

**Project EDDIE: CLIMATE CHANGE**

**Instructor’s Manual**

This module was initially developed by O’Reilly, C.M., D.C. Richardson, and R.D. Gougis. 15 March 2017. Project EDDIE: Climate Change. Project EDDIE Module 8, Version 1. <http://cemast.illinoisstate.edu/data-for-students/modules/climate-change.shtml>. Module development was supported by NSF DEB 1245707.

Overall description: Scientists agree that the climate is changing rapidly and that humans are a primary cause for this rapid change through increased emissions of CO2 and other greenhouse gases to the atmosphere. In this module, students will explore how we know that the climate is changing from both recent record and pre-historic ice-core data and will focus on graphing temporal data to examine these long-term changes.

Pedagogical connections:

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| **Phase** | **Functions** | **Examples from this module** |
| Engagement | Introduce controls on global temperature. Pose questions and allow groups to discussion. Address misconceptions. | Small group discussion. Introductory lecture. |
| Exploration | Engage students in inquiry using authentic data. | Graphing global average air temperatures s and using linear regression to determine a rate of change. |
| Explanation | Engaging with additional information to allow students to develop evidence-based reasoning. | Examining changes in atmospheric CO2. Exploring the relationship between temperature and atmospheric CO2 concentrations. |
| Expansion | Broaden students’ schemata to account for more observations and develop proportional reasoning | Expanding temporally with Vostok ice core datasets. Compare current and pre-historic rate of change and using these for evidence-based reasoning about climate change. |
| Evaluation | Assess students’ understanding formatively and summatively. | Suggested questions to ask during discussion. |

Learning objectives:

* To analyze global temperature data to see if Earth’s average global temperatures are really increasing
* To analyze CO2 data to see if atmospheric levels are really increasing
* To correlate CO2 data with global temperature to see if there is a relationship
* To compare current trends with rates of change during pre-historic periods using ice core data
* To interpret what these results mean for understanding current climate change
* To learn basic shortcuts and graphing in Excel

How to use this module:

This entire module can be completed in one 3 hour lab period or two 50 minute lecture periods for introductory or intermediate level students. If students have experience graphing in Excel, it is possible to complete Activities A and C within a single 70 minute class period, although there is not much time for discussion (this option excludes doing Activity B, which could subsequently be assigned for homework). One option is to have students complete as much as possible in a single class period, complete the rest for homework and to use the subsequent class period for discussion of their results.

## Quick overview of the activities in this module

* *Activity A*: Determine current rates of air temperature and CO2 change from modern datasets.
* *Activity B*: Explore whether temperature and CO2 concentrations are related.
* *Activity C*: Compare current rates to pre-historical rates of change using data from an ice core to investigate how climate has changed in the past.

Workflow of this module:

1. Assign any pre-class readings
2. Give students their handout when they arrive to class
3. Instructor gives brief Power Point presentation with background material. Discussion of the readings can be integrated into this presentation or done before.
4. Students can then work through the module activities.

Potential pre-class readings.

No readings are required for this exercise, but here are some that might be appropriate, depending upon course level and the instructor’s goals.

1. IPCC. 2013. Physical Science Basis, Summary for Policymakers <http://www.ipcc.ch/report/ar5/wg1/>
2. A. Seidl 2010. Early Spring: An ecology and her children wake to a warming world. ‘Chapter 1 (Weather)’ Penguin Random House.
3. Barnola, J. M., et al. 1987. "Historical carbon dioxide record from the Vostok ice core." *Nature* 329: 408-414.

