Chapter 1
Climate Change as a Global Problem

1.1. Today's vision of climate change: principal conclusions from the IPCC Assessment Reports

1.1.1 Understanding of human-induced climate change

Many definitions for climate change have been developed; however, the recognized authority on climate change research, the Intergovernmental Panel on Climate Change (IPCC), believes that to understand a complex subject such as climate change, one must first understand the meaning of *climate*. According to the IPCC definition (IPCC, 2007d, p. 871), "Climate in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years". The 'relevant quantities' are most often surface variables such as air temperature, precipitation and wind; the classical period for averaging is 30 years as defined by the World Meteorological Organization (WMO). In a wider sense, climate *"*is the state, including a statistical description, of the climate system*"*. The latter is the highly complex system consisting of five major components – *atmosphere, hydrosphere, cryosphere, land surface and biosphere* – as well as of the interactions between them. The following figure from the IPCC Third Assessment Report (IPCC, 2001b) aids the understanding of how these five components interact (Fig. 1.1).

The scientific understanding of the global *climate system* has greatly improved since 1900. However, until the 1960s the study of climate 'history' was mainly viewed as a specialized part of Atmospheric Sciences and Geography disciplines. In the early 1970s climate came into focus as a global issue. Ironically, several articles and books which appeared around this time suggested the beginning of global climate cooling, sparking scientific and public concern that the Earth was moving to a new Ice Age. Glantz and Adeel (2000) explained this phenomenon by stating that the period from the 1940s to the early 1970s was cooler than the long-term average for the previous decades. Several additional examples supported this theory of global cooling. A list of subtle environmental changes reinforced the global cooling hypothesis, in particular an unusual inter-annual variability, coupled with famines in Africa in the early 1970s. The reanalysis of the climate system behavior began in the mid-1970s, opening a debate about the stability of the global climate. During the 1980s, scientific interest in the climate change issue grew significantly, resulting in the United Nation Framework Convention on Climate Change (UNFCCC) and the creation of the IPCC, although each had its own area of study (Box 1.1).

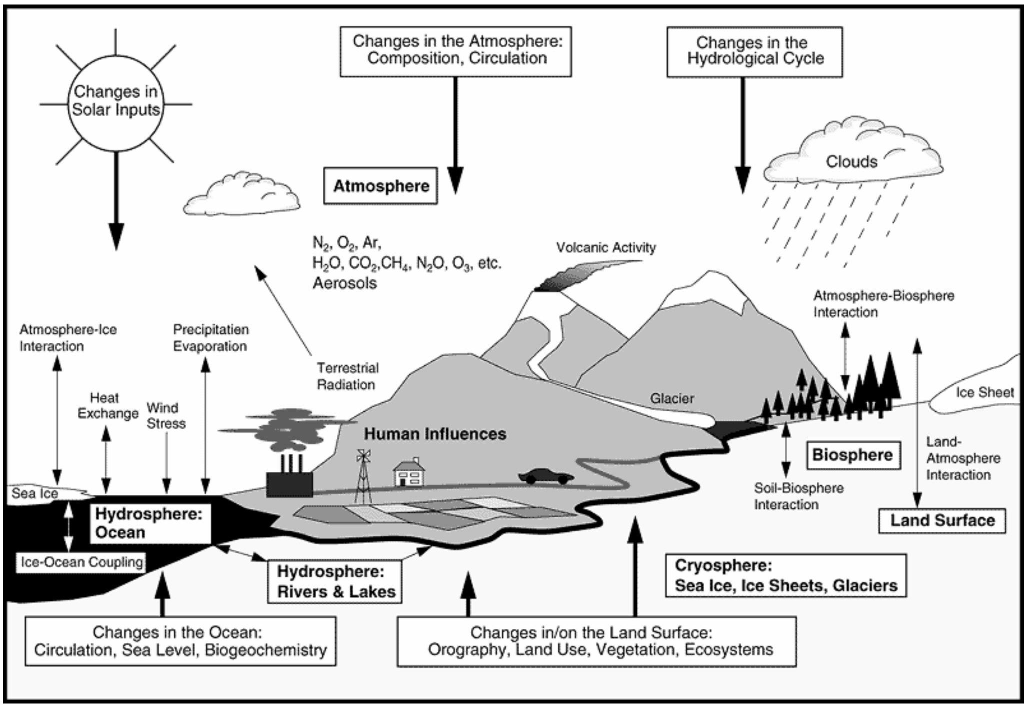

Fig. 1.1 Schematic view of the components of the global climate system *(bold),* their processes and interactions *(thin arrows)* and some aspects that may change *(bold arrows)*. *Source*: IPCC, 2001b

Box 1.1 Definitions of climate change

The IPCC refers *climate change* to a change in the state of the *climate* that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural *internal processes* or *external forcing*, or to persistent *anthropogenic* changes in the composition of the *atmosphere* or in *land use*.

The UNFCCC defines *climate change* as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. Thus, the UNFCCC makes a distinction between climate change attributable to human activities altering the atmospheric composition, and *climate variability* attributable to natural causes.

