**I. BASIC CONCEPTS**

*Introduction.* The course is designed to answer the “a part of/apart from” question, and begins with a discussion of this phrase. Relationship of humanity to Earth Systems; examples of impacts of these processes (tsunami, earthquake) and human impacts (desertification, deforestation, etc). Example of Munch’s “*The Scream*” as a means of discussing impacts of volcanoes on climate, which then leads to a discussion of the General Crisis of the mid-seventeenth century, and then can be turned to a discussion of climate change and current events, such as the possible link between drought and the recent Arab Spring uprisings.

*“When” are we? Geologic Time and Human Evolution”* It is essential that students have a basic understanding of the age of the universe, the Earth, and humanity’s incredibly recent appearance on our planet. Discussion of the newest findings regarding the origins of humanity and our migration across the planet are discussed. The importance of the relatively benign climate of the interglacial period (Holocene) to the success of human civilization is emphasized vis-a-vis potentialities for disruptive anthropogenic climate change. Discussion of rates of change in the context of “human time” versus geologic time.

*“Why numbers matter: population growth”* Concept of linear and exponential growth introduced; introduction to basic demography (birth,death rates; fertility; population pyramids); the trajectory of human population growth; implications of population growth on resources; location of future growth (megacities)—discussion of location of these cities in areas subject to natural forces—earthquakes, volcanoes, rising sea levels. Further discussion of rates of change.

*“The human footprint”* This lecture follows the previous discussion of population growth and focuses on the “IPAT” concept developed by Ehrlich and Holdren (1971), and then moves on to “ecological footprint” as developed by Wackernagel and Rees (1996). Students use online resources to calculate their personal footprint, and then calculate an average footprint for the class. Provides the link between personal consumption patterns and resource impacts. Further discussion of relationship between consumption, population growth, environmental impacts; sustainability; externalities; planetary boundaries

*“And now the Anthropocene”* introduces the concept of the Anthropocene, the various opinions as to when it began, and a discussion of the “Great Acceleration,” the period starting in the 1950’s when virtually all metrics of human modification of Earth System processes begin exponential increases (See Steffen et al. 2015). This is a key lecture, and the concepts of the Anthropocene as outlined in Crutzen (2000) paper are presented. Discussion of rates of change.

**II. TECTONIC PROCESSES**

*“The Earth in motion; plate tectonics*” An understanding of Earth Systems processes requires that students understand plate tectonic theory. Like evolutionary theory for the life sciences, plate tectonic theory is the unifying theory of earth science, and everyone should have a basic understanding of how it works. History of continental drift; development of plate tectonic theory, subduction zones and their relationship to volcanism and seismic activity.

*“Volcanism: much more important than you thought*” This lecture could follow the lectures on earthquakes, discretion of the instructor. Basic explanation of volcanism, emphasis on volcanic activity and its role in extinction events (flood basalts), impacts on climate—discussion of aerosols, global cooling (discussion of the “General Crisis” of the mid-seventeenth century; *cf* Parker (2013)); location of human populations near volcanoes, impacts of volcanic eruptions (lahars, pyroclastic flows).

*“Earthquakes”* These lectures can be arranged in two ways—a first lecture discussing earthquakes and their impacts, followed by a second lecture on the actual mechanisms of seismic activity. I prefer an impact discussion first, then the mechanisms after, but most earth science texts prefer the opposite.

**III. PLANETARY BOUNDARIES (PB)**

**A. PB: Land-system change; biogeochemical flows**

***Production Ecosystems: Terrestrial***

This section of the course uses agriculture, particularly American agriculture, as a means of exploring the intimate relationship between natural processes involving soil and water resources—and human modification of these systems for agricultural purposes. This allows broad discussion of soil systems (“Critical Zone Science”), surface and groundwater flow, human modification (monoculture, irrigation systems), and the links between virtual flows of energy and water that arise from such modification. It further serves as a means of discussion for pollutants—eutrophication, pesticides, herbicides, antibiotics, and persistent organic pollutants.

*“Grass, Baseball, and Iowa; the importance of dirt*” This lecture begins with a discussion of the movie “*Field of Dreams*,” which takes place in Iowa. The movie serves as a metaphor for the theme of repairing the past in order to repair the present. The grassy baseball field, carved out of a corn field (another species of grass) reminds us that the corn replaced the original Great Plains ecosystems, one of the outstanding biomes on the planet. Students learn about the original ecosystem, which was a fire-herbivore dominated landscape that evolved on loess left by the retreating ice sheets. This allows for discussion of climate change, soil development and ecosystem resilience, followed by the destruction of this ecosystem by modern agriculture within 150 years. Norman Borglum, the Nobel laureate and father of the Green Revolution, was born in Iowa. This allows a nice lead-in to a discussion of the importance of the Green Revolution, and its requirements for water, fertilizer and pesticides—the topics of the next series of lectures.

