Answer Sheet

LABORATORY 7: CLIMATE CHANGE – PART 2

Student Name ________________________________

Student Number ______________________________

QUESTION 1

NASA maintains a dataset of land-based weather station (Global Historical Climatology Network – GHCN Version 4) and sea surface temperature (Extended Reconstructed Sea Surface Temperature – ERSST Version 5) measurements that are commonly used to calculate our planet's annual mean global temperature. Using this dataset, NASA has been able to determine annual global mean temperatures back to 1880. You can access this dataset and do some simple comparative analyses using a utility that creates global maps at the following web address:

https://data.giss.nasa.gov/gistemp/maps/index_v4.html

The screen capture below shows a comparison of average annual (Dec-Nov) global mean temperature for the decade 1980 to 1989 to a baseline thirty-year period from 1951-1980 (NASA's preferred **climate normal**). The map produced shows the temperature difference or anomaly between the two periods. This web tool also calculates the global temperature difference between the averages of these two periods for the entire surface of our planet. In this comparison, it tells us that the average of the ten-year period 1980-1989 was 0.25°C warmer than the 1951-1980 thirty-year average (see red circle).

Careful examination of the map indicates that the warming during the decade 1980-1989 was not spatially homogeneous. The warming in the Southern Hemisphere was quite similar over land and ocean surfaces measuring about 0.2 to 0.5 °C. There are some smaller areas where the warming was a bit higher reaching between 0.5 to 1.0 °C. A few areas over the oceans show no change and a couple of spots along the edge of Antarctica actually show a cooling trend. In the Northern Hemisphere, warming seems to be greater on land surfaces. There is a large area of warming in central North America and Siberia measuring between 0.5 to 1.0 °C. Most of the ocean surfaces in the Northern Hemisphere show no change in surface temperature. There are two areas of colder temperatures occurring over the middle of the North Pacific Ocean and around the bottom of Greenland.

GISS Surface Temperature Analysis (v4)

Global Maps

Select parameters on the following form to create a surface temperature anomaly or trend map. An explanation of the input elements appears at the bottom of this page. *Note that generating figures takes 5 or 6 seconds; please be patient.*

Data Sources: Land Surface Air Temperature : GHCNv4
Sea Surface Temperature: ERSST_v5

or

Remote Sensed Surface Temperature Anomaly: none

Map Type: Anomalies

Mean Period: Annual (Dec-Nov)

Time Interval: Begin 1980 – End 1989

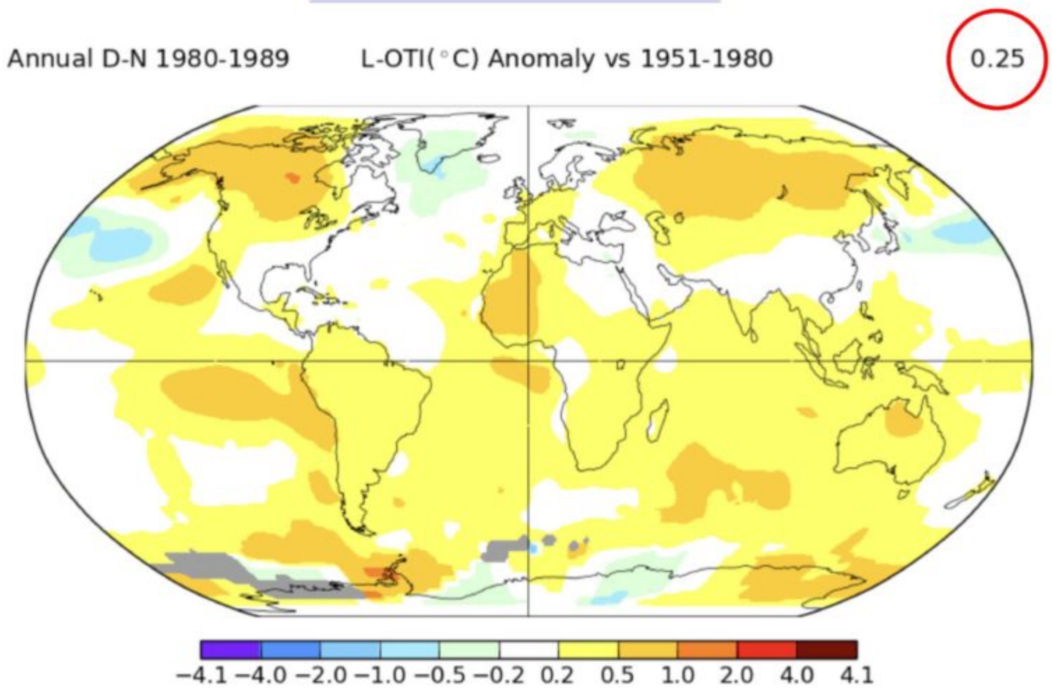
Base Period: Begin 1951 – End 1980

Smoothing Radius: 1200 km

Map Projection: Robinson

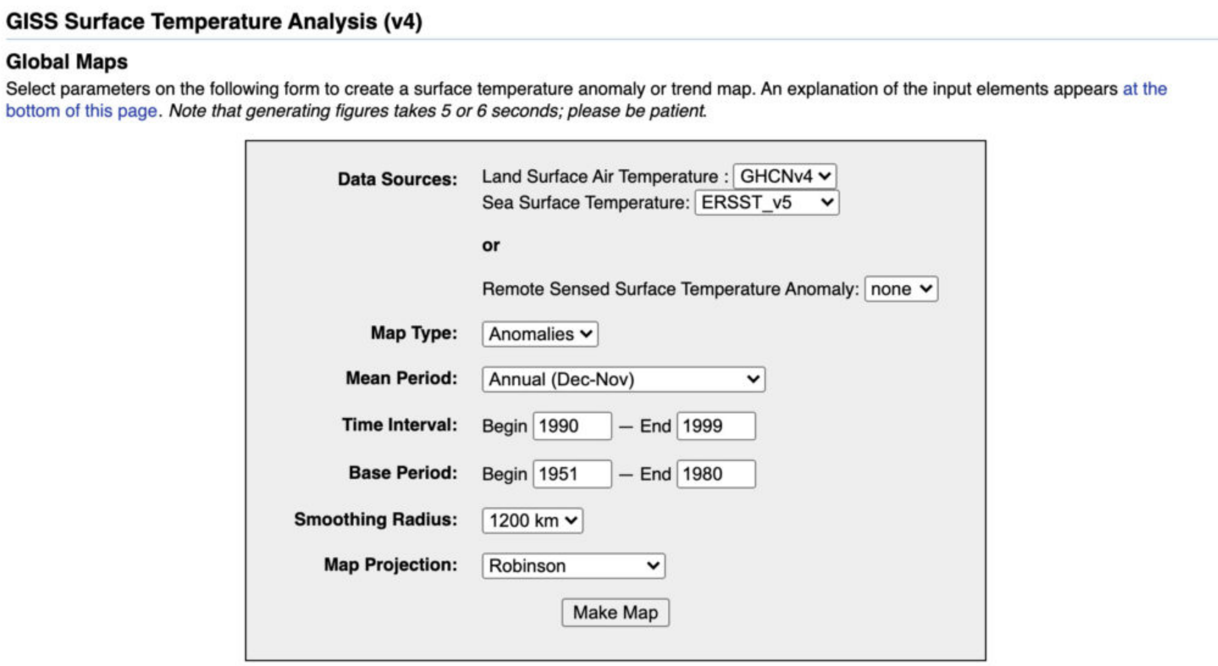
Make Map

Sources and parameters: GHCNv4_ERSSTv5__1200km_Anom1212_1980_1989_1951_1980_100__180_90_0__2_



Using NASA's climate dataset and mapping website described above, answer the following questions.