Source: IPCC, 2007b

As is well known, the global mean climate is determined by incoming energy from the Sun, the properties of the Earth and its atmosphere, namely through reflection, absorption and emission of energy within the atmosphere (Fig. 1.1). Any change in the amount of solar energy inevitably affects the Earth's energy budget; however, Earth's atmosphere and the planet surface also are important and may be affected by climate feedbacks (Solomon *et al.,* 2007). The character of astrophysics and celestial mechanics (cyclic variations of solar radiation flux, variations in elements of the Earth's orbit, e.g., eccentricity, longitude of perihelion or obliquity of the ecliptic), in combination with the nonlinearity of the Earth's climate system, induce natural variations in climate and form a baseline for its change

(Semenov, 2004). In addition to its own internal dynamics, the climate system is evolving over time under the influence of *external forcing,* such as volcanic eruptions.

The global climate has always varied naturally, but compelling evidence from around the world indicates that a new kind of change in climate is now under way, foreshadowing the drastic impacts on people, ecosystems and economies (IPCC, 2007a).

The Fourth Assessment Report of IPCC (hereinafter AR4) confirmed previous IPCC assessments that *anthropogenic (or human)* forcing, caused by the changes in several aspects of the atmosphere and the Earth surface (e.g., in a land-use practice, which transforms landscapes and leads to changes in albedo), alter the global energy budget and therefore can cause the climate to change (Solomon *et al.,* 2007). Among these changes are increases in greenhouse gas (Box 1.2) concentrations that act primarily to increase the atmospheric absorption of outgoing radiation, and increases in aerosols (microscopic airborne particles or droplets) that act to reflect and absorb incoming solar radiation and change cloud radiative properties. Such changes cause a radiative forcing[1] of the climate system. Forcing agents can differ considerably in their magnitudes of forcing, as well as spatial and temporal features. Positive and negative radiative forcings contribute to increases and decreases, respectively, in global average surface temperature.

The dominant factor in the radiative forcing of climate is the increasing concentration of various GHGs in the atmosphere. It is well known that the Earth's ability to support life – human societies – is influenced by the level of GHGs that envelop our planet, warm its surface, and deteriorate the atmosphere that protects us from harmful radiation. The warming effect of GHGs, referred to as the *greenhouse effect,* maintains a habitable climate, accounts for human, animal and plant life on the Earth and explains its absence on other planets of our solar system. For example, the abundance of GHGs on the planet Venus makes it too hot for human habitation, but the low levels of GHGs on the planet Mars make it too cold for life. Earth's temperature, like

Box 1.2 Greenhouse gases

Greenhouse gases (GHG) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the *greenhouse effect*. Water vapor (H_2O), *carbon dioxide* (CO_2), *nitrous oxide* (N_2O), *methane* (CH_4) and *ozone* (O_3) are the primary GHG in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHG in the atmosphere, such as the *halocarbons* and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the *Kyoto Protocol* deals with *sulfur hexafluoride* (SF_6), *hydrofluorocarbons* (HFCs) and *perfluorocarbons* (PFCs) greenhouse gases.

Source: IPCC, 2007b

1 *Radiative forcing* is the change in the net vertical irradiance at the tropopause due to an internal or external change in the forcing of the climate system, such as a change in the concentration of CO_2 or the output of the Sun. *Radiative forcing* is also a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the factor importance as a potential climate change mechanism. Positive forcing tends to warm the surface, while negative – to cool it. In AR4, radiative forcing values are for changes relative to a pre-industrial background at 1750, are expressed in Watts per square metre (W m^{-2}) and, unless otherwise noted, refer to a global and annual average value (IPCC, 2007a, b)

Goldilocks' porridge[2], is just right (Rosa, 2001). However, if the level of GHGs on Earth will become too high, the resulting overall rise in air temperatures – *global warming* – is liable to disrupt natural patterns of the Earth's climate.

Some GHGs occur naturally; however, increases in their atmospheric concentrations over the last 250 years are largely due to or entirely the result of human activities. Several industrial, economic and residential activities were thought to be contributors, including the heavy use of fossil fuels, tropical deforestation, formations from precursor species emitted to the atmosphere (as a refrigerant and foam-blowing agent), and so on. Levels of CO_2 and other GHGs in the atmosphere have risen steeply spurred by economic and population growth as well as by new tendencies in global socio-economic development (UNFCCC, 2005). Nijkamp and Verbruggen (2003) have found several megatrends that are likely to act as drivers in the occurrence of global warming. Because this list is almost endless, depending on the disciplinary angle taken, the authors selected eight driving forces which are directly linked with human behavior patterns. In Table 1.1 they are presented along with AR4's list.

Table 1.1 Two lists of assumed socio-economic drivers of anthropogenic climate change

AR4 Synthesis Report (IPCC, 2007a)	*Nijkamp and Verbruggen* (2003)
• governance	• institutional change
• technