remain in the atmosphere for decades and longer and that inhibit the escape of longwave radiation are called 'greenhouse gases' (GHGs).

The most common GHG is carbon dioxide, an essential link between plants and animals. Animals produce carbon dioxide and exhale it, while plants absorb carbon dioxide during photosynthesis and store it within their material structures. Plant material decomposes as bacteria and other organisms consume the mass, releasing carbon dioxide back to the atmosphere. In the absence of oxygen, bacteria produce methane, the second most common GHG. Since the advent of the Industrial Revolution, in the mid 18th century, intense and inefficient burning of wood, charcoal, coal, oil, and gas has resulted in increased concentrations of GHGs in the Earth's atmosphere. The use of artificial fertilizers, made possible by techniques developed in the late 19th century, has led to practices resulting in releases of nitrous oxide, another GHG, into air and water. Since the 1920s, industrial activities have applied a number of manmade carbon compounds for refrigeration, fire suppression, and other purposes some of which have been found to be very powerful GHGs (UNEP 2009).

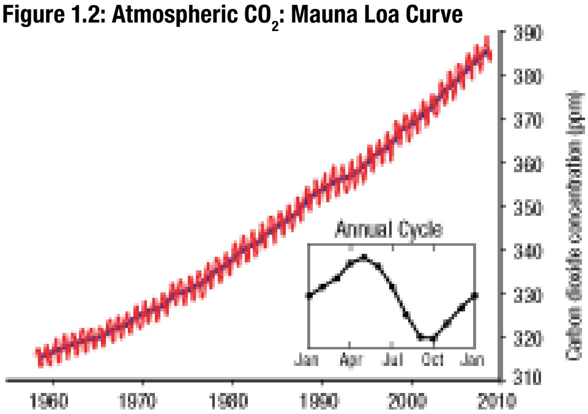
Climate and Earth Systems

In 1957 and 1958, the International Geophysical Year (IGY) produced a coordinated effort to fill gaps in scientific understanding of the Earth using innovative technologies such as rockets, radar, and computers (NOAA-ESRL 2008). Among the many observations and research programmes that originated from IGY, measurements of the gases that comprise the Earth's atmosphere—and the fluctuations in their proportions—provided new insights to the field of study that is now known as Earth System Science.

Measurements of carbon dioxide taken at the Mauna Loa Observatory in Hawaii revealed that the proportion of carbon dioxide in the atmosphere increases during the northern hemisphere autumn and winter and decreases in spring and summer. This cycle tracked the respiration of carbon dioxide when plant matter decomposes during the dormant season and the photosynthesis of carbon dioxide back into plant matter during the growing season. The seasons of the northern hemisphere dominate this cycle because of the overwhelming amount of land in that hemisphere compared to the vast ocean coverage in the south. As observations continued for years and then decades, scientists realized that while the annual variations went up and down, the overall trend of carbon dioxide in the atmosphere was going up (Keeling and Whorf 2005).

Debates among scientists continued, as more and more data were collected and information was extracted from many of the programmes established in the Earth Sciences since IGY. Some of the most intriguing information described the fluctuations of ice sheets across the northern hemisphere for the previous 1.5 to 2.5 million years. Those fluctuations or pulses of ice coverage could last for hundreds of thousands of years, according to measurements of elemental isotope ratios of compounds

Figure 1.2: Atmospheric CO_2: Mauna Loa Curve

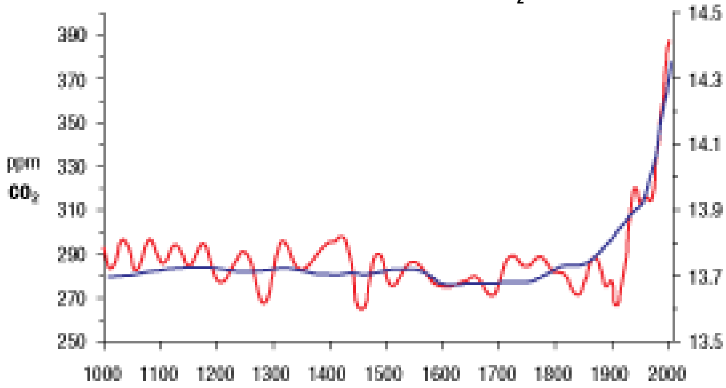


Source: Keeling 2009, Rhode 2009

trapped in coral reefs, ocean sediments, and ice cores. At the same time the atmospheric evidence of the ice pulses was being documented, examination of forcing from orbital variations suggested the Earth could be ending the interglacial period during which human civilization had flourished. But correlations between the curves of carbon dioxide in the atmosphere and the average global temperature appeared to be very strong: Over a 1000-year period, a fairly level trend seemed to start a sharp rise since the late 1800s. Was the climate changing—and, if so, how? And could human activity possible have anything to do with it? To answer such questions, researchers needed to use innovative approaches working with interdisciplinary teams that could incorporate data, information, and knowledge from many sources.

Demand for innovative approaches came from many directions, not the least from multinational environmental agreements. The UNFCCC's Article 2 commits signatory nations to stabilizing greenhouse gas concentrations at levels that prevent dangerous anthropogenic interference with the climate system. This stabilization is to be achieved within a timeframe that is sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner. The debate about what is dangerous anthropogenic interference and what is a sufficient

Figure 1.3: Correlation between temperature and CO_2



Atmospheric CO_2 concentration and mean global temperature during the past millennium. CO_2 levels (blue line, left-hand axis) are given in parts per million, temperatures (red line, right-hand axis) in degrees Celsius. *Source: Hanno 2009*

Box 1.1: Formalizing Earth System Science

At a meeting in 2000 in Amsterdam, scientists from around the world gathered to formally establish an interdisciplinary field of study called Earth System Science. The Amsterdam Declaration on Global Change defines the parameters:

1) The Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological, and human components.

2) Human activities are significantly influencing Earth's environment in many ways in addition to greenhouse gas emissions and climate change.

3) Global change cannot be understood in terms of a simple cause-effect paradigm.

4) Earth System dynamics are characterized by critical thresholds and abrupt changes.

5) Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants.

6) In terms of some key environmental parameters, the Earth System has moved well outside the range of the natural variability exhibited over the last half million years at least.

7) An ethical framework for global stewardship and strategies for Earth System management are urgently needed.

Source: Earth System Science Partnership 2001