This chapter discusses the natural cycles of carbon, methane and nitrogen, elements of three of the most potent and harmful greenhouse gases; and how these cycles are being disrupted by human-caused, aka anthropogenic forces. These natural cycles are a complex exchange between the atmosphere, the oceans, and living organisms.

The methane cycle ($\text{CH}_4$) is a relatively short cycle. There are three main contributors that can be the direct result of either human activities or natural processes. They are biogenic, thermogenic or pyrogenic. 

**Biogenic** sources are due to degradation of organic matter in anaerobic conditions (without oxygen, e.g. natural wetlands, ruminants, waste, landfills, rice paddies, fresh waters, termites). 

**Thermogenic** sources come from the slow transformation of organic matter into fossil fuels on geological timescales (natural gas, coal, oil). 

**Pyrogenic** sources are due to incomplete combustion of organic matter (biomass and biofuel burning).

Methane is the most powerful anthropogenic greenhouse gas, trapping 34 times more heat than carbon dioxide. For various debatable reasons, the growth rate of atmospheric methane was declining since the mid 1980’s then stabilized in 1999-2006. Since 2007, atmospheric methane was observed increasing again, which is consistent with anthropogenic emissions. Anthropogenic forces account for 50% of the global methane emissions. Thawing permafrost, agriculture, landfill, sewage and decomposing waste are among the highest contributors.

The nitrogen oxide (NO) concentration increase is due to the growing human population and food demand. Food production is likely responsible for 80% of the current concentration. The use of synthetic fertilizer and manure causes an increase in the amount of nitrous oxide ($\text{N}_2\text{O}$) in soils and after nitrogen leaching and runoff occurs, aquatic systems; even leading to increasing atmospheric nitrous oxide levels. Global emissions of $\text{N}_2\text{O}$ are difficult to estimate due to extreme fluctuations in concentrations. The long atmospheric life span of nitrous oxide implies that it will take more than a century before atmospheric abundances stabilize, even after the stabilization of global emissions.

The carbon cycle is the largest and most complex of the three. There are two main “domains” to this system, slow and fast. Each system can be viewed as a series of reservoirs, carbon holding tanks or carbon “sinks” in the Earth’s system. These include, but are not limited to, the oceans, terrestrial ecosystems and the atmosphere. The fast carbon domain involves the oceans, atmosphere and biosphere. The exchange process through the fast domain can take weeks to centuries. The slow carbon domain is a gradual process that can take millions of years for a natural exchange to occur. This domain consists of carbon fixed in the Earth, e.g. in rocks and buried organic matter located in land or in the ocean seabed. The combustion of fossil fuels and cement production are the largest drivers of carbon dioxide levels. When these are paired with deforestation and land use changes that would normally remove carbon dioxide from the atmosphere, then the atmospheric concentration can increase rapidly.

The carbon cycle is having the biggest effect on natural processes. Humans have moved much carbon from the slow domain, into the fast. For example, fossil fuels take many millions of years to form, and we are burning them in just decades. As a result, the oceans are rapidly acidifying, and the atmospheric carbon concentrations are at an 800,000 year high. This cycle and its disruption will have the longest lasting and most severe repercussions.

Some theoretical possibilities have been proposed to help resolve CO2 concentration levels, called Carbon Dioxide Removal (CDR) and Bio-Geoengineering. CDR is a method to collect atmospheric carbon and store it. There are other natural processes we can utilize, including photosynthesis of land and ocean organisms. Any Bio-Geoengineering processes that we implement must remain active forever, or else all the greenhouse gases they were trapping will be released.
Carbon, nitrogen, and methane cycles have been in flux for much of the Earth’s existence, billions of years. There are many natural processes which can cause an increase in these concentrations. However, when analyzing the climate system, the increase in atmospheric methane, carbon and nitrogen levels are only explained when the human element is considered. We have tipped the Earth’s scales. The natural balance has been altered in unprecedented ways.

Figure 6.1: Simplified schematic of the global carbon cycle. Numbers represent reservoir mass, also called ‘carbon stocks’ in PgC (1 PgC = 1015 gC) and annual carbon exchange fluxes (in PgC yr–1). Black numbers and arrows indicate reservoir mass and exchange fluxes estimated for the time prior to the Industrial Era, circa 1750 (see Section 6.1.1.1 for references).