WORKSHOP EXERCISE

The purpose of this exercise is to learn to read in the high-resolution climate projections, calculate a range of different annual indicators, and plot the results.

STEP ONE: RUN THE PROGRAM

Open the statistical programming package R on your computer. Make sure it is being run in interactive mode.

Set the work directory. Type

```
setwd('working_directory')
```

– but don't actually type the words 'working_directory' – instead, substitute the actual directory that is written on the whiteboard.

Then, at the prompt, type

```
source('indicator.projections.r')
```

You are now running the program. It will ask you a series of questions to see what you want to calculate.

The first question is, in what directory is the code? Type in the code directory exactly as instructed. Don't forget the final slash at the end!

The second question is, what is your input directory? Type in the input directory exactly as instructed. Again, don't forget the final slash at the end!

And the third question is, what is your output directory? One more time, type in the directory path exactly as instructed.

Now you're ready to go.

STEP TWO: CALCULATE WEATHER STATION INDICATORS

Now you are going to calculate daytime maximum temperature for the hottest day of the year for a weather station of your choice.

To do this, answer the next questions like this:

```
Do you want to generate the data to create a map of India or a time
series for an individual weather station? Enter 1 for a map, 2 for a
weather station:
```

Enter "2" for an individual weather station.

```
Which weather station do you want to use? Enter the number of the
weather station:
```

Review the list of 64 stations and select which station you want to use. Enter its number (e.g. 1 for Kakinada, 2 for Ramgundam, etcetera).

```
Which variable do you want to work with? Enter the variable number:
```

Enter "1" for maximum temperature.

```
Which type of indicator do you want to calculate? Enter the indicator
type:
```

Enter "3" for an extreme value.

```
For how many days in a row do you want to calculate an extreme? Enter
your answer in number of days, from 1 to 14:
```

Enter "1" for one day.

```
Do you want the coldest or hottest day(s)? Enter 1 for coldest, 2 for
hottest:
```

Enter "2" for hottest.

Now the program will calculate the average daytime maximum temperature for the hottest day in each year from 1950 to 2100. It will also calculate the averages for 5 different time periods: 1950-1979, 1980-2009, 2010-2039, 2040-2069 and 2070-2099. The output will be two comma-separated text files in your output directory. This is a type of file that can be read in by Excel.

Check the output directory to make sure the two files are there, but don't open them yet – we won't need them until STEP 4.

STEP THREE: CALCULATE GRIDDED INDICATORS

Now, we are going to make a map of the average precipitation in each year during the monsoon season from July to September. Calculations on gridded data take a lot of time, so you are going to start this calculation and then let it run while you move on to STEP 4.

First, repeat STEP 1. After you have entered the input and output directories, then answer the rest of the program's questions like this:

```
Do you want to generate the data to create a map of India or a time
series for an individual weather station? Enter 1 for a map, 2 for a
weather station:
```

Enter "1" for the gridded data.

```
Do you want to map the results from one climate model, or from an
ensemble average of multiple models? Warning: the ensemble average may
take over an hour to calculate, depending on the speed of your
computer - don't do it unless you have the time! Enter 1 for one model,
and 2 for all the models:
```

It takes a long time to calculate an ensemble average, so for this exercise we are just going to use one model. If we select one model, the code will select the default model, CCSM4. Enter "1" to use only the default model.

```
Which variable do you want to work with? Enter the variable number:
```

Enter "4" for precipitation.

```
Which type of indicator do you want to calculate? Enter the indicator
type:
```

Enter "1" for an annual or seasonal average.

```
In what month does your season begin? Enter the first month here,
using numbers from 1 (Jan) to 12 (Dec):
```

Enter "7" for July.

```
In what month does your season end? Enter the last month here, using
numbers from 1 (Jan) to 12 (Dec):
```

Enter "9" for September.