1.1) Generate a map showing the difference between the decade 1990-1999 and the 1951-1980 thirty-year climate normal using the input values shown below.



GISS Surface Temperature Analysis (v4)

Global Maps

Select parameters on the following form to create a surface temperature anomaly or trend map. An explanation of the input elements appears at the bottom of this page. *Note that generating figures takes 5 or 6 seconds; please be patient.*

Data Sources: Land Surface Air Temperature : GHCNv4
Sea Surface Temperature: ERSST_v5

or

Remote Sensed Surface Temperature Anomaly: none

Map Type: Anomalies

Mean Period: Annual (Dec-Nov)

Time Interval: Begin 1990 — End 1999

Base Period: Begin 1951 — End 1980

Smoothing Radius: 1200 km

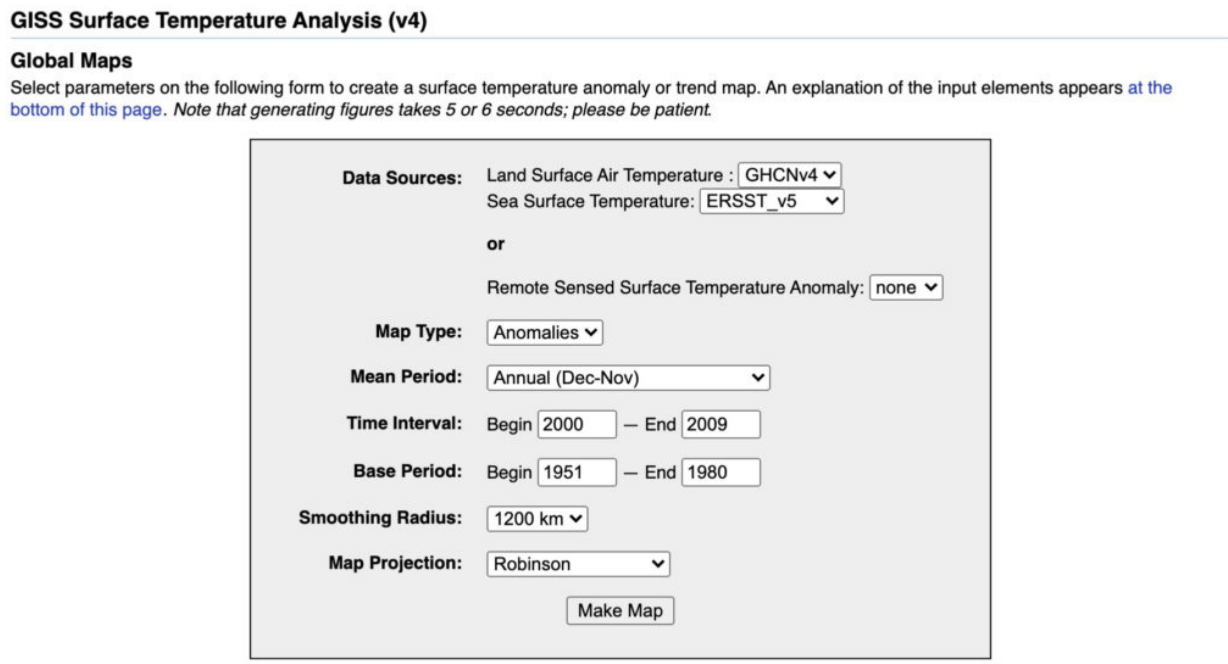
Map Projection: Robinson

Make Map

1.1a) Globally, how much warmer was the average of the decade 1990-1999 than the 1951-1980 climate normal in °C?

1.1b) Describe the patterns of warming and/or cooling seen in the generated anomaly map of 1990-1999 vs the 1951-1980 climate normal. What is the relationship of the warming with latitude? Is there greater warming over land or over ocean surfaces? Is one hemisphere warming differently than the other?

1.2) Generate a map showing the difference between the decade 2000-2009 and the 1951-1980 thirty-year climate normal using the input values shown below.


GISS Surface Temperature Analysis (v4)

Global Maps

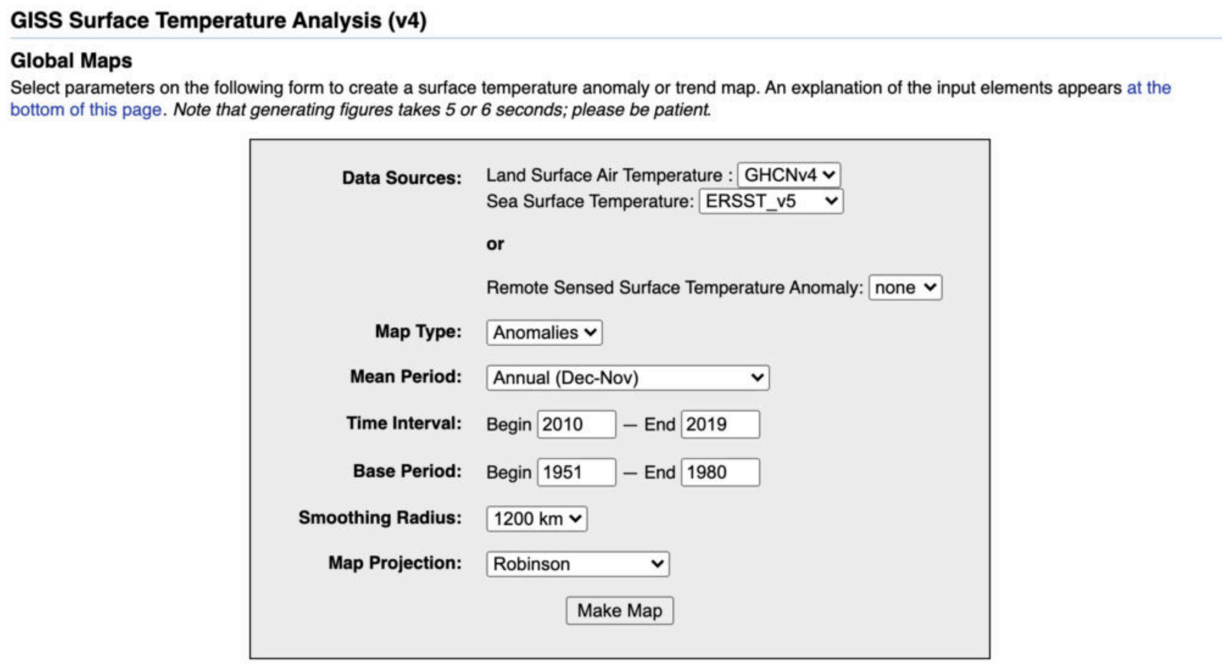
Select parameters on the following form to create a surface temperature anomaly or trend map. An explanation of the input elements appears at the bottom of this page. *Note that generating figures takes 5 or 6 seconds; please be patient.*

Data Sources:	Land Surface Air Temperature : GHCNv4 Sea Surface Temperature: ERSST_v5 **or** Remote Sensed Surface Temperature Anomaly: none
Map Type:	Anomalies
Mean Period:	Annual (Dec-Nov)
Time Interval:	Begin 2000 — End 2009
Base Period:	Begin 1951 — End 1980
Smoothing Radius:	1200 km
Map Projection:	Robinson
	Make Map

1.2a) Globally, how much warmer was the average of the decade 2000-2009 than the 1951-1980 climate normal in °C?