Notes on the student handout:

* The student handout that is included in this module packet was generally designed for a general education science course and to be used in combination with the power point presentation. We recommend that the instructor revise the handout and presentation as appropriate for their own classroom. For example, integrating information from the presentation into the text (such as the overview of trendlines and slope) may be necessary if the instructor does not include this in their lecture. Alternatively, for a more advanced class some material may be removed from the module.
* In this module, the students are asked to download some data directly from the internet. In more introductory-level courses, it may be easier to provide pre-prepared Excel files for students to use. The instructor may also choose to provide the Vostok ice core dataset with the temperatures already calculated rather than have students use the equation tools in Excel.
* No instructions for how to make graphs in Excel are included in the student handout because the steps vary depending upon the operating platform and the version. We recommend that instructors develop a separate handout with general instructions for making a graph in Excel and adding trendlines that show the equation and the R2 value.
* It is particularly helpful to ask students to write their current and pre-historic rates of change on the board as they calculate them. This will allow them to see that different students get different answers, depending upon exactly what data they select, but that the general pattern holds across all results.

**Presentation**

The notes below apply to the slide within the PowerPoint presentation. They are intended to help the instructor think about the key concepts that students need to know. Instructors should alter this presentation to focus on what’s most appropriate for their classroom.

Background information

* Controls on earth’s temperature: Fundamentally, these are the only three things that influence how much energy the earth receives and stores. It is important to identify these, because these are also the only ways we can change the earth’s temperature. Most of the conversation in society is focused on the greenhouse gasses, but there are other examples, either extreme, in practice on small scales, or proposed geoengineering that focus on #1 and #2. For example, ski resorts (and for the 2012 Winter Olympics) cover snow or parts of glaciers with large white reflective sheets to increase albedo and store snow. Additionally, there have been proposals to seed the atmosphere with sulfur aerosols to increase atmospheric albedo, in much the same way a large volcanic eruption does, to reduce the amount of energy reaching earth’s surface.

1. Amount of energy received from the sun
2. There are multiple scales of the earth moving around the sun beyond the daily rotation and annual orbits. These are called the Milankovitch cycles.
3. Shape of the earth’s orbit changes between circular orbit and elliptical every 100k years, due to interaction with gravity from other orbits. The tilt of the earth relative to its plane of orbit oscillates between 22 and 24.5 degrees on a 41k cycle. Precession describes whether the northern hemisphere is tilted away from or towards the sun when the earth is at its furthest point. The Milankovitch cycles are most known for their influence on glacial cycles over the past 500,000 years. Glacial periods have occurred on about a 100,000 year cycle, due to eccentricity.
4. The amount of energy received from the sun also varies depending upon how active the sun is. The sunspots on the sun are bright spots as a result of the sun’s magnetic activity. Sunspots go on about an 11 year cycle between maxima or minima. We have very long records of sunspot activity from personal observations (yes, those people probably went blind), and we have more modern measurements of energy that correlate well with the sunspot count.
5. Reflection of energy

Think about wearing a dark vs. light t-shirt on a really sunny day -which is going to be warmer? Or how fast parking lot blacktop heats up in summer compared to cement sidewalks. Light colors represent the reflection of heat (energy), dark colors represent the absorption. Aerosols in the atmosphere lead to cooling because of energy reflection before reaching earth, and after a large volcanic eruption, the sulfate aerosols lead to 1-2 years of cooler than normal global air temperatures.

1. Atmospheric composition/Greenhouse effect

* Atmospheric composition is the third way that the earth’s temperature is influenced. This is typically described as the greenhouse effect. A good activity could be to get the *students to partner up and draw the greenhouse effect* indicating misconceptions the students may have. Students think they know this, but when you get them to draw it, they realize they don’t really understand it very well. After a short discussion, go on to the next slide. Many students do not identify that it is the returning longwave radiation (heat waves) that are trapped. Solar energy passes through the atmosphere and hit the earth. Some heat makes its way back to space through the gases but some is reflected back to earth. Certain gases are better are trapping and reflecting the energy back to earth. If the earth didn’t have the atmosphere it does, then the earth’s surface temperature would be below freezing and there would be no liquid water (i.e. life).
* This is a good place to talk about lag times - the warming follows the increase in greenhouse gasses. An analogy is covering yourself with a blanket - you don’t instantly feel warm, but gradually become warmer as the blanket traps heat.