Now the program will calculate the average July to August precipitation for 5 different time periods: 1950-1979, 1980-2009, 2010-2039, 2040-2069 and 2070-2099. The output will be a netCDF file (that ends in ".nc") in your output directory. This is a type of file that can be read in by Panoply.

This calculation will take a while to run. So, leave it running for now and move on to STEP 4. If you want to check on it once in a while, you can: it will give you an update every 10 years.

STEP FOUR: PLOT WEATHER STATION INDICATORS

Now you're going to plot the daytime maximum temperature for the hottest day of the year that you calculated in STEP 2.

In Microsoft Excel, open the file "Sample.Plots" and save it under a new name.

Next, open your two output files in Excel. They are comma-separated files, so they should open automatically with the data in 7 columns: year, observations, lowest model value, mean model value, and highest model value for the lower RCP 4.5 scenario, followed by the same three columns for the higher RCP 8.5 scenario.

Select and copy the data from the output file showing values for each 30-year time period. Paste the data into the page in the Sample.Plots file called "bar chart data". Now select and copy the data from the other output file, the one that has values for every year from 1950 to 2100. Paste that data into the page in the Sample.Plots file called "time series data".

The time series plot and the bar plot will automatically update. Just go to those pages and view! If there is a problem, you probably didn't put the data in the right place: open the Sample.Plots file again, name it something else, and try again.

For the time series and the bar chart, you have two choices: an orange colour scheme or a blue colour scheme. Orange usually looks good for temperature; blue looks good for precipitation.

You may need to adjust the scale on the Y-axis. It doesn't have to start at zero – choose whatever maximum and minimum values make sense for the data you are plotting.

Once your plots look right, give them a good title and then save each one (either the orange or the blue one – not both!) as an image by right-clicking on the plot and selecting "Save as a Picture".

Thought Questions*. How is the hottest day of the year expected to change in the future? Is there a difference between what's projected to occur under a higher versus a lower scenario? What implications do these projections have for public health in your part of the country? What will people have to do differently to adapt to these changes?*

STEP FIVE: MAKE INDICATOR MAPS

Hopefully by now your calculations for STEP 3 are done. If they aren't, go back and repeat STEPS 2 and 4 for a different weather station or a different variable, while you are waiting.

Once STEP 3 is finished, you can now plot output using a program called Panoply. If you've never heard of it, don't worry – it is easy to use, and it makes beautiful maps!

Open Panoply and from the "Open..." popup dialog box, choose the file you just created. It will be in the output directory you told the program to use, and it will end with ".nc".

Once it opens, you will see the variables list in the left pane and the file header in the right pane. There will be two variables: one for the higher scenario (RCP 8.5) and one for the lower scenario (RCP 4.5).

In the left pane, click on the climate variable for the higher scenario. Now, the right pane now shows the variable attributes. With the higher climate variable highlighted, click on "Create Plot" icon in the upper left. The "Create Plot" popup dialog box gives three options. Since you want to make a map, choose the default option "Create georeferenced Longitude-Latitude plot" and then click "Create".

A plot should come up, covering the entire planet, with only the grid cells with values (those over the region of interest) are colored in. The plot is for the first time period, 1950-1979. This isn't what you want, but don't worry: you can fix this!

Before you start to modify the map, note a few important things. First, at very top of plotting window, you can see the variable name. At the bottom of the plot there is a color scale bar. It might need to be fixed as well. If you click on the "Array 1" tab in upper left, you will see the actual values being plotted.

Now you're going to modify the plot.

First, click on the "Map" tab below the plot and make the following changes:

- Change “Projection” to “Equirectangular (Regional)”
- Change the “Center on:” to 85E for longitude and 20N for latitude
- Change the “Height” to 40 degrees – but now the plot is a bit stretched.
- To fix this, click on the “Fix Proportions” button.

This will cause the plot to zoom in on India. You can also change the rendering of the grid on this tab. Feel free to explore the different options if you want. Note that you can zoom the map in even further, if you’d like to plot a smaller region. Use the “Height” and “Width” options to zoom and the “Center on” options to re-center.