1.2b) Describe the patterns of warming and/or cooling seen in the generated anomaly map of 2000-2009 vs the 1951-1980 climate normal. What is the relationship of the warming with latitude? Is there greater warming over land or over ocean surfaces? Is one hemisphere warming differently than the other?

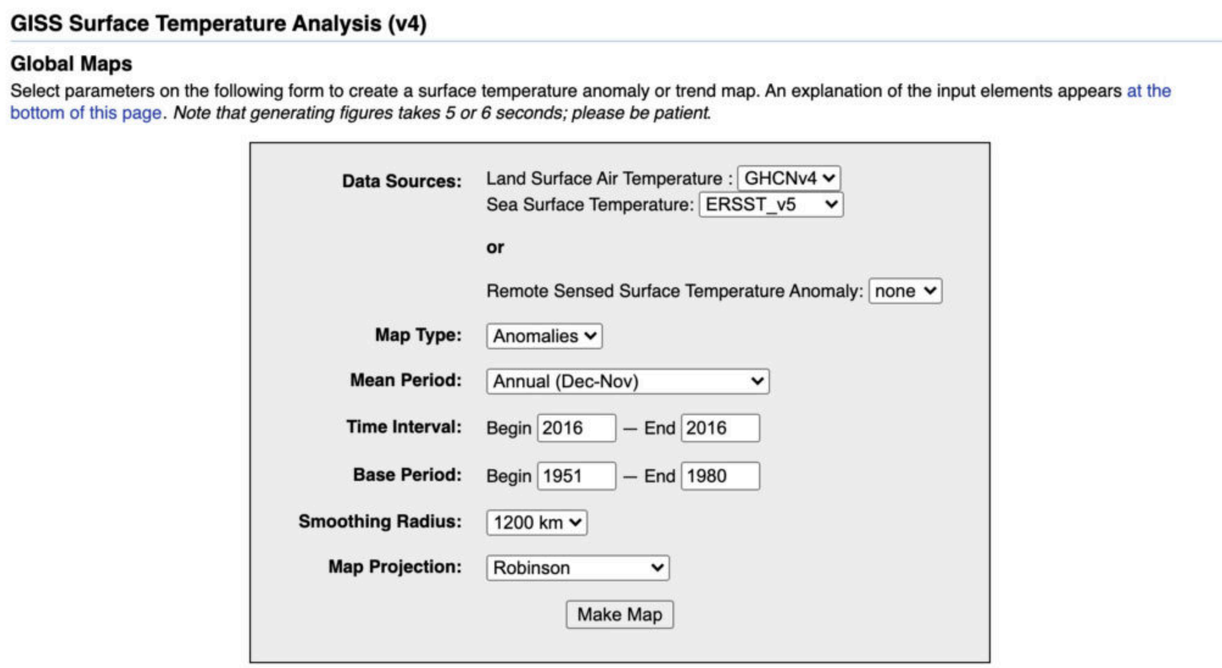
1.3) Generate a map showing the difference between the decade 2010-2019 and the 1951-1980 climate normal using the input values shown below.



1.3a) Globally, how much warmer was the average of the decade 2000-2009 than the 1951-1980 climate normal in °C?

1.3b) Describe the patterns of warming and/or cooling seen in the generated anomaly map of 2010-2019 vs the 1951-1980 climate normal. What is the relationship of the warming with latitude? Is there greater warming over land or over ocean surfaces? Is one hemisphere warming differently than the other?

1.4) Generate a map showing the difference between the year 2016 and the 1951-1980 climate normal using the input values shown below. Climatologist has identified 2016 as the warmest year in the historical record dating back to 1880.



GISS Surface Temperature Analysis (v4)

Global Maps

Select parameters on the following form to create a surface temperature anomaly or trend map. An explanation of the input elements appears at the bottom of this page. *Note that generating figures takes 5 or 6 seconds; please be patient.*

Data Sources: Land Surface Air Temperature : GHCNv4
Sea Surface Temperature: ERSST_v5

or

Remote Sensed Surface Temperature Anomaly: none

Map Type: Anomalies

Mean Period: Annual (Dec-Nov)

Time Interval: Begin 2016 — End 2016

Base Period: Begin 1951 — End 1980

Smoothing Radius: 1200 km

Map Projection: Robinson

Make Map

1.4a) Globally, how much warmer was the year 2016 than the 1951-1980 climate normal in °C?

1.4b) Describe the patterns of warming and/or cooling seen in the generated anomaly map of 2016 vs the 1951-1980 climate normal. What is the relationship of the warming with latitude? Is there greater warming over land or over ocean surfaces? Is one hemisphere warming differently than the other?

QUESTION 2

Use the following link to go to **Climate Reanalyzer**, Monthly Reanalysis Maps.