**B. PB: Freshwater Use**

*“Water and Food, the role of groundwater.”* Discussion of basic groundwater principles; importance of groundwater as a critical resource worldwide for agriculture and drinking water. Consequences of groundwater withdrawals; subsidence, etc. Impacts of drought in California’s Central Valley—groundwater withdrawn for agriculture leaves citizens without drinking water. Virtual groundwater transfers; water “footprint”. Water scarcity; cash crops (cotton), biofuels versus food for humans. Possible impacts of a warming climate.

*“Streams and Floods”* Introduction to the hydrologic cycle, stream flow basics, floodplains, deltas. Discussion of stream response to land use change (stream hydrograph); levees; Mississippi River floods.

*“Signature of the Anthropocene: Megadams”* Discussion of dams, particularly megadams as one of the hallmarks of the Anthropocene. Benefits and costs (economic, environmental) of dam construction. Implications of the Grand Renaissance Dam for Ethiopia, Sudan and Egypt.

*“Water Pollution”* Surface water pollutants derived from agricultural related activities; eutrophication; Dead Zones. Groundwater pollution (arsenic and Bangladesh); point and non-point pollution; groundwater plumes and drinking water wells; septic systems and water wells; antibiotics and CAFOs (concentrated animal feed operations) and environmental justice

**C. PB: Novel Entities**

*“Birds, Bees and POP’s*” Historical context of pesticide use; Rachel Carson and DDT; persistant organic pollutants—bioaccumulation and biomagnification. New evidence for epigenetic effects of low-dose exposure of children to pesticides and industrial chemicals. Changing role of pesticides in modern agriculture; genetically modified organisms and pesticides. Glyphosate as an example of herbicide-GMO-human health controversy. Impacts of pesticides on soil ecosystems; neonicotinoids and honeybee colony collapse.

**D. PB: Climate Change**

*Energy and Climate; Significance of Coal*

The final section of the course begins with an exploration of coal, and its role as the critical energy resource of the industrial revolution. Coal exemplifies many problems with energy resource extraction, and can be used to illustrate the link between agriculture, water, energy and climate change. Coal combustion by China, India and other developing nations is likely to overwhelm any decreases by the United States or other countries in carbon emissions. Study of its extraction and combustion illustrate the enormous impact of human activity has on the environment and human health, both at a local, regional and global level.

*“Coal: Burning the past to fuel the future”* Discussion of why coal, and not other fossil fuels. Coal is the primary driver of carbon dioxide emissions and is the most important fuel for electricity production around the globe. Significance of China and India. Historical glance at coal use in England (quotes from Dickens, images of London fog/smog, paintings of Monet); inversions; killer smog of 1952; Donora Pennsylvania; Shanghai, Beijing.

*“Coal: Origins”* Geologic origins of coal deposits, distribution, rank, mining techniques (surface and underground). Discussion of Navajo Generating Station illustrates link between energy, water, agriculture, population growth, pollution. Mountain top mining in West Virginia.

*“Mountaintop Mining”* Readings from *Science* on impacts of MTM. Video on MTM; in-class worksheet that describes environmental, economic, health impacts of MTM on local areas. Linked to on-line Earth Observatory (NASA) imagery and on-line quiz about identifying CT powerplants that use MTM coal.

*Climate Change From the Past to the Future*

1. *“The past as prologue”* Overview of ocean circulation (thermohaline circulation); short-term versus millennial climate change. Ice sheets, glaciers; causes of past global climate change—volcanism, solar activity, plate tectonics, albedo. Study of climate proxies; Milankovitch cycles, greenhouse gases; the Keeling curve.
2. *“Planetary Change in a Warming World”* What do we know? Conclusions from Berkeley Earth regarding carbon dioxide and global temperature increase; rates of increase; where increases are occurring. Impacts: cryosphere (glaciers, ice sheets, sea ice, permafrost), sea level rise; feedback loops.
3. *“What will a warming world look like?”* Recapitulation of temperature/carbon dioxide changes; sea level rise; role of coal, China and India; long residence time for carbon dioxide—locked-in sea level rise and warming; changes in biomes; species distributions. Importance of “tipping points” (Younger Dryas event); discussion of sudden ice sheet disintegration and sea level rise; inundation of coastal areas. Role of renewables. Uncertainty of global climate model projections; Paris conference. Importance of intergenerational equity.

**E. PB: Biosphere Integrity/Extinction; Ocean Acidification**

*Production Ecosystems: Marine*

Discussion of fisheries; unsustainable catch rates; threats to local economies due to unsustainable practices, pollution, hypoxia, plastics; climate velocity exercises illustrating socioeconomic and ecosystem impacts of warming ocean waters on New England fisheries

*A Telecoupled World*

Connecting human and environmental systems at a distance; deforestation in the tropics; Case Study: Pork & Beans—Sino-Brazil soy connection

*The Dark Supply Chain*

Rare Earth Elements; artisanal mining; conflict minerals

**IV. The Moral Imperative of the Anthropocene: Intergenerational Equity and Sustainability**

*“Tragedy of the Commons”; “Our Common Home”; “wicked problems;”* supply chain custody: encouraging human and environmental sustainability

**V. Student Presentations**

Brief oral presentations by each student on their term paper topic.