**Unit 1 Lecture Notes (3 Parts, 70-75 minutes total class time)**

**Learning goals**

1. Summarize the cause and evidence for anthropogenic climate change.
2. Describe some of the impacts of climate change on people and the environment.

**Part 1. Scientific evidence and consensus for global climate change (20-25 minute Lecture & discussion)**

**Slide 1:** Begin class by asking the students

* what is climate change?
* what causes it?
* what impacts will it have?

In the Student Materials, students are directed to [AAAS climate change consensus site](http://whatweknow.aaas.org/get-the-facts/) as well as and the [National Climate Assessment](http://nca2014.globalchange.gov/) to inform their responses. This is a good opportunity to address common misconceptions identified by the climate literacy assessment or raised by students in class.

Students may mention natural disasters like Hurricane Katrina (top left animation of radar loop), Hurricane Sandy a.k.a Frankenstorm (top right, flooding of the Brooklyn Battery Tunnel; bottom left, flooding of Marblehead, MA), or perhaps the melting of the Arctic ice caps (bottom right, polar bear). Interact with the students by pressing them to provide details and examples. *Suggestion: note ecological, social, or economic consequences in separate columns on the board.*

Then ask the class ***where*** they learned about climate change. *If you’re so inclined, it is very effective to add a collection of climate headlines and the latest memes applied to climate, energy, or environmental issues.* Briefly discuss the importance of social media in dispersing scientific information and misinformation about climate change.

**Slide 2:** Scientists do not make or accept scientific claims lightly. Scientific claims must undergo peer-review, i.e., the process of peer experts examining and validating/disproving the latest research before it is published. This process works well on the Internet with some research journals allowing open and anonymous comment periods. But the average person may struggle to understand the subtlety and complexity of scientific articles. The peer-review process has served science well for centuries; it is the default method for scientists to communicate. **Slide 2** shows an assortment of peer-reviewed climate change articles. Note that the press and social media have increased the speed with which scientific results are dispersed, a benefit, but also allowed the persistence of weak claims that have not been formally reviewed. It can be become difficult to separate truth from baseless claims in popular science.

*The detection and attribution of climate change are based on the strength of the scientific community and voiced through the peer-reviewed literature.*

**Slide 3:** Scientists band together in various societies, including the three listed on **Slide 3**, the American Geophysical Union (AGU), the largest society of earth scientists in the world; the American Meteorological Society (AMS), the principal society of meteorologists; and the American Association for the Advancement of Science (AAAS), the world’s largest scientific society. The statements on **Slide 3** summarize the *consensus* of each society’s members. It is clear that climate change is widely accepted to be not only occurring, but anthropogenic.

Large groups of scientists are also requested to create summary reports that assess the current understanding of a certain topic. Two important assessment reports have been released in the last 3 years: the U.S. National Climate Assessment (NCA) and the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), which is created through two United Nations organizations: the U.N. Environmental Programme (UNEP) and the World Meteorological Organization (WMO). Both assessment reports (US NCA and IPCC AR5) are written by a collection of scientists from industry, academia, and government. The IPCC AR5 is the gold standard; all members of the U.N. must offer approval before publication of the report. Both reports underscore the *scientific consensus* that climate change is occurring and is manmade. *There is no question; scientists have concluded that the warming of the planet is unequivocal*.

***Instructor Side Note***

Temperatures in upcoming slides are displayed as anomalies. An anomaly is the difference from a long-term average or “normal”. Geoscientists commonly use the 1951-1980 period to define the “climate normal”, although 1961-1990 is becoming increasingly popular. **Figure 1** describes the process of producing temperature anomalies from raw data. Notice that the magnitude, trends, and overall shape within the dataset do not change; only the values (y-axis) change. Temperature anomalies are used because of their utility: a single temperature anomaly is valid up to 1200km and protects against changes in station siting and measurement accuracy.



