4.1 Introduction

The elements of carbon, hydrogen and oxygen, and the basic nutrient elements nitrogen, phosphorus and sulphur, are essential for life on earth. The term ‘global biogeochemical cycles’ is used for describing the transport and transformation of these substances in the global environment. In recent decades detailed studies have been carried out on the global biogeochemical cycles of the basic elements, in particular carbon (C), nitrogen (N), phosphorus (P), and sulphur (S) (Bolin et al., 1979; Bolin and Cook, 1983; Bolin et al., 1983; Schlesinger, 1991; Butcher et al., 1992; Wollast et al., 1993; Den Elzen et al., 1995).

Through an intricate web of biogeochemical processes the cycles of elements C, N, P, S are always in a state of disturbance. These changes could be natural, as part of a constant disturbance or variability (like the constant change in solar external forcing, temperature and sea level changes, changes in atmospheric composition over the different glacial-interglacial scales, etc.). However, these changes could also be human-induced, leading to new, extremely fast global environmental changes, as observed over the past decades. The main causes of these changes are the changes in the rates of fluxes and flows of chemicals, gases and other compounds to the compartments water, air and soil. Human activities, like agricultural, industrial, transport and urbanisation activities, but also biomass burning (deforestation), lead directly to changes in the biogeochemical cycles, thereby changing the composition of the atmosphere (e.g. greenhouse gases, stratospheric ozone depleting gases, and toxic pollutants), and the chemistry of aquatic systems and soils (SO$_4$, NO$_3$, PO$_4$, heavy metals, pesticides and...
organic micro-pollutants). Evidently all these changes differ with respect to scales in time (seasonal, yearly, decades till centurial) and space (local, regional, continental till global).

Research has hitherto mainly been focused on separate global cycles rather than on interactions between the various global cycles. It is only in the last decade that a start has been made on quantitative studies of the interactions between the global cycles, using sophisticated compartment models (e.g. Keller and Goldstein, 1994; Hudson et al., 1994; MacKenzie et al., 1992). What is lacking so far, however, is an integrated framework which describes the global cycles of carbon, nitrogen, phosphorus and sulphur: where each originates, where it remains and how the various global budgets can be balanced.

In order to demonstrate how current global environmental problems, and the global climate change problem in particular, could be reconsidered in terms of human disturbances of the various global element cycles, this Chapter discusses the current and future state of the global element cycles. It will be discussed to what extent these global cycles are being perturbed by human activities, in a direct and indirect way, and what the possible future changes could mean in terms of global climate change. Finally, various of the most important interactions between the global element cycles of C, N, P and S are treated.

4.2 The global carbon cycle

4.2.1 Introduction

Among the group of elements essential to life on Earth carbon is the most important one. All life forms on Earth are primarily composed of carbon, so that studying the global carbon cycle in the past and present gives an indication of the comparative state of the biosphere. The natural global carbon cycle encompasses exchanges of CO$_2$, carbonates, organic carbon, etc., between three reservoirs: the atmosphere, the hydrosphere, and the terrestrial biosphere, of several billions of tonnes of carbon per year (see Figure 4.1).

The anthropogenic increment of carbon due to the burning of fossil fuels and changing land use is disturbing the balance of the global carbon cycle, which will ultimately change the Earth’s climate (Intergovernmental Panel on Climate Change (IPCC), 1990, 1992, 1994, 1995).