

# NASA Climate Change Education Program

## Module Two Suggested Answers:

### Exercise One: Recent Changes in Global Temperature

- Temperature increased rapidly in two phases over the last 100 years. The first phase, from 1910 until 1945, was followed by thirty years of static or even slightly declining temperature before the temperature started to rise again from 1965 to the present. Note that it wasn't until 1980 that temperatures were again as high as they were in 1945.
- The [GISS](#) and [CRU](#) data match well. They use very similar methods to determine global temperature from measurements taken from ground stations around the world as part of the [Global Historical Climatology Network](#) the United States Historical Climatology Network (USHCN) data, and SCAR (Scientific Committee on Antarctic Research) data from Antarctic stations. In general the CRU data tend to give slightly lower estimates of global warming than GISS because NASA extrapolate data into the Arctic where there are fewer ground stations but warming is most rapid and most apparent.
- The land and surface ocean data are consistent and show the same overall pattern of global temperature change.
- The most rapid rate of climate change is around 1.7°C-2°C per century, but the overall rate of change is just under 1°C per century.
- Climate models are not able to reproduce recent warming using natural causes alone. When man-made greenhouse gases are included in these calculations there is a much closer match with observations.
- Note the temperature spikes in both ocean and land data that correspond to El Niño events such as the major 1997-1998 event. Some of the short-term drops in temperature can be related to volcanic eruptions such as Mount St. Helens in 1980 and Mount Pinatubo in 1991.

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

- Loehle, C. 2007. A 2000-year global temperature reconstruction based on non-tree ring proxies. *Energy & Environment* 18(7-8): 1049-1058. ([Data](#))

- The data from [Jones and Mann 2004](#) Climate Over Past Millennia, Reviews of Geophysics, vol. 42, rg2002, 42 pp., 2004 ([Data](#))
- The range of each data series varies, but when combined they span the last 2,000 years.
- Tree ring data were excluded, because the use of tree ring data tends to reduce the amplitude of the Medieval Warm Period and Little Ice Age temperature anomalies. There is little scientific validity to this method. Excluding valid data introduces unnecessary bias. Some data from the Southern Hemisphere is included, but there is a strong unavoidable Northern Hemisphere bias in most of these constructions.
- The Little Ice Age is clearly visible in both sets of data. It is more likely that this was a period of global climate change, probably related to changes in the intensity of solar irradiance.
- Both data sets show that recent warming exceeds anything observed over the last 2,000 years.
- There were periods of time when the temperature appears to have risen as fast as today, but not for such a sustained period.
- The Loehle graph represents data combined from 18 different proxy sources that was smoothed over 30 years and then plotted as the apparent difference in temperature from the “mean” of each data series.
- The Jones and Mann data represent a broad range of proxies, including tree ring data that are used to estimate global temperature relative to the average over the period from 1961 to 1990
- The papers use different methods to define a base line for temperature change. There is no “right” way to do this, but there are many “wrong” ways that have been used to obfuscate the real temperature trends. Ask your professor to discuss how changing the base period can have a large impact on the climate anomaly, especially when taken over a short period of time. Look out for this “trick” on many climate skeptic blogs and web pages.

### Exercise Three: Changes in atmospheric carbon dioxide

- This [graph represents](#) the level of well-mixed carbon dioxide in the atmosphere over the Island of Mauna Loa in the Pacific Ocean

- The dates range from the 1959 to the present day
- The annual cyclicity is a consequence of seasonal changes in the Northern Hemisphere. There is more land in this hemisphere, and changes in vegetation cover modulate the level of carbon dioxide in the atmosphere
- The rate varies over time, but is around 2ppm/yr
- This has not been constant. It has changed from year to year, but generally increased from less than 1ppm/yr in the 1960s to around 2mm/yr over the last decade
- Given a constant rate of 2mm/yr (probably too low) the level will exceed 570 ppm by the end of this century and more than 670 ppm by 2150

#### Exercise Four: Changes in the sun

- This graph represents the number of sun spots recorded each year since 1750
- The graph shows 23 complete cycles. We are currently on cycle number 24
- The average time between maxima is 11 years
- There were 239 sunspots observed in 1957
- The three cycles following cycle 4 from around 1790 to 1830 were a time of unusually low sunspot activity
- Cycles 16 to 19 show an marked increase in sunspot activity from 1940 to 1960
- Global temperature show no significant increase during this time
- Sunspot activity reduced from 2000 to 2010 at the end of cycle 23. Cycle 24 has been very slow to start and sunspot activity is still very low
- Global temperatures have continued to rise

## Exercise Five: Changes in solar irradiance

### The Graph

- The [Solanki et al](#) graph represents an estimate of how sunspot activity has varied over the last 11,405 years as determined from the level of Carbon 14 recorded in tree rings
- [Data](#) range from 11,405 to the present day
- As with most proxy data, there is increasing uncertainty as age increases

