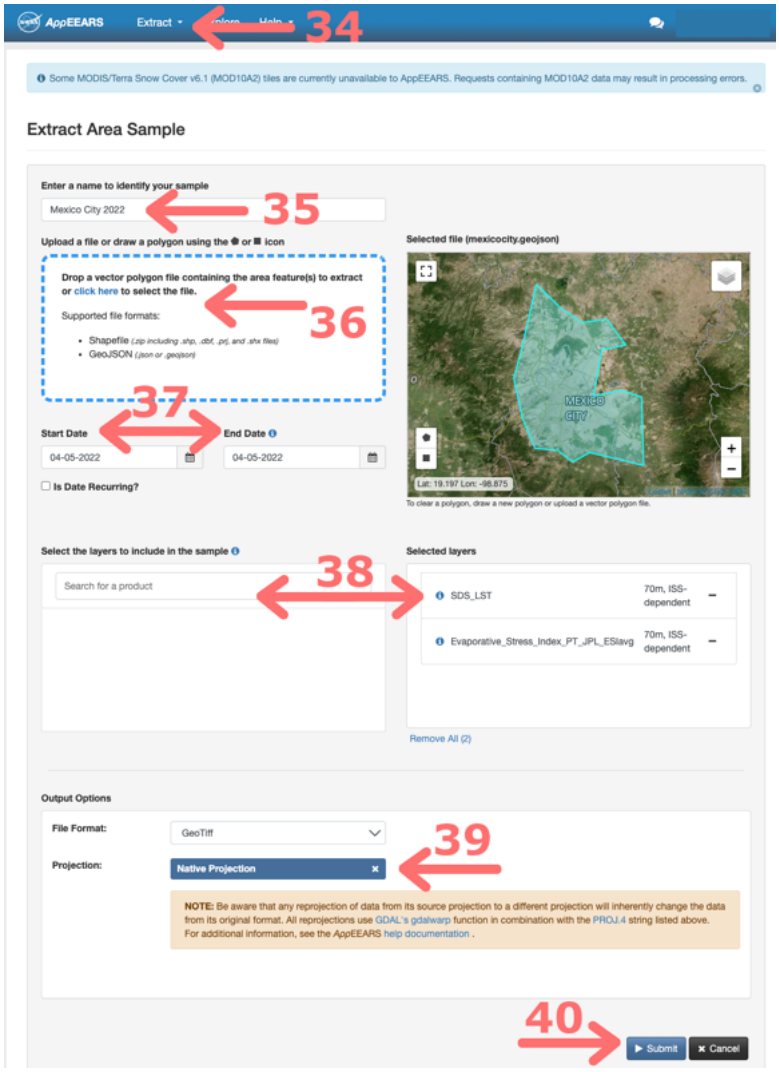
30. Select the "..." option next to the *Filename* input window to choose a logical location to save your GeoJSON file.
31. Name the file something appropriate, perhaps "MexicoCity-Outline."

32. Uncheck the box labeled “Add saved file to map.”
33. Click “OK”.

Creating an Area Request for Mexico City (2022) in AρρEEARS

Return to AρρEEARS to create a new area request. We have preselected dates with good data coverage (few-to-no clouds, orbit path that aligns with a single shot for the area of interest) in 2021 & 2022.

34. Use the *Extract* dropdown menu to select *Area*. Next, select: *Start a new request*.



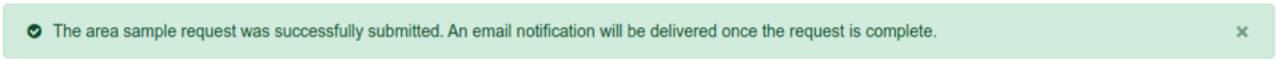
35. Enter a useful name for the request you are going to submit, maybe something like “Mexico City 2022”.
36. Drag and drop (or use the *click here to select the file* link) to upload the GeoJSON file we just exported in steps 10-33. The map should be updated with your polygon surrounding Mexico City.
37. Update the *Start* and *End* Date Fields for our preselected date of interest: 04/05/2022 to 04/05/2022.
38. Under *Select the layers to include in the sample* type the words “ECOSTRESS” and “ESI” Select *ECOSTRESS Evaporative Stress Index PT-JPL*. Click on the “+” signs to add the following layers to your cart:

- Evaporative_Stress_Index_PT_JPL_ESIavg

Next, clear the selection of the current category using the small "x" to the right of the *ECOSTRESS Evaporative Stress Index PT-JPL* box.
Then, under *Select the layers to include in the sample* type the words "ECOSTRESS" and "LST." Select *ECOSTRESS Land Surface Temperature & Emissivity (LST&E)*. Click on the "+" signs to add the following layers to your cart:

- SDS_LST

Clear the selection of the current category using the small "x" to the right of the *ECOSTRESS Land Surface Temperature & Emissivity (LST&E)* box.
39. Under *Output Options*, we want to use GeoTIFF (Geographic Tagged Image File Format; essentially, an image file where the corresponding geographic information is embedded in the file) and *Native Projection* for projection.
40. Click *Submit* to complete the data request. At the top, you should see a green banner:



Creating an Area Request for Mexico City (2021) in AρρEEARS

41. Repeat steps 34 - 40 with the same layers and GeoJSON file. Call the request "Mexico City 2021" and change the date to 4/28/2021.
42. Use the *Explore* drop-down at the top to monitor the status of your request. Requests will likely go quickly, given that it is only one day's worth of data.