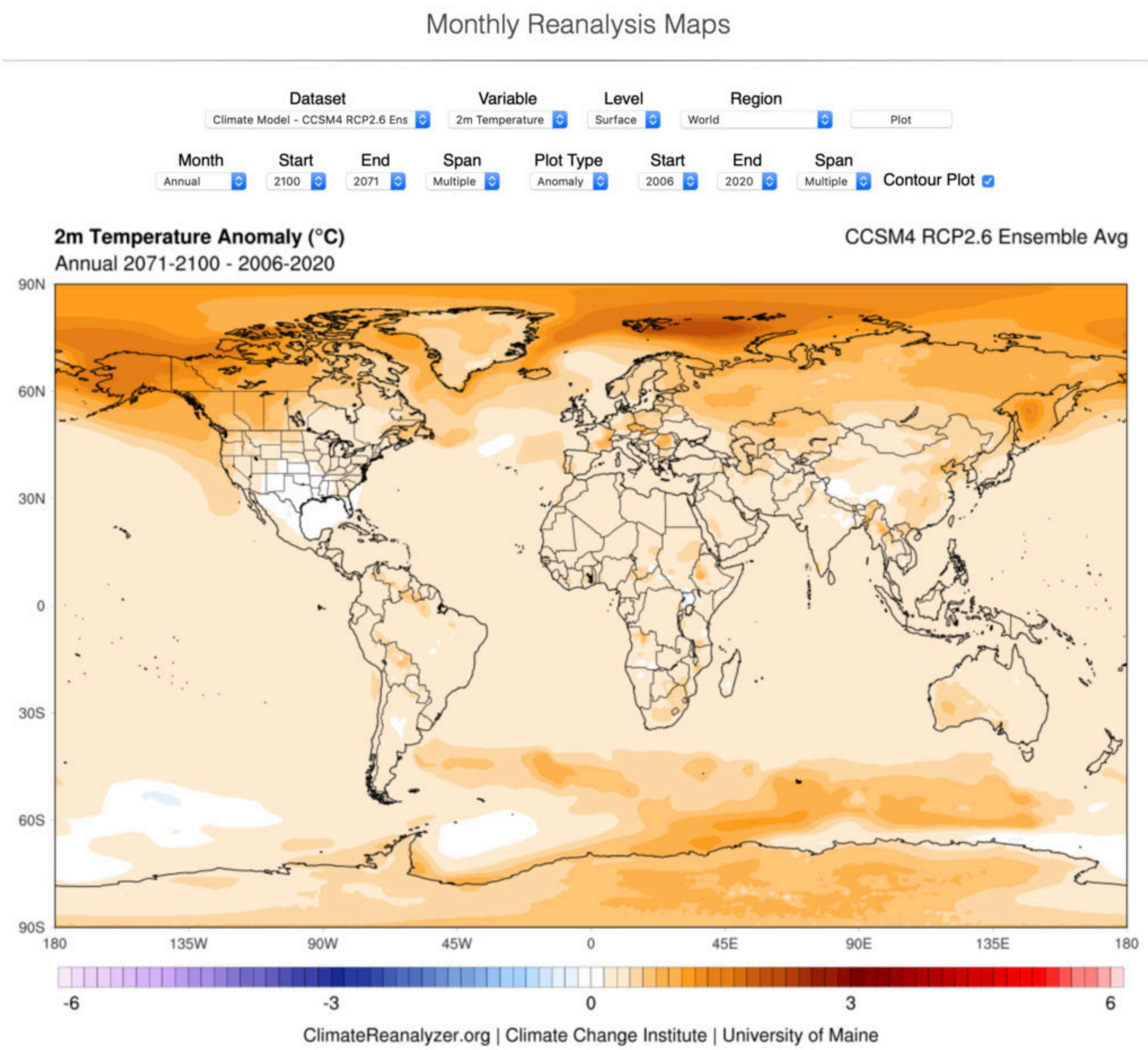
https://climatereanalyzer.org/reanalysis/monthly_maps/

One very interesting dataset available for analysis on the Monthly Reanalysis Maps webpage is climate simulation model forecasts for individual years from 2005 to 2100. This output was produced by the Community Climate System Model version 4 (CCSM4) Global Climate Model (GCM) developed by the University Corporation for Atmospheric Research (UCAR) at Boulder, Colorado, USA. Output is available for all four greenhouse gas emission scenarios: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5.

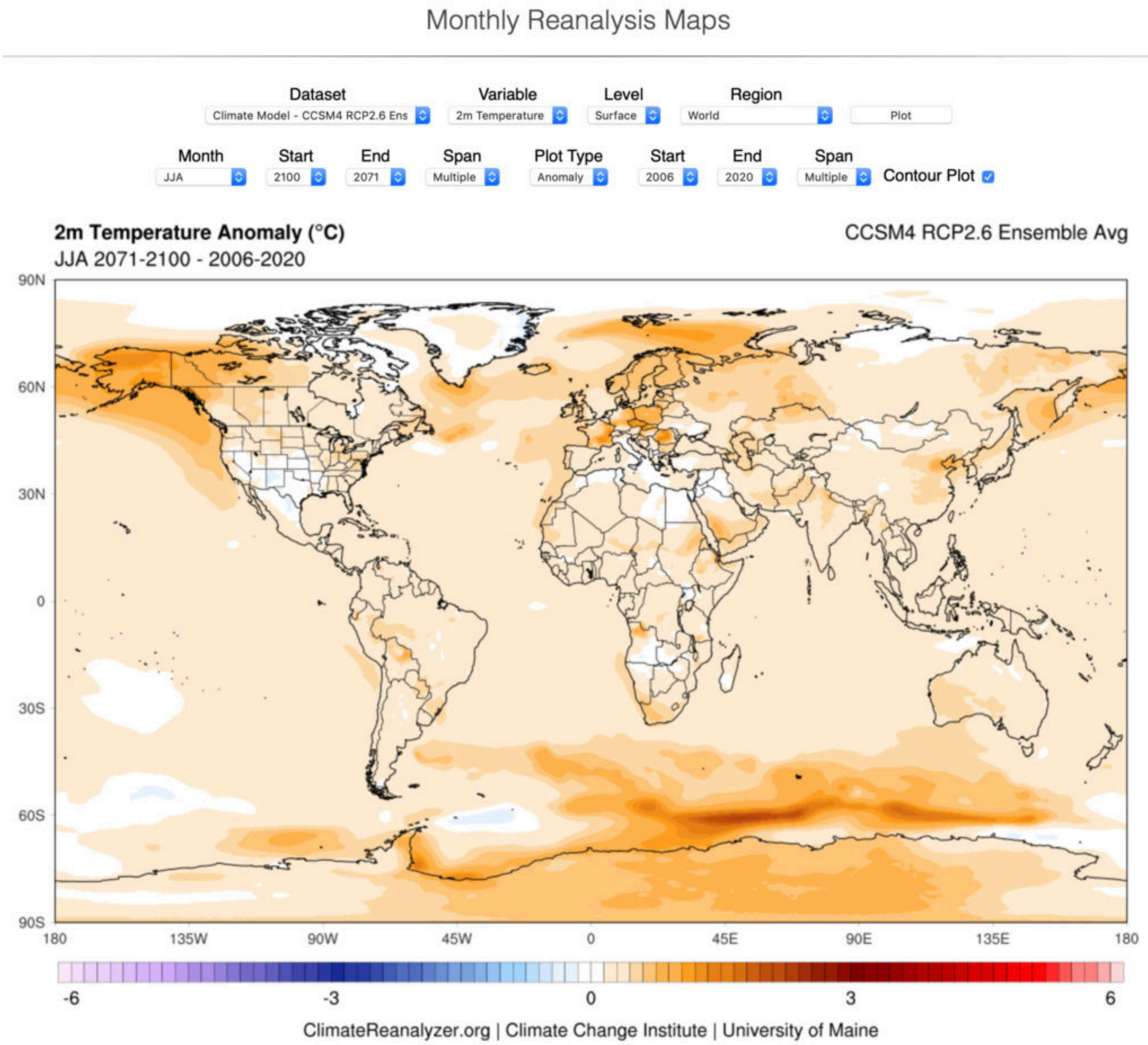
The next three maps were produced to examine the spatial change in surface mean temperatures (2 meters above ground level) under the RCP 2.6 greenhouse gas emission scenario **annually**, for **summer** (June, July, and August), and for **winter** (December, January, and February). In these three maps, the forecasted average conditions for 2071-2100 are compared to a 15-year base period of 2006-2020.

