Module Two

Open the spreadsheet for module two and click on the tab for the first exercise. Each exercise has two tabs: one for the data and a second with some graphical analysis to help you with your answer these questions.

Exercise One: Recent changes in global temperature

Open the spreadsheet for module two and click on the first tab. This is global temperature anomaly data from NASA, NCDC1 and CRU2.

Column A is the year
Column B is global temperature as determined by the CRU
Column C is global temperature as determined by GISS3
Column D is ocean temperature as determined UK CRU
Column E is ocean temperature as determined by the NCDC

- Look at the global curves and describe how global temperature has changed over the last 100 years.
- Compare the GISS and CRU data. GISS and CRU use different methods to estimate global temperature, what are these and what difference can it make?
- Compare the ocean and land datasets. Discuss any differences you see.
- How fast was the climate warming from 1910 to 1945 and from 1965 to 2010?
- Why is the warming from 1965 to 2010 probably not due to changes in solar activity?

Compare the 1998 values for temperature anomalies on land and in the oceans. Why are these different? What happened this year that made the world warm so suddenly?

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[1] National Climate Data Center
[2] U.K. Climate Research Unit
[3] NASA Goddard Institute of Space Studies

Exercise Two: Temperature change over the last 2,000 years

These data are from two sources. Loehle excludes important tree ring data that has provided so much important information about past climate in other analyses and only includes other proxy sources such as corals, ice cores, lake sediments and stalactites. The second data set from Jones and Mann includes tree ring data. Both data sets have a strong northern hemisphere bias.

- What does this graph represent?
- What is the age range?
- Why would anyone want to exclude data?
- Can you observe the Medieval Warm Period (anomaly) in the data?
- Can you observe the Little Ice Age in the data?
- According to each analysis, was there any time over the previous 2,000 years when global temperatures were warmer than today?
- According to each analysis, was there anytime over the previous 2,000 years when the temperature was rising so fast as over the last 50 years?
- What is the temperature anomaly they measure?
- Do both papers use the same base period for analysis?

Exercise Three: Changes in atmospheric carbon dioxide

This data is from the CO_2 observatory on Mauna Loa in Hawaii.

- What does this graph represent?
- What is the age range?
- Why does the graph show so annual cyclicity?
- Calculate the rate at which CO_2 is increasing.
- Has this been constant over the previous 50 years?
- Given a constant rate of CO_2 production, what will the concentration in the atmosphere be by the years 2100 and 2150?

Exercise Four: Changes in the sun

This table lists sunspot data back to the year 1750 when systematic observations began.

- What does this graph represent?
- How many complete cycles have there been since records began.
- What is the average time between sunspot maxima?
- What year has the record for the largest number of sunspots?
- What year has the record for the lowest number of sunspots?
- Can you spot the Dalton minimum, a time when very cold winter and summer temperatures were recorded in the northern hemisphere?
- What happened to sunspot intensity between 1940 and 1960?
- What was happening to global temperature during this time?

- What has happened to sunspot activity from 2000 to 2010?
- What impact should this have on global temperature?

Exercise Five: Changes in solar irradiance

This data is based on solar proxies (carbon 14 from wood dated by dendrochronology) that estimate the level of total solar irradiance before the time that sunspots were observed directly.

- **Look at the first (upper) graph**
    - What does the first graph represent?
    - What is the age range?
    - Is this data reliable over the full age range?
- Over what period was sunspot activity the most intense?
    - Use data from module one to compare activity over this period with both global temperature and solar intensity due to Milankovitch cycles.
    - Discuss any relationships you discover, and determine what impact these should have had on global climate
    - What was the overall trend in solar intensity between 8,000 years ago and 3,000 years ago?
    - When was the last time the sun was as active as it is today?
    - What was the climate like at that time (use Module One).
- How many prolonged minima with sunspot number lower than 10 can you recognize?
    - How long do these minima last?
    - What impact do they have on global climate?
    - Can you relate any of these periods to important moment in human history?
- **Look at the second (lower) graph**
    - What does the graph represent?
    - What is the age range?
    - Is this data reliable over the full age range?
- What is the general trend in sunspot number from 2,000 to 250 years ago?
    - To help with this exercise, take 20 sunspots as a base line and color everything above 20 and then below 20 with different colors
    - What happens to the frequency of solar minima?
    - Identify the Dalton, Maunder, Spörer, Wolf and Oort solar minima
- Compare the number of sunspots estimated during the Medieval Warm Period with the number today.
    - If the sun were the only factor responsible for climate change what would we expect to see today?
    - If you take Milankovitch cycles into account, does this make any difference? (Also see following exercise).

Exercise Six: Changes in the Earth's Orbit (Milankovitch Cycles)

These data are calculated from knowledge of the regular changes in the Earth's obliquity (tilt), precession (wobble) and orbit (eccentricity) that impact the amount of solar irradiance reaching the top of the atmosphere at a latitude of 65°N of the equator.

- What impact would Milankovitch cycles have had on the climate in the Northern Hemisphere during the Medieval Warm Period around 1,000 years ago?
- What has been happening to the amount of solar insolation arriving at the top of the atmosphere since that time?
- How would this affect global temperature?

Exercise Seven: Changes in the atmosphere and oceans

This is data on the NAO, PDO, ENSO and AMO, a graph of global ocean temperature is included for reference along with diagrams to compare the PDO and ENSO and the frequency of Atlantic Hurricanes.

- What does each graph represent?
- What is the age range of each graph?
- Now look at the PDO data from 1900 to 2010.
    - Describe what you observe.
    - How much variation is there?
    - Try using excel to fit a polynomial to these data
    - How long are the cycles you can observe?
    - When did the changes you observe occur?
    - How does the pattern of the PDO compare to changes in global temperature?
    - Discuss the significance of the PDO data between 1940-1950
- Look at the ENSO data.
    - Describe what you observe.
    - Compare this with the PDO data.
    - Look at the period from 1980 to 2010 and describe the relationship over this period between the PDO and ENSO
- Locate the 1998 ENSO event.
    - How long did this last?
    - Now look at the temperature data.
    - How long did this ENSO event effect global and ocean temperature?
- Look at the NAO data.
    - Describe what you observe?
    - Can you see any clear cyclicity or trend in this data?
- Look at the AMO data
- What is the wavelength of the cycle you observe?
- Use the graph of Atlantic Hurricane frequency and determine
- Which years had more than 4 major hurricanes?

- Which years had fewer than 4 major hurricanes?
- Is there any relationship between this observation and the frequency of intense hurricanes?

Exercise Eight: Net Radiative Forcing

This data is used to estimate the impact of all factors (the total net forcing) on climate.

- What happened in 1883, 1980 and 1991 that caused major negative spikes in forcing of more than -1 Wm^{-2}?
- What is the most likely cause of positive forcing between 1920 and 1960?
- How does the rate of forcing change after 1960?
- What is the probable reason for this change?
- If solar intensity increases, and more greenhouse gases are added to the atmosphere how will the net radiative forcing relative to 1880 change over the next 50 years?