**Figure 1 – Graphical description of a temperature anomaly. Raw test data is plotted on the left for 100 temperature measurements. The right graph shows the same data as an anomaly from the average of the 51st to 80th measurements. The average of the 51st to 80th raw measurements is 16.81; anomalies are calculated by subtracting this number from the raw data, producing an average anomaly of 0.00 over this interval.**

**Slide 4**: Description of IPCC

**Slide 5:** Main conclusion of IPCC

**Slide 6:** When a climate scientist thinks about recent climate change, the first thing s/he pictures is this graph, which shows the increase in global mean surface temperature (GMST) between 1850 and 2016. GMST is the temperature of the Earth; scientists combine more than *5,000* land-station records with observations of ocean temperature to produce the Earth’s average temperature. There are various ways to aggregate available observations to produce an estimate of the Earth’s temperature and the graph shows the results of four *independent* analyses. Links to the research groups are provided below. *Only small differences exist between the four independent analyses.* **Slide 6** shows that the change in temperature (ΔT) between the 1850s and present-day is about ~1.0°C (1.53°F). The magnitude of change differs slightly between the various analyses, but all agree: *Earth is warming*. This warming is *unequivocal* and has been dubbed *global warming*. However, as will be shown, changes in temperature are only one symptom of manmade climate change.

**Slide 7**points out that 2014, 2015, and 2016 are the warmest years on record.

**Slide 8** shows a highlighted result from IPCC report: climate change is anthropogenic. The graph shows three lines:

1. The black line shows observed climate change (same as in **Slide 7**)
2. The blue line shows the climate change simulated by state of the science climate models accounting for only *natural* changes. These natural drivers of climate include volcanic eruptions and changes in the amount of sunlight reaching Earth. Note the blue line is pretty flat, indicating little climate change.
3. The pink line shows the climate change simulated by state of the science climate models accounting for both *natural and anthropogenic* drivers of the climate system. The anthropogenic drivers of climate include increased abundance of greenhouse gases (CO2, methane, N2O, etc.), particulates, and land cover change. Note the pink line follows the black line.

This graph is one line of evidence that climate change is anthropogenic: **we cannot explain our modern climate change without including the influence of humans**. Additional lines of evidence underscore this point. The methodologies of these studies are complicated, but the result is consistent: the expected “fingerprints” of anthropogenic CO2 emissions correspond with many observed climate changes.

**Slide 9** summarizes the scientific consensus on global climate change: 1) We know the climate is changing; 2) We know that it is anthropogenic; and 3) The only way to avoid exacerbated impacts is to reduce CO2 emissions. The graph in **Slide 9** shows this last point with a further application of state of the science climate models. The graph shows projections of future temperature change. The black/gray lines show the historical record as discussed in **Slide 8**, The blue line shows the best case scenario, which envisions a world that drastically reduces CO2 emissions; the red line shows the worst case scenario, a world that allows greenhouse gas emissions to continually rise. The other color bars represent additional potential future CO2 emission pathways. The point here is this: **the range of future climate change depends on current and future decisions about CO2 emission policies.**

**Slide 10:** The troposphere is a thin shell. **Slide 10** shows a cross-section of the atmosphere taken from the International Space Station. The atmosphere is extremely thin; if you could drive a car upwards, you’d be in outer space in about an hour! Most of the discussion of climate change involves the warming of air temperatures and changes in precipitation within the troposphere, the layer of the atmosphere that is colored orange.

**Slide 11:** Emphasize that we’re all together on our one planet Earth. We inhabit a finite area. The atmosphere and climate system connect us.

**Slides 12-14** introduce students to the concept of Earth as a system of connected spheresto make the point that if we influence one component (the atmosphere), impacts will propagate throughout the entire Earth System.

**Slide 12:** The Earth System (all of the Earth) is composed of six components, sometimes labeled as “spheres”, defined by common properties.

1. The atmosphere – The component containing all of Earth’s air and weather

2. The cryosphere – The ice-covered portion of the Earth. Extremely important in regulating the energy absorbed by the Earth from the Sun; has become center stage as Northern Polar Cap becomes smaller and thinner

3. The oceans/lakes/rivers (hydrosphere) – Cover more than 70% of the world. Important in slowing down climate changes through feedback with the atmosphere.

4. The biosphere – Living sector of the Earth, usually focused on living plants that participate in the carbon cycle and evapotranspiration.

5. The geosphere (lithosphere) – The component of solid Earth including the crust and mantle. Very long time scales for change.