The RCP 2.6 greenhouse gas emission scenario assumes that we begin our path to lowering emissions of greenhouse gases starting in the year 2020 and eventually reaching zero emissions by 2100. This scenario also assumes that humans invest heavily in technologies to remove carbon dioxide from the atmosphere.

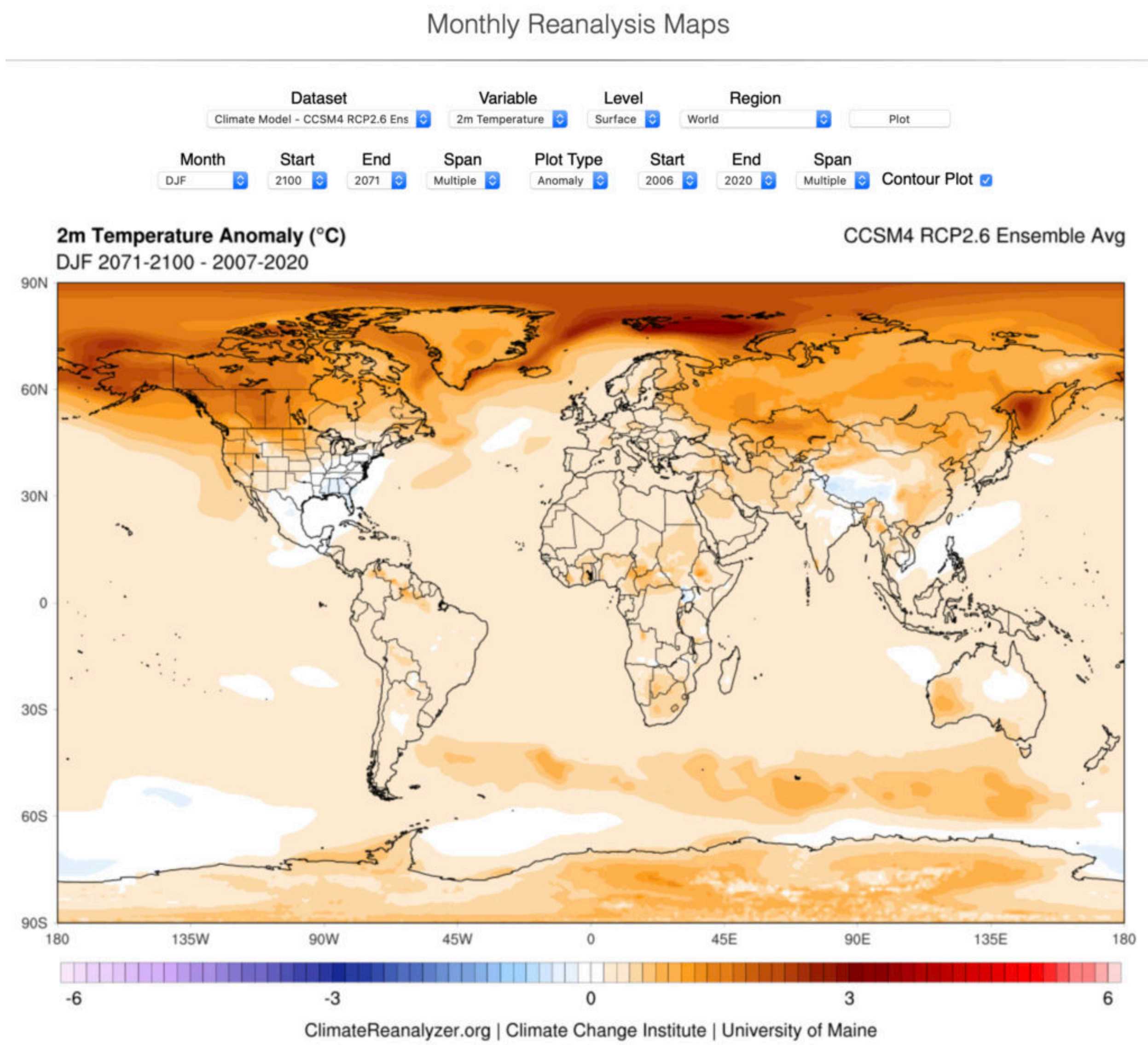
The **first map** compares the forecasted annual mean temperature in 2071-2100 to the base period of 2006-2020. The first thing to recognize on this anomaly map is that the predicted temperature change is not uniform across Earth's surface. In general, warming increases in strength as we move from the equator to the poles. Regional hotspots (> 1 °C) occur over Alaska and in the Arctic Ocean north of Scandinavia. No or little warming occurs around northern Mexico and Texas, the Himalayas, and two patches in the ocean surrounding Antarctica.



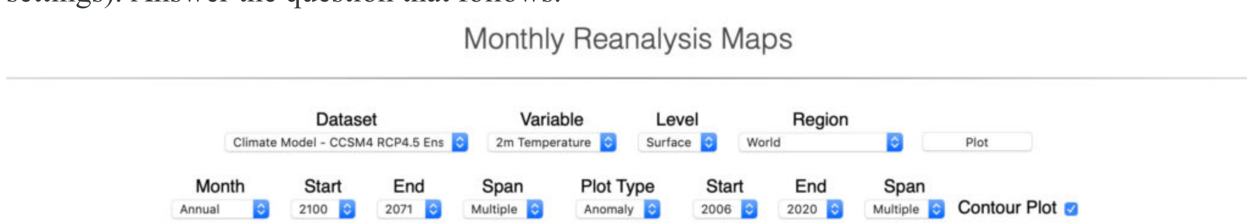
The **second map** (below) compares forecasted summer mean temperature in 2071-2100 to the base period of 2006-2020. It differs from the annual map in that the degree of warming occurring in the Northern Hemisphere is muted. Much of the Arctic Ocean and the edge of Greenland show little or no warming. Hotspot areas on Antarctica and in the ocean between South America and Australia are somewhat greater than what was seen in the annual map.



The **third map** (below) compares forecasted winter mean temperature in 2071-2100 to the base period of 2007-2020. It differs from the annual map in that the degree of warming occurring in the Northern Hemisphere is much greater especially at higher latitudes. Hotspot areas on Antarctica and in the ocean between South America and Australia is somewhat less than what was seen in the annual map.

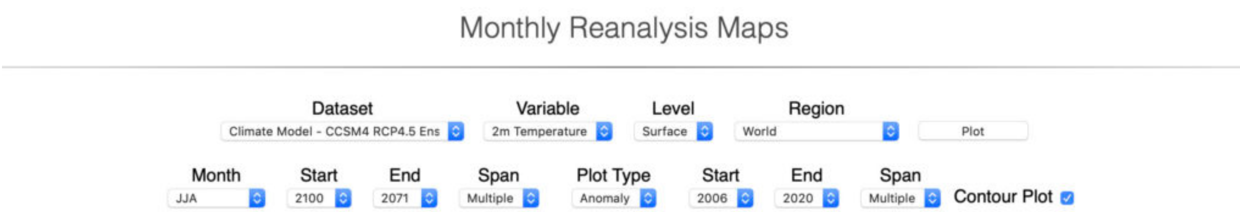


2.1) From the **Climate Reanalyzer**, Monthly Reanalysis Maps website, create a map that compares the forecasted annual mean temperature in 2071-2100 to the base period of 2006-2020 using the best-case RCP 4.5 greenhouse gas emission scenario (see image below for input settings). Answer the question that follows.