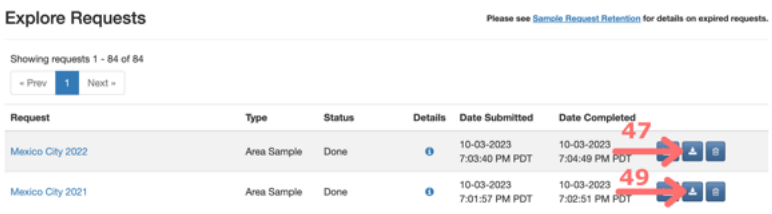
11.2 VISUALIZING ESI TIMESERIES POINT DATA IN AρρEEARS

43. When your first timeseries point data request ("Mexico City ESI 2021-2022") is complete, use the link on the *Explore* page to access the details. AρρEEARS returns this data in a .csv spreadsheet that can be opened with free statistical software such as R, the paid program Microsoft Excel, or the free alternative Libreoffice Calc. These software options can create graphs and run statistical comparisons.
44. Additionally, you can use the AρρEEARS interface to do some light visualizations, which will serve our purposes today.
45. Our goal for the ESI timeseries point analysis is not to visualize the data in space, but rather to compare the differences between the two years (the known drought year of 2021 and 2022). The benefit of this point data is that AρρEEARS has conveniently packaged our variable of interest in an easy-to-manage format to track changes over time. The disadvantage of this type of data retrieval is that it can only be done for a single pixel per request.
46. First, select the *Evaporative_Stress_Index_PT_JPL_ESIavg* layer:
The top panel displays the entire timeseries for the dates we have requested. The bottom panel compares years by plotting different years in our data in different colors.
Notice that the dry season (October - April) has much more drought stress (low ESI) compared to the wet season (May - September). Our goal was to compare 2022 to the known drought year of 2021. What

conclusions can you draw from these data? Include your assessment in the write-up accompanying your "Map of the Week". Verify that any sources of errors are mentioned, specifically describing the shortcomings of point analyses (e.g., using only one pixel of data).

