CHAPTER 1

Greenhouse Gases and the Carbon Cycle

KEY POINTS

- Global carbon dioxide (CO₂) emissions from fossil fuel burning in 2008 were nearly 40% higher than those in 1990, with a 2.5-fold acceleration over the past 20 years.

- Global CO₂ emissions from fossil fuel burning are tracking near the highest scenarios considered so far by the Intergovernmental Panel on Climate Change (IPCC).

- The fraction of CO₂ emissions absorbed by the land and ocean CO₂ reservoirs has likely decreased by ~5% (from 60 to 55%) in the past 50 years, though uncertainty is large.

GLOBAL CARBON DIOXIDE EMISSIONS

In 2008, combined global emissions of CO₂ from fossil fuel burning, cement production, and land use change (mainly deforestation) were 24% higher than the year 1990 (Le Quéré et al., 2009). Of this combined total, the CO₂ emissions from fossil fuel burning and cement production were 38% higher in 2008 compared to 1990. The global rate of fossil fuel CO₂ emissions has accelerated over the last 20 years, increasing from 1.0% per year in the 1990s to 2.5% per year between 2000 and 2009 (Fig. 1.1). The accelerated growth in fossil fuel CO₂ emissions since 2000 was primarily caused by fast growth rates in emerging countries (particularly China) in part due to increased international trade of goods (Peters & Hertwich, 2008), and an increasing reliance on coal as a fuel source (Raupach et al., 2007). The observed acceleration in fossil fuel CO₂ emissions is tracking the upper-end of the emissions scenarios used by IPCC AR4 (Nakicenovic et al., 2000). In contrast, CO₂ emissions from
land use change were relatively constant in the past few decades, and may have decreased since 2000 (Friedlingstein et al., 2010). Total CO₂ emissions have dropped by 1.9% in 2009 as a result of the global financial recession, but they are projected to increase again by more than 3% in 2010 (Fig. 1.1).

**Carbon Dioxide**

The concentration of CO₂ in the atmosphere reached 389 parts per million (ppm) in 2010 (Fig. 1.2). The atmospheric CO₂ concentration is more than 105 ppm above its natural pre-industrial level. The present concentration is higher than at any time in the last 800,000 years, and potentially the last 3 to 20 million years (Lüthi et al., 2008; Raymo et al., 1996; Tripati et al., 2009). CO₂ levels increased at a rate of 1.9 ppm/year between 2000 and 2009, compared to 1.5 ppm/year in the 1990s. This rate of increase of atmospheric CO₂ is more than 10 times faster than the highest rate that has been detected in ice core data; such high rates would be discernable in ice cores if they had occurred at any time in the last 22,000 years (Joos & Spahni, 2008).
Methane

The concentration of methane (CH$_4$) in the atmosphere increased since 2007 to 1800 parts per billion (ppb) after almost a decade of little change (Fig. 1.2). The causes of the recent increase in CH$_4$ have not yet been determined. The spatial distribution of the CH$_4$ increase shows that an increase in Northern Hemisphere CH$_4$ emissions has played a role and could dominate the signal (Rigby et al., 2008), but the source of the increase is unknown. CH$_4$ is emitted by many industrial processes (ruminant farming, rice agriculture, biomass burning, coal mining, and gas and oil industry) and by natural reservoirs (wetlands, permafrost, and peatlands). Annual industrial emissions of CH$_4$ are not available as they are difficult to quantify. CH$_4$ emissions from natural reservoirs can increase under warming conditions. This has been observed from permafrost thawing in Sweden (see Chapter 5), but no large-scale evidence is available to clearly connect this process to the recent CH$_4$ increase. If the CH$_4$ increase is caused by the...
response of natural reservoirs to warming, it could continue for decades to centuries and enhance the greenhouse gas burden of the atmosphere.

CARBON SINKS AND FUTURE VULNERABILITIES

The oceanic and terrestrial CO$_2$ reservoirs—the “CO$_2$ sinks”—have continued to absorb more than half of the total emissions of CO$_2$. However, the fraction of emissions absorbed by the reservoirs has likely decreased by ~5% (from 60 to 55%) in the past 50 years (Canadell et al., 2007). The uncertainty in this estimate is large because of the significant background interannual variability and because of uncertainty in CO$_2$ emissions from land use change.

Models show that the response of the land and ocean CO$_2$ sinks to climate variability and recent climate change can account for the decrease in uptake efficiency of the sinks suggested by the observations (Le Quéré et al., 2009). A long-term decrease in the efficiency of the land and ocean CO$_2$ sinks would enhance climate change via an increase in the amount of CO$_2$ remaining in the atmosphere. Many new observational studies have shown a recent decrease in the efficiency of the oceanic carbon sink at removing anthropogenic CO$_2$ from the atmosphere in large regions of the world. In the Southern Ocean, the CO$_2$ sink has not increased since 1981 in spite of the large increase in atmospheric CO$_2$ (Le Quéré et al., 2007; Metzl, 2009; Takahashi et al., 2009). The Southern Ocean trends have been attributed to an increase in winds, itself a likely consequence of ozone depletion (Lovenduski et al., 2008). Similarly, in the North Atlantic, the CO$_2$ sink decreased by ~50% since 1990 (Schuster et al., 2009), though part of the decrease has been associated with natural variability (Thomas et al., 2008). As yet, there is no direct evidence of large-scale changes in the efficiency of the terrestrial sink.

Future vulnerabilities of the global CO$_2$ sinks (ocean and land) have not been revised since the IPCC AR4. Our current understanding indicates that the natural CO$_2$ sinks will decrease in efficiency during this century, and the terrestrial sink could even start to emit CO$_2$ (Friedlingstein et al., 2006). The response of the sinks to elevated CO$_2$ and climate change is shown in models to amplify global warming by 5–30%. The observations available so far are insufficient to provide greater certainty, but they do not exclude the largest global warming amplification projected by the models (Le Quéré et al., 2009).
Q & A

Is the Greenhouse Effect Already Saturated, so that Adding more CO₂ Makes no Difference?

No, not even remotely. It isn’t even saturated on the runaway greenhouse planet Venus, with its atmosphere made up of 96% CO₂ and a surface temperature of 467 °C, hotter even than Mercury (Weart and Pierrehumbert, 2007). The reason is simple: the air gets ever thinner when we go up higher in the atmosphere. Heat radiation escaping into space mostly occurs higher up in the atmosphere, not at the surface — on average from an altitude of about 5.5 km. It is here that adding more CO₂ does make a difference. When we add more CO₂, the layer near the surface where the CO₂ effect is largely saturated gets thicker — one can visualize this as a layer of fog, visible only in the infrared. When this “fog layer” gets thicker, radiation can only escape to space from higher up in the atmosphere, and the radiative equilibrium temperature of −18 °C therefore also occurs higher up. That upward shift heats the surface, because the temperature increases by 6.5 °C per kilometer as one goes down through the atmosphere due to the pressure increase. Thus, adding one kilometer to the “CO₂ fog layer” that envelopes our Earth will heat the surface climate by about 6.5 °C.