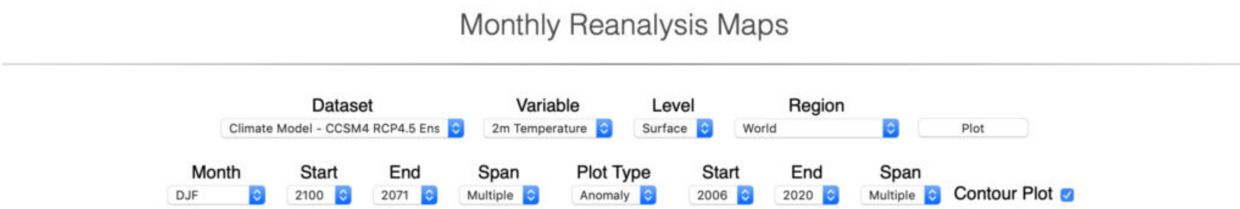
2.1a) Describe the patterns of warming and/or cooling seen in the map produced for the comparison of annual mean temperatures forecasted for 2071-2100 to the base period 2006-2020. How does the RCP 4.5 emission scenario compare to RCP 2.6?

2.2) From the **Climate Reanalyzer**, Monthly Reanalysis Maps website, create a map that compares the forecasted summer mean temperature in 2071-2100 to the base period of 2006-2020 using the RCP 4.5 greenhouse gas emission best-case scenario (see image below for input settings). Answer the question that follows.



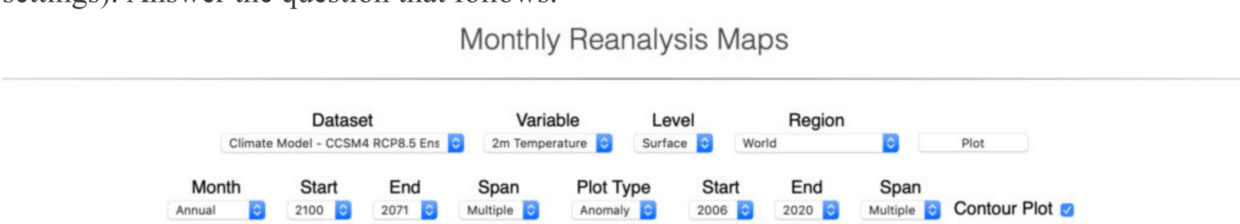
2.2a) Describe the patterns of warming and/or cooling seen in the map produced for the comparison of summer mean temperatures forecasted for 2071-2100 to the base period 2006-2020. How does the RCP 4.5 emission scenario compare to RCP 2.6?

2.3) From the **Climate Reanalyzer**, [Monthly Reanalysis Maps] website, create a map that compares the forecasted winter mean temperature in 2071-2100 to the base period of 2007-2020 using the RCP 4.5 greenhouse gas emission best-case scenario (see image below for input settings). Answer the question that follows.



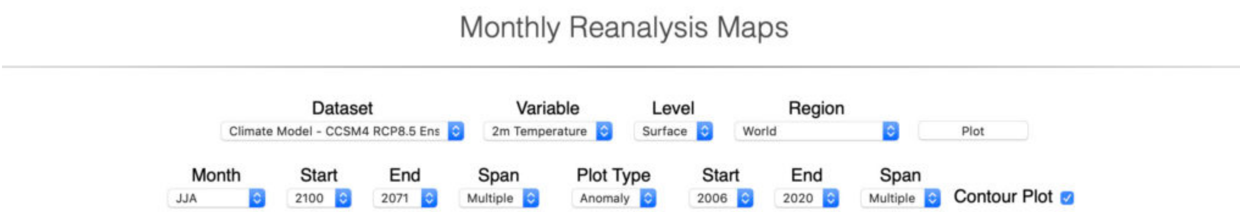
2.3a) Describe the patterns of warming and/or cooling seen in the map produced for the comparison of winter mean temperatures forecasted for 2071-2100 to the base period 2006-2020. How does the RCP 4.5 emission scenario compare to RCP 2.6?

2.4) From the **Climate Reanalyzer**, [Monthly Reanalysis Maps] website, create a map that compares the forecasted annual mean temperature in 2071-2100 to the base period of 2006-2020 using the worst-case RCP 8.5 greenhouse gas emission scenario (see image below of input settings). Answer the question that follows.



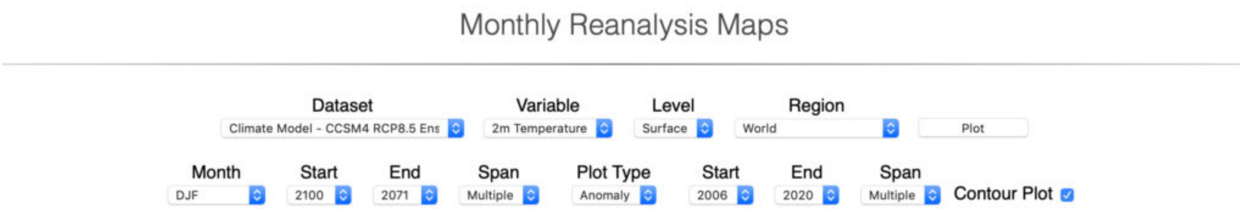
2.4a) Describe the patterns of warming and/or cooling seen in the map produced for the comparison of annual mean temperatures forecasted for 2071-2100 to the base period 2006-2020. How does the RCP 8.5 emission scenario compare to RCP 2.6?

2.5) From the **Climate Reanalyzer**, Monthly Reanalysis Maps website, create a map that compares the forecasted summer mean temperature in 2071-2100 to the base period of 2006-2020 using the worst-case RCP 8.5 greenhouse gas emission scenario (see image below for input settings). Answer the question that follows.



2.5a) Describe the patterns of warming and/or cooling seen in the map produced for the comparison of summer mean temperatures forecasted for 2071-2100 to the base period 2006-2020. How does the RCP 8.5 emission scenario compare to RCP 2.6?

2.6) From the **Climate Reanalyzer**, Monthly Reanalysis Maps website, create a map that compares the forecasted winter mean temperature in 2071-2100 to the base period of 2007-2020 using the worst-case RCP 8.5 greenhouse gas emission scenario (see image below for input settings). Answer the question that follows.



2.6a) Describe the patterns of warming and/or cooling seen in the map produced for the comparison of winter mean temperatures forecasted for 2071-2100 to the base period 2006-2020. How does the RCP 8.5 emission scenario compare to RCP 2.6?