Determining rates of change – linear regression and the equation of a line. This section focuses primarily on the background material need in order to extract a rate of change from the dataset.

* To determine the rate of change, it’s easiest to make a graph with time on the x axis and the variable of interest on the y axis.

We will use the linear relationship with 4 components. Recall from high school introductory algebra that:

x = the independent variable, which is in this first data set time (years)

y = the dependent variable, which is in this case average global temperature (oC)

m = the slope of the line which indicates the relationship between the two variables. *What are the units for this?* (oC/year),

b = the intercept of the line with the y axis.

* To understand how well the data fits the line (how good of a model is the equation), we use a statistic call R2. R2 values indicate the spread or variation of the data around the line. Perfect R2=1 means that the independent variable perfectly predicts the dependent variable, typically, biology and environmental science is complex, so there are other factors can contribute to the variation. The instructor could also discuss p-values if the class is advanced enough.

Current changes in temperature and CO2 - this section contains some background information on the datasets.

* Global temperatures – how are they measured? We hear about global warming - what does it mean to have an increasing global temperature? How do we know the global temperature? 1) Data from weather stations around the world are averaged together and interpolated where cover is sparse, and 2) Over the oceans, there are buckets from ships to measure temperatures, buoys, and satellite measurements. These are all averaged together to create a global temperature
* Manua Loa dataset - collection of CO2 concentration in the atmosphere starting in 1958. That method is still continued today along with sensors. Why Hawaii? Because in the USA’s latitude, air flows from west to east. So the air over Hawaii is largely free of local human effects, integrates air happening across the world and is representative of the global air composition.
* It can also be useful for students to look at the correlation between air temperature and CO2 (Activity B). It helps them realize that there are multiple ways to use data to support conclusions. This can be used to talk about correlation vs. causation.

Pre-historic rates of change using ice core data - this set of slides can be used to describe the ice core dataset.

* Put this long-term data record into historical and temporal context, the last glaciation was 10k+ years ago and the planet looked very different at that point
* Some instructors have ‘sent’ their students on a trip to Antarctic to collect the ice cores (and listen to the Metallica concert; Metallica played a concert in Antarctica. Because of sound regulations, the concert had to be heard through headphones only). The data then comes back to them after the cores have been analyzed by their research technician.
* The US has an Antarctic research center on the southern tip of Ross Island which is a New Zealand claimed island in the McMurdo Sound. It is operating via the National Science Foundation and can support over 1000 residents. Werner Herzog made a documentary about the continent and the people at McMurdo in a 2007 documentary called Encounters at the End of the World. Vostok Station (Vostok is Russian for east) lies within Australian territory but close to the geographic south pole at the coldest temperatures measured on earth (-90 C).
* Scientists drill for ice, thousands of meters deep through ice that has been frozen solid for thousands of years. All these cores are carefully collected and stored. There are limited funds to analyze them all but any scientist can get permission to use them for research. You can subsample using thin slices cut by a band saw. Each ice core represents a history of ice at that point. The first 15 meters are snow and in contact with the atmosphere. The next ~50 m are called firn from the Swiss German for last year’s or before. It is snow that has been leftover from past seasons and recrystallized into something denser than snow. Below that is ice and that is isolated from the atmosphere trapping bubbles that represent the atmosphere when the ice was frozen.
* Scientists can measure different things from the air bubbles including carbon dioxide concentrations and isotope ratios in water. The air bubbles are created as snow is gradually compacted over time, trapping in air. Thus, the air in the bubble is actually younger than the ice that surrounds it. The isotope ratios will reflect how water moves around the hydrologic cycle (evaporation), and thus can be converted into temperature.
* Students will download the data and need to convert it into Excel format. They will calculate the temperature from the isotope ratios (or the instructor can prepare the worksheet in advance with this already done.)
* If you want, the students can check to confirm that their ice core-derived temperatures make sense. This is a useful exercise if the students calculate the temperatures themselves from the isotope ratios, or if think there are students who might not think that such calculations are reliable. Get the students to pull up the current weather conditions in Antarctica and think about if that makes sense. There is a weather station at Vostok that is accessible on wunderground, and there are other ways to look at the current weather. The time of year that you look at the current numbers should also be taken into account, because the numbers are not exactly the same as the ice core values. The numbers are all in degrees C but they are low negative values.
* Orientation to the ice-core graphs is a bit challenging, since the x axis does not report time in the same direction as the modern data. To help orient the students, a series of questions are posed in the handout. Determining *whether we are in a glacial or interglacial period* asks students to look for large-scale patterns in the data rather than small-scale ups and downs, asking them to generalize about whether a time period was ‘warm’ or ‘cool’. The last glacial period ended ~15k ago and the last interglacial period was 145k to 115k. Depending upon the course, the instructor can also ask students to identify when *Homo sapiens* evolved (200 thousand years ago) and when *Homo neanderthalensis* went extinct (about 40 thousand years ago) to provide additional context.
* To identify the most rapid rates of change, students will have to make new graphs using only a portion of the data. It is also important for them to consider their units to make sure they are equivalent to the current rate of change and to understand that a negative slope is still a rate of change and occurs because of the direction time is moving in with these data.