Second, click on the "Scale" tab. Here, you can change the colour table, tick format, and scale bar caption, among other things. If the scale bar looks strange – the bottom number is too low or the top number is too high – enter whatever scale range you want in the Min and Max windows at the top left, or click the "Fit to Data" button. You can also choose a colour scheme that you like here, too. There are about a hundred to choose from.

Third, open the “Array” tab. Here, you can choose which time step to plot. Choose different time steps and see how the numbers change.

Fourth, explore the "Overlay" tab, where you can choose from various overlays for your plot, and then the “Contours” tab, where you can add contours to your plot. The variables we are calculating don’t need Vectors, so you can just ignore that tab. Click on the “Labels” tab to change the labels on the plot if you want to.

Once you have the plot looking exactly how you like it, click on the "Plot" menu item at the top of the page, then select "Save Plot Settings to Preferences”. Now, every new plot you make will use these settings as a default – although of course you can change them any time you want.

Now let’s save it!

On the “Array” tab, select the 1980-2009 time period. Then click on the “File” menu item at the top of the page, and select “Save Image As”. Note the different file formats available, and choose the one that makes the most sense for your use. Rename the file as necessary, making sure to include the time frame in the title, then click "Save".

Now select the 2070-2099 time period and save that map as a file. Make sure to include the higher scenario in the title.

Now go back to the Sources window (you might have to close the Plot window to find it again) and select the climate variable for the **lower** scenario. Click on "Create Plot" icon in the upper left and select "Create georeferenced Longitude-Latitude plot" and then click “Create”. On the “Array” tab, select the 2070-2099 time period. Now save this map as an image file. Make sure to include the fact that this map is for the lower scenario in the title of the file.

Thought Questions*. How is precipitation during the monsoon season expected to change in the future? Is there a difference between what’s projected to occur under a higher versus a*

lower scenario? What implications do these projections have for water planning and flood control in your part of the country?

STEP SIX: COMPARING GRID VS STATION

Repeat STEP 2, except this time choose July to September precipitation for your weather station indicator.

Now repeat STEP 3, but now choose the hottest day of the year for the gridded indicator.

Create the Excel plots in STEP 4 for July to September precipitation. Consider changing the colour of the lines and the shaded areas in the timeseries and the bar plots, so they use blue rather than orange colours (to communicate precipitation rather than temperature). Then create maps as in STEP 5 for temperature on the hottest day of the year.

***Thought Questions**. What's the difference between projected changes for the grid cell versus the station? Which one is more relevant to your work?*

STEP SEVEN: ADD MORE VARIABLES

Repeat STEP TWO, except this time create plots of other indicators that are relevant to your city or region.

For example, you could calculate the number of dry days per year (i.e., days with less than 0.01 inches of rain or 0.025 cm). To do this, select "precipitation" and "threshold". Repeat STEP FOUR, reading the resulting data file into Excel and saving the time series and bar plot as images.

Or you could repeat STEP 3, except this time creating a map of the number of days per year above 35^{o}C. To do this, use "daily maximum temperature" and "threshold". Repeat STEP FIVE, reading the resulting data file into Panoply and plotting the 1980-2009 and 2070-2099 average for the higher RCP8.5 and the lower RCP4.5 scenarios.

Finally, you can follow the instructions in STEP 2 to create a time series for a new weather station for the variable *cooling degree-days*. Cooling degree-days are a measure of how much air conditioning people will use, if they have it. When you select this variable, the program will ask what base temperature threshold you want to use. The base temperature indicates at what temperature people will turn on their air conditioning. Anything between 18^{o}C and 28^{o}C is reasonable: choose whatever temperature you would turn on the A/C at! Calculate the annual CDD values and plot them as described in STEP 4.