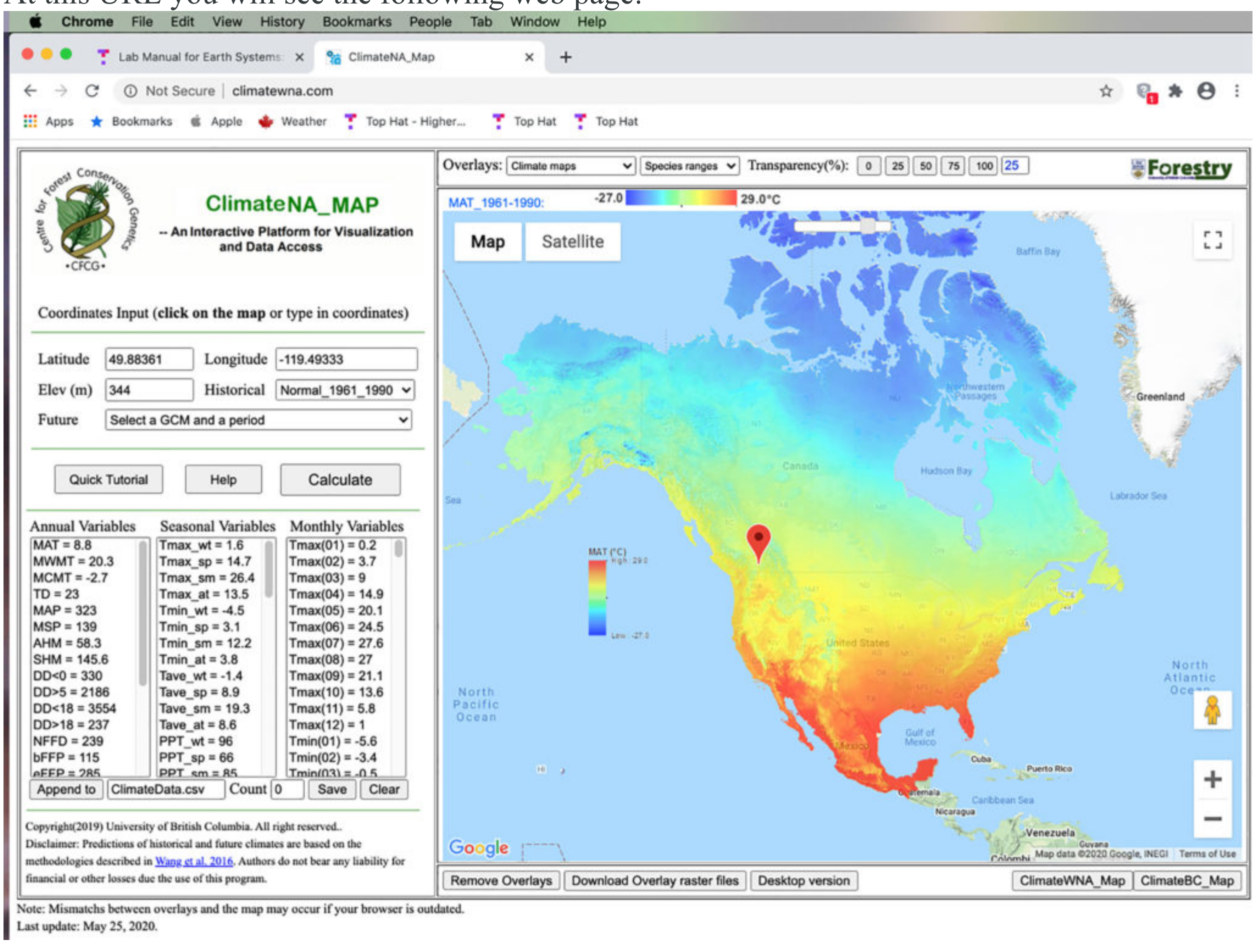
QUESTION 3

ClimateNA is a computer database that can downscale North American climate data to the local level. From this climate database, we can generate historic (1901 to 2019) and future climate data for any location in North America. Future forecasts are based on the output generated from a number of global circulation models programmed with a variety of different greenhouse gas emission scenarios.

The **ClimateNA** computer model can be run from an Internet browser like **Google Chrome**, **Firefox** or **Safari**. To begin this process, you must go to the following URL:

http://www.climatewna.com

At this URL you will see the following web page:



The **ClimateNA** model input window above shows the Normal 1961-1990 output for Kelowna. To run the **ClimateNA** model four pieces of information must be entered: latitude and longitude of the location, the location's elevation, and the *select period (Historical or Future)*.

For the output shown above the *period* selected was **Normal 1961-1990** from the historical drop-down button. Note that a variety of different options can be selected to produce **Historical** output. Historical output can be generated for a single year between 1901 to 2015, or an average for a 10-year period, or an average for a 30-year period.

To generate **Future** output, we need to select the drop-down button labeled **Future**. Once again, a number of options are available. These options include the outputs of three different computer models, three different future greenhouse gas scenarios, and three different future time periods. The following information describes some of the specifics related to these model inputs.

Computer Models

- ***CanESM2*** – a fourth-generation coupled general circulation model (GCM) developed by Environment Canada's Centre for Climate Modelling and Analysis.
- ***CNRM-CM5*** – an earth system model (ESM) developed by Météo-France and the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique.
- ***HadGEM2-ES*** – a second-generation general circulation model (GCM) developed by the United Kingdom's Met Office Hadley Centre.

Future Greenhouse Gas Scenarios

- ***RCP2.6*** – this scenario assumes that the equivalent quantity of carbon dioxide in the atmosphere reaches 490 ppm and that the amount of radiative forcing added to the Earth's climate is equal to 2.6 Wm^2 by the year 2100.
- ***RCP4.5*** – this scenario assumes that the equivalent quantity of carbon dioxide in the atmosphere reaches 650 ppm and that the amount of radiative forcing added to the Earth's climate is equal to 4.5 Wm^2 by the year 2100.
- ***RCP8.5*** – this scenario assumes that the equivalent quantity of carbon dioxide in the atmosphere reaches 1370 ppm and that the amount of radiative forcing added to the Earth's climate is equal to 8.5 Wm^2 by the year 2100.

Future Period

- *2025 (average 2010-2014)*
- *2055 (average 2040-2070)*
- *2085 (average 2070-2100)*

Output from the model is located in three columns on the web page. In the **Annual Variables** column, data for the following calculated variables are shown:

1. **MAT** Mean annual temperature (°C)
2. **MWMT** Mean warmest month temperature (°C)
3. **MCMT** Mean coldest month temperature (°C)
4. **TD** Temperature difference between MWMT and MCMT, or continentality (°C)
5. **MAP** Mean annual precipitation (mm)
6. **MSP** Mean annual summer (May to Sept.) precipitation (mm)

7. **AHM** Annual heat: moisture index (MAT+10)/(MAP/1000))
8. **SHM** Summer heat: moisture index ((MWMT)/(MSP/1000))
9. **DD<0** Degree-days below 0°C, chilling degree-days
10. **DD>5** Degree-days above 5°C, growing degree-days
11. **DD<18** Degree-days below 18°C, heating degree-days
12. **DD>18** Degree-days above 18°C, cooling degree-days
13. **NFFD** The number of frost-free days
14. **FFP** Frost-free period
15. **bFFP** The Julian date on which FFP begins
16. **eFFP** The Julian date on which FFP ends
17. **PAS** Precipitation as snow (mm)
18. **EMT** Extreme minimum temperature over 30 years
19. **EXT** Extreme maximum temperature over 30 years. For an individual year, the EXT is estimated for the 30-year normal period where the individual year is centred
20. **Eref** Hargreaves reference evaporation
21. **CMD** Hargreaves climatic moisture deficit