### Sunspot Activity

- Sunspot activity was most intense around 12,000-11,000 years ago and the last time solar activity was as intense as today, was around 8,000 years ago
- Global temperature has fallen over this time due to Milankovitch cycles. Solar intensity at latitude 65°N has been decreasing over the last 10,000 years due to the Earth's obliquity cycle. Changes in solar activity have a demonstrable impact on climate, but appear to modulate the underlying Milankovitch forcing
- These data also show no consistent relationship between sunspot number and millennial scale changes in global temperature. Other data do suggest a better relationship between decadal changes in temperature and the length of each solar cycle. Sunspots do have a short-term impact on climate, this is clear from the impact of solar minima on global temperature, but they do not drive the overall direction of climate change. Until the last century, recent climate change was directed by Milankovitch cycles alone, but is now driven by a combination of Milankovitch cycles, and anthropogenic greenhouse gases. Solar activity will continue to modulate the underlying trend
- Sunspot activity declined markedly over the last 2,000 years only to rise rapidly over the last 150 years following the end of the Maunder Minimum around 300 years ago
- More recent data missing from this exercise show that the sun was last as active 8,000 years ago
- Ice core and other proxy data suggest the temperature was 1-2 °C warmer than today

### Sunspot Minima

- There are at least 18 times in the last 8,000 years when the average number of sunspots fell below 10
- Sunspot minima typically last between 50 and 150 years

- Sunspot minima can be related to short-term periods of colder climate
- It is hard to relate any of these periods to changes in human history with certainty. More recent observations suggest that minima at 2,300, 2,700 and 4,800 years ago should have had an impact on marginal human populations.

### Graph II

- This graph is a record of more recent changes in sunspot number
- The data cover the previous 2,000 years
- More recent data is more reliable and can include early human observations

### General Trend

- The general trend is a slow decline in sunspot number until the end of the Maunder Minimum
- The frequency and amplitude of solar minima (sunspot number below 20) appear to increase over the last millennium
- The named solar minima are indicated on the chart

### Medieval Warm Period

- Sunspot activity was relatively intense during the Medieval Warm Period, and appears to have modulated the underlying global cooling level on at least a regional scale. The Little Ice Age was certainly associated with periods of lower than average sunspot activity
- Based on sunspot activity alone, we should have experienced falling temperatures over most of the last 2,000 years with increasing temperatures over the 250 years following the end of the Maunder Minimum. Over the short term, and in the absence of other factors, we should have experienced slight cooling over the last decade at the end of cycle 23
- The overall cooling observed over the last 8,000 years due to changes in the Earth's obliquity should continue for some time. Natural forcing alone cannot explain recent warming trends. Unusually intense solar activity has certainly contributed to global warming, but cannot explain continued warming during the recent short-term solar minimum. Climate models can only reproduce these trends by combining the impact of anthropogenic greenhouse gases and solar activity

### Exercise Six: Changes in the Earth's orbit

- Changes in the [Earth's obliquity](#) have reduced the amount of radiation reaching the northern hemisphere for the last 10,000 years, and if unchecked, would continue to push the Earth towards a colder climate

### Exercise Seven: Changes in the atmosphere and oceans

- The first graph is global temperature data from [GISS/CRU](#)
- The second graph plots the [Pacific Decadal Oscillation](#) (PDO) index
- The third graph plots the [El Niño Southern Oscillation](#) (ENSO) index
- The fourth graph plots the [Atlantic Multidecadal Index](#)
- The fifth graph is a plot of [data](#) from the [North Atlantic Oscillation](#)
- The data are all post 1900

#### PDO Data

- The data shows a lot of annual variation, but there is a clear underlying cycle
- The PDO varies according to a cycle that appears to last around 20-30 years. The positive phase of each cycle creates an El Niño like temperature profile over most of the Pacific. On a shorter time scale there can be significant reversals of the general trend that can last as much as 5 years
- The last three phases of the PDO correlate with changes in global temperature
- A negative phase of the PDO cycle occurred between approximately 1945 and 1976. This phase coincides very closely with a marked change in the rate of global warming. The PDO cannot explain the underlying trend in global temperature, but (like the sunspot cycle) it appears to modulate the underlying warming trend and could mask this trend for short periods of time

#### ENSO Data

- The ENSO data shows a cycle that seems to occur every 5-7 years and lasts between 6 to 18 months

- There is clearly some relationship between the PDO and ENSO, but this is inconsistent
- Some recent [research](#) suggests the PDO is driven by changes in ENSO

#### 1998 ENSO

- This episode lasted almost two years
- The impact of the 1998 ENSO appears to have lasted slightly longer than the main event

#### NAO Data

- The NAO data is very noisy and shows no consistent long term trend, but can have a very real short term impact on climate

#### AMO Data

- The AMO data varies on a cycle as long as 60 years
- The data on [North Atlantic Hurricanes](#) shows that:
  - During the period from 1950 to 1969 there were 8 years with 4 or more major hurricanes reported
  - During the period from 1970 to 1994 there were no major hurricanes reported
  - During the period from 1995 to 2009 there were 6 years with 4 or more major hurricanes reported
- There is a close correlation between the number of intense hurricanes and the AMO. The current trend suggests that the number of intense hurricanes during the next decade will increase

### Exercise Eight: Net radiative forcing

- There were major volcanic eruptions that had an impact on the stratosphere on these dates. Krakatau erupted in 1882, Nova Erupta (Katmai) in 1912, Mont Pelée 1902, El Chichón in 1982 and Mount Pinatubo in 1991
- The most likely source of positive forcing from 1920 to 1960 is the sun

- The rate of forcing increases again after 1960
- Positive forcing post 1960 is due to a combination of a weakening solar and strengthening anthropogenic effect
- In the absence of major volcanic forcing, net global radiative forcing is expected to increase over the next decade as more greenhouse gases are added to the atmosphere, sunspot activity increases, and less pollution reduces the overall impact of global dimming