Conclusion and evaluation

* *How do we know human activities have contributed to current climate change?* Many students may just assume that human are responsible for current climate change. But they don’t have a good (or any!) reason or logic behind this. By asking them this question, they are forced to confront and recognize their lack of complete understanding of the climate change issue. Have them discuss this in small groups before moving on to the next slide with the answers. Understanding how to use their results from the data to support their answer is a key component of this exercise.
* Fundamentally, these are the 3 main arguments that are used to support a human component to climate change.

1. Correlations. Students often come up with responses that fit into this category, but they don’t use the word ‘correlation’. This is a good opportunity to discuss the difference between correlation and causation. Correlation is a relationship between two variables A and B - there can be weak or strong and positive or negative correlations. However, it could be that A causes B or B causes A or A and B are caused by a third variable C or that it is coincidence that A and B are correlated. Causation is a specific kind of relationship that A causes B. Only where you have evidence or prior knowledge that this is the link should you do a linear regression which indicates cause and effect.
2. Rates of change. If students have compared modern rates of change to the Vostok ice core, then they typically mention rates of change. If they don’t, then maybe they didn’t fully get the main point of the ice core data.
3. Models. The IPCC shows these figures for several regions and globally in the Working Group 1 report. Models have to include humans activities in them in order to match the observed temperature record. Models that just use climate drivers (solar irradiance, albedo, etc), but don’t include human combustion of fossil fuels and other human activities that influence atmospheric composition, don’t reproduce temperature observations. Essentially, this is model validation. If you wanted to project into the future, what model would you want to use?

Optional:

* *Does one extreme weather event dictate climate?* Any recent local weather event could be used. Get the students to discuss this scenario of one really cold and big snow storm. They should be able to use the concepts that the learned in the module to address this. If desirable, the instructor can lead a larger discussion about climate vs. weather. A short video about climate and weather is available here <https://www.youtube.com/watch?v=e0vj-0imOLw&feature=youtu.be> “You pick your vacation based on climate (expected and average values) but pack based on the weather (immediate and short term specific conditions)”

Optional:

* We can put current changes into an even longer context. This graph has temperature and CO2 estimates compiled from a range of different source that go further back in time. *Ask students where the current conditions fall on this graph* (they should know the global average air temperature and CO2 levels from their data). This graph is useful to drive home the fact that temperatures and CO2 have been higher in the earth’s past, so it’s not so much the actual magnitudes that we are concerned about, but the rates of change. Students can even ball-park rates of change off this graph if desired.