In the **Seasonal Variables** column, data for the following calculated variables are shown:

1. **TAV_wt** Winter mean temperature (°C)
2. **TAV_sp** Spring mean temperature (°C)
3. **TAV_sm** Summer mean temperature (°C)
4. **TAV_at** Autumn mean temperature (°C)
5. **TMAX_wt** Winter mean maximum temperature (°C)
6. **TMAX_sp** Spring mean maximum temperature (°C)
7. **TMAX_sm** Summer mean maximum temperature (°C)
8. **TMAX_at** Autumn mean maximum temperature (°C)
9. **TMIN_wt** Winter mean minimum temperature (°C)
10. **TMIN_sp** Spring mean minimum temperature (°C)
11. **TMIN_sm** Summer mean minimum temperature (°C)
12. **TMIN_at** Autumn mean minimum temperature (°C)
13. **PPT_wt** winter precipitation (mm)
14. **PPT_sp** spring precipitation (mm)
15. **PPT_sm** summer precipitation (mm)
16. **PPT_at** autumn precipitation (mm)

In the **Monthly Variables** column, data for the following calculated variables are shown:

1. **Tave01 – Tave12** January – December mean temperatures (°C)
2. **Tmax1 – Tmax12** January – December maximum mean temperatures (°C)
3. **Tmin01 – Tmin12** January – December minimum mean temperatures (°C)
4. **PPT01 – PPT12** January – December precipitation (mm)
5. **DD_0_01 – DD_0_12** January – December degree-days below 0°C

6. **DD5_01 – DD5_12** January – December degree-days above 5°C
7. **DD_18_01 – DD_18_12** January – December degree-days below 18°C
8. **DD18_01 – DD18_12** January – December degree-days above 18°C
9. **NFFD01 – NFFD12** January – December number of frost-free days
10. **PAS01 – PAS12** January – December precipitation as snow
11. **Eref01 – Eref12** January – December Hargreaves reference evaporation
12. **CMD01 – CMD12** January – December Hargreaves climatic moisture deficit

3.1) Using the web-based **ClimateNA** model, generate the missing monthly and annual (**Tave** & **MAT**) temperature and precipitation (**Prec** & **MAP**) data associated with the **1961-1990 Normal** and the ***CanESM2* Model** (**CGCM**) and with the ***RCP8.5***greenhouse gas emission scenario for the **period 2085** for Kelowna, British Columbia, Canada. Also, calculate the difference between this future climate state and the 1961-1990 Normal period. Use the Microsoft Word file found in Top Hat called *Lab_7_Question_3.doc* to enter your answers for the table. Send this completed file to your TA or Instructor.

Note that ClimateNA requires that the user hit "calculate" every time the model is rerun.

Temperature (°C) - **Kelowna, Latitude** 49.88361 N, **Longitude** -119.49333 W **Elevation** 344 m

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1961-90 Normal				8.9	13.5	17.7	20.3	19.8	14.7	8.5	2.7	-1.7	
2085 CanESM2 RCP85				15.0	19.9	25.7	31.7	30.3	23.4	14.2	8.3	4.1	
Difference				6.1	6.4	8.0	11.4	10.5	8.7	5.7	5.6	5.8	

Precipitation (mm) - **Kelowna**, **Latitude** 49.88361 N, **Longitude** -119.49333 W **Elevation** 344 m

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1961-90 Normal	35	22	17	21				30	28	20	29	39	
2085 CanESM2 RCP85	41	26	18	26				20	21	25	35	40	
Difference	6	4	1	5				-10	-7	5	6	1	

3.1a) How much snow (PAS) falls annually in Kelowna according to the 1961-1990 output in mm water equivalent?

3.1b) How much snow (PAS) will fall in Kelowna according to the 2085 future forecast in mm water equivalent?

Growing degree days (DD>5) are a measure of the heat available for growing crops. Forage and cereal crops do not grow well at temperatures less than 5 degrees Celsius, so this value is often used as a threshold. Other crops thrive at higher temperatures.

3.1c) How many growing degree days (DD>5) did Kelowna have during the 1961-1990 Normal?

3.1d) How many growing degree days (DD>5) will Kelowna have according to the 2085 future forecast?

Frost-free period (FFP) is calculated as the consecutive number of days between the last day the minimum daily temperature is below 0°C in spring to the first day the minimum daily temperature drops below 0°C in the fall.

3.1e) How long was Kelowna's frost-free period (FFP) during the 1961-1990 Normal?

3.1f) How long will Kelowna's frost-free period (FFP) be according to the 2085 future forecast?

3.2) Using the web-based ClimateNA model, generate the missing temperature and precipitation values forecasted by the ***CanESM2* Model** (CGCM) and with the ***RCP8.5*** greenhouse gas emission scenario for the **period 2085** for Fresno, California, USA. Calculate the difference between this future climate state and the 1961-1990 Normal period and use the annual data to answer the questions that follow. Use the Microsoft Word file found in Top Hat called *Lab_7_Question_3.doc*to enter your answers for the table. Send this completed file to your TA or Instructor.

Note that ClimateNA requires that the user hit "calculate" every time the model is rerun.

Temperature (°C) - **Fresno**, **Latitude** 36.75 N, **Longitude** -119.76666 W **Elevation** 94 m

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1961-90 Normal	7.2	10.2	12.4	15.5	19.8	23.9	27.0	26.0	23.0	18.1	12.0	7.3	16.9
2085 CanESM2 RCP85													
Difference													

Precipitation (mm) - **Fresno**, **Latitude** 36.75 N, **Longitude** -119.76666 W **Elevation** 94 m

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1961-90 Normal	50	44	49	25	7	3	0	0	6	12	35	42	273
2085 CanESM2 RCP85													
Difference													

3.2a) How many growing degree days (DD>5) did Fresno have during the 1961-1990 Normal?

3.2b) How many growing degree days (DD>5) will Fresno have according to the 2085 future forecast?

Cooling degree days (DD>18) are a measure of how much energy may be required to cool homes and buildings. Let us examine how the 2085 forecast will affect the need for air conditioning in Fresno.

3.2c) How many cooling degree days (DD>18), degree days above 18 degrees Celsius, did Fresno have during the 1961-1990 Normal?

3.2d) How many cooling degree days (DD>18), degree days above 18 degrees Celsius, will Fresno have according to the 2085 future forecast?

Heating degree days (DD<18) are a measure of how much energy may be required to warm homes and buildings. Let us examine how the 2085 forecast will affect the need for home heating in Fresno.

3.2e) How many heating degree days (DD<18), degree days below 18 degrees Celsius, did Fresno have during the 1961-1990 Normal?

3.2f) How many heating degree days (DD<18), degree days below 18 degrees Celsius, will Fresno have according to the 2085 future forecast?