11.3 VISUALIZING AREA ESI DATA WITH QGIS

11.3.1 Download Area ESI Data in A$\rho\rho$EEARS

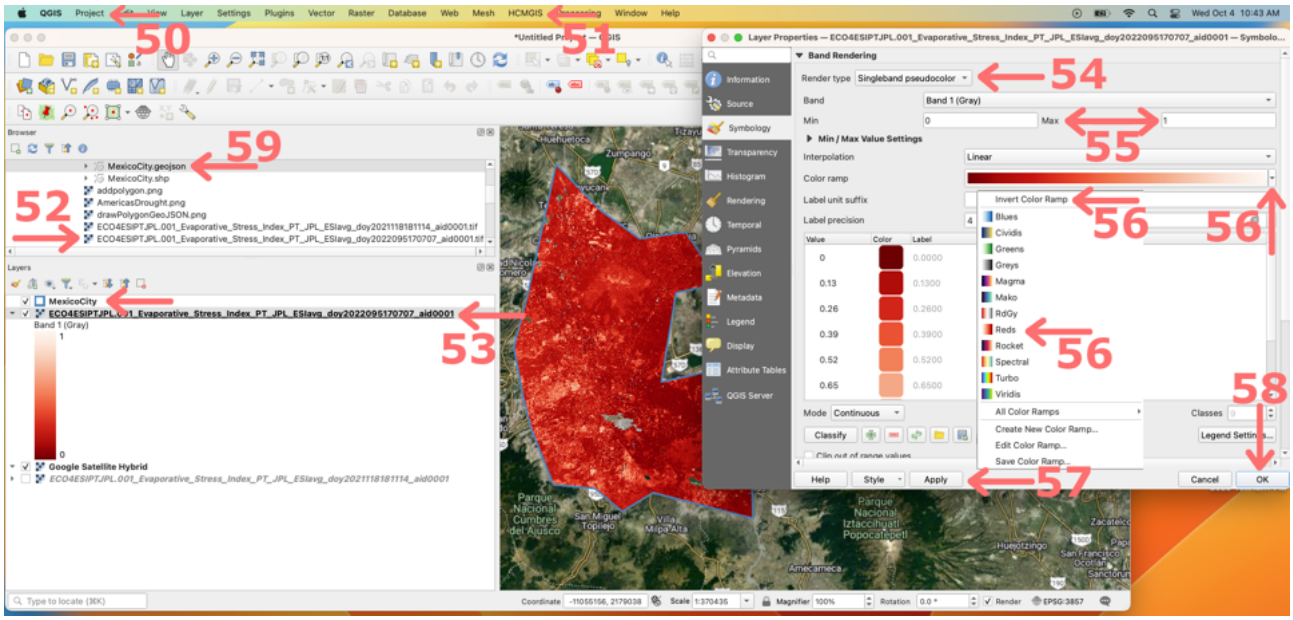


47. By now, your area requests should be complete. From the *Explore* dropdown menu at the top of the A$\rho\rho$EEARS interface, click the download button (middle blue button) for the first area request "Mexico City 2022".

48. Select the following filename: ECO4ESIPTJPL.001_Evaporative_Stress_Index_PT_JPL_ESIavg_doy2022095170707_aid0001.tif. Download the file using the *Download* button, which for some reason does not look much like a button, in the upper right corner of the screen. Save the file somewhere you can remember.
49. Repeat steps 47 - 48 to download the file from the second request "Mexico City 2021" to download the following filename: ECO4ESIPTJPL.001_Evaporative_Stress_Index_PT_JPL_ESIavg_doy2021118181114_aid0001.tif

11.3.2 Adding a Google Satellite Basemap

50. Switch to QGIS and start a new project by selecting the *Project* menu, then *New*.
51. To add a basemap, find the *HCMGIS* menu bar, select *Basemap*, then pick your preferred map. For today's map, we will use *Google Satellite*. Note that clicking on a basemap type automatically adds a new layer to your map, as seen in the layer browser window.



11.3.3 Add in ESI layer

52. Use the *browser* window to find the folder where you saved the 2022 ESI file: ECO4ESIPTJPL.001_Evaporative_Stress_Index_PT_JPL_ESIavg_doy2022095170707_aid0001.tif. Double-click on it to add it to your map. Again, notice that the layer from this GeoTIFF file is now also listed in the *Layers* window.

NOTE: QGIS can automatically zoom to your layer's area of interest by right clicking (ctrl-click on Mac) on the layer and selecting *Zoom to Layer(s).*

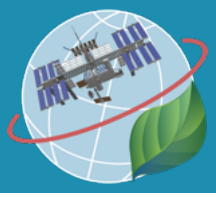
53. Now, you have ECOSTRESS ESI data on your map, but we need to change it from grayscale. Right-click (ctrl-click on Mac) on the layer name in the *Layers* window and select *Layer Properties*.
54. On the menu bar to the left, select *Symbology* and change *Render type* to Singleband pseudocolor.
55. QGIS has automatically determined the minimum and maximum values from the datafiles; however, we are going to want to compare two different years and need to match them. The ESI range is 0-1, so specify 0 as the minimum and 1 as the maximum.
56. Now, we need to change the color ramp to effectively communicate ESI. Let's select the "Reds" option, but remember that the scale for ESI is inverted (0 indicating drought stress & 1 indicating non drought conditions). To address this, check the *invert color ramp* checkbox.
57. Click *apply*.
58. Then click *ok*.
59. Finally, add the polygon border from your Mexico City GeoJSON file by double clicking on it in the *Browser* window. Right-click (ctrl-click on Mac) on the layer in the *Layers* window and change the symbology to *outline blue*.

11.4 ADD MAP ELEMENTS

60. Following the procedure described in Tutorial #5 : Adding Elements To Maps, make a professional map complete with scalebars, labels, a legend, titles, and a North arrow. Use a basemap that highlights the study region (Mexico City) with this ESI map from 2022 as an inset.
61. Repeat steps 52 - 60 for the Mexico City 2021 data and include it as an inset on the same map. This map will be your part of your map of the week assignment.

Map of the Week Assignments

1. Make a map comparing 2021 and 2022 ESI data for Mexico City. Include a basemap that presents the region and the ESI data for 2021 and 2022 as insets. The map(s) should be complete with scalebars(s), north arrow(s), legend(s), title(s), and label(s).
2. Provide a 1-2 paragraph description of your map and ESI timeseries point data that includes your reflections on whether 2022 should be considered a drought year, knowing that 2021 was the worst drought in more than 30 years. How do the different sources of data (timeseries point vs. geographic area) contribute to your analysis? Address the limitations of your analysis.



Datafiles

In case you encountered any issues with the A$\rho\rho$EEARS database, here are copies of the ECOSTRESS GeoTIFF file for Mexico City ESI 2022:

1. ECO4ESIPTJPL.001_Evaporative_Stress_Index_PT_JPL_ESIavg_doy2022095170707_aid0001.tif

And Mexico City ESI 2021:

1. ECO4ESIPTJPL.001_Evaporative_Stress_Index_PT_JPL_ESIavg_doy2021118181114_aid0001.tif

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