6. The anthrosphere – The component of the Earth that has been built by humans (infrastructure)

**Slide 13** shows that all of the Earth System’s components interact with each other. For example, water can evaporate from the ocean (**hydrosphere**) and form clouds and rain (**atmosphere**). Life (**biosphere**) depends on both the temperature of the atmosphere and water from the hydrosphere to flourish.

All of these components are “driven” by the Sun (the **heliosphere**), which is external to the Earth System. Right now, the **anthrosphere** is dramatically impacting all of these “spheres” within the Earth System directly or indirectly.

As just discussed, the Earth System is composed of many “spheres” that interact with each other. Scientists often study or think about one component of the Earth System at a time. However, each component is influenced by and influences the other “spheres”. In order to fully understand changes to the Earth System, we have to understand how such perturbations propagate through each component and influence the entire system. A helpful way is to diagram the interactions between the various components of a system, as seen in **Slide 13**.

**Slide 14:** To encourage ***systems thinking***, ask students: How would a warming atmosphere impact each of the “spheres”?

Answers: less ice, more evaporation, longer growing seasons, accelerated weathering

*We suggest listing responses on the board, potentially grouping them by sphere. If possible, take a picture to insert into subsequent powerpoints.*

**Slide 15:** Transition to Gallery Walk activity.

**Part 2. Impacts of Climate Change (up to 45 minute Gallery walk activity)**

Please see separate gallery walk instructor sheet for this activity.

**Part 3. Summarize with Systems Thinking (5 minute Discussion)**

**Slide 16:** Summarize components discussed in class today. In the following unit, students will be asked to diagram (aka concept map) aspects of the climate system. You can help them along by diagramming on the board what they have learned so far:

carbon emissions 🡪 climate change 🡪 impacts

As shown by the NCA, some of these impacts will be devastating and costly. We’ll get to the costs of climate change later in the module. In the next class, we drill down on the science behind climate change. The climate system will be discussed more thoroughly and the connections between emissions and climate change will be clarified.

**EXTRA SLIDES – OPTIONAL**

The following slides may be inserted above for more advanced or science-oriented courses.

**Slide 18**: Scientists have extremely high confidence that the Earth is warming, but *where* *is the warming occurring?* **Slide 18** shows the change in temperature between 1901 and 2012. Note a couple important aspects of this map: a + indicates a change that is statistically significant, i.e., very certain to have occurred; and white areas indicate locations where there is not sufficient data to calculate a change.

We saw that the GMST had increased by about 1.0°C. This corresponds to the dark orange color in the color scale. However, *warming is not uniform*. There is spatial structure in the warming, with some locations even showing insignificant changes (no + sign).

This is caused by two important considerations:

* *Warming occurs at a slower/faster rate in some locations.* Note that the dark orange color denotes areas with a temperature change comparable to the *global mean surface temperature*. Some areas with a + show smaller changes (lighter colors) and others show larger changes (darker colors). This underscores that some locations may face greater climate change impacts than others. *Note that the largest change is in the Arctic region.* This will be mentioned again later.
* *Natural variations can be significant in some locations.* Natural fluctuations of temperature and precipitation (not shown) occur on many time scales: day, week, month, year, decade, century, and all values between. Such natural changes can temporally obfuscate or exacerbate climate change. Natural variations become less important, but still important, as the spatial scale grows to encompass greater area and longer time periods are examined. For example, climate change is more easily detected on the global scale than in a specific city or region. Also, climate change is more easily observed when using 30-year averages instead of single years.

The southeast US is a good example of natural variations masking the warming effect. This region is particularly sensitive to natural changes in Atlantic and Pacific ocean temperatures.

**Slide 19** shows an example of natural variations. The graph displays the daily temperature measured in Ithaca, NY in 2007. In comparison, **Slide 20** shows the climatological value for each data over-plotted on the same graph. The green line represents 116 years worth of data, while the purple line only uses data from 1 year. Thus, for a particular day, for example April 1, the green line is the average of 116 April 1s, while the purple line is only 1 value. Over such a long period, the “warmer than normal” and “cooler than normal” values average out. **Slide 21:** The 116-year average is thus the climatological condition or what is expected. It is this expectation that is changing; normal year-to-year variability will always exist around this expectation.