***Thought Questions**. What implications do these results have for water shortages, for agriculture, and for electricity demand in the future? How could this information be used as input to future planning?*

STEP EIGHT: MAKE YOUR OWN PRESENTATION!

Now you have many figures you can use. You can make more, if you need them. In this final step, you're going to take those figures and turn them into a powerpoint presentation that you could show.

Open the powerpoint file, "Sample.Presentation".

On the first slide, replace the image with a picture of your city or region. (You can use Google to find images, if you don't have them.)

On the next introductory slides, review and change anything that you want.

The following section contains the methods slides. Review the methods description and make any changes you want.

Next comes the results section. Here, insert your figures, one map or plot on each slide. Organize the slides by variable: the first section can show temperature, the second section can show precipitation, or vice versa.

What changes are already occurring, according to the historical data? How does temperature and precipitation affect your city and region? Is there an indicator that you didn't plot yet? Does flooding occur when more than a certain amount of rain falls? Is it a heat wave when temperatures soar above 40^{o}C? If so, you can go back and make some extra figures (especially if they are for a weather station – those calculations can be done very quickly).

At the end comes the conclusion section. What did you learn from looking at this information? What implications do these projections have for your city or region? Select highlights from your answers to the ***Thought Questions*** above to write your own conclusions.

Congratulations - now you have a presentation of future climate projections for your region!

CODE DESIGN

Open R and run the code using the following command

```
source('indicator.projections.r')
```

Once it starts running, it will ask the following questions:

QUESTIONS 0

```
Please enter the name of the directory containing the code. Make sure
to include the final slash at the end:

Please enter the name of the input directory. Make sure to include the
final slash at the end:

Please enter the name of the output directory:
```

QUESTION 1

```
Do you want to generate the data to create a map of India or a time
series for an individual weather station? Enter 1 for a map, 2 for a
weather station:
```

IF 1, THEN THE CODE WILL ASK QUESTION 1A:

```
Do you want to map the results from one climate model, or from an
ensemble average of multiple models? Warning: the ensemble average may
take over an hour to calculate, depending on the speed of your
computer - don't do it unless you have the time! Enter 1 for one model,
and 2 for all the models:
```

IF 2, THEN THE CODE WILL ASK QUESTION 1B:

```
Which weather station do you want to use? Enter the number of the
weather station:

[a list of the stations will print, like this:]

1 – KAKINADA
2 – RAMGUNDAM
3 – ETC
```

QUESTION 2

```
Which variable do you want to work with? Enter the variable number:

[a list of the variables will print, like this:]
```

1 – maximum daily temperature
2 – minimum daily temperature
3 – average daily temperature
4 – precipitation
5 – cooling degree-days

QUESTION 3

Which type of indicator do you want to calculate? Enter the indicator type:

[a list of the indicator types will print, like this:]

1 – an annual or seasonal average
2 – the number of days above or below a threshold value
3 – an extreme or record value for each year

QUESTION 4

If indicator type 1, then:

(a) In which month does your season begin? Enter the first month here, using numbers from 1 (Jan) to 12 (Dec):
(b) In which month does your season end? Enter the first month here, using numbers from 1 (Jan) to 12 (Dec):

If indicator type 2, then:

(a) Enter the threshold value in degrees C for temperature or mm for precipitation:
(b) Would you like to calculate the number of days per year above or below that threshold? Enter 1 for above, 2 for below.

If indicator type 3, and a weather station is selected, then:

(a) For how many days in a row do you want to calculate an extreme? For example, if you want one day, enter 1; a week, enter 7; two weeks, enter 14. Enter your answer in number of days from 1 to 14:
(b) Do you want the coldest or hottest/wettest day(s)? Enter 1 for coldest, 2 for hottest/wettest:

QUESTION 5

If variable 5 (cooling degree-days) is selected, then the code will ask:

What threshold would you like to use to calculate Cooling Degree-Days? Values typically range from 18 to 25°C. Enter the temperature at which people turn on their air conditioning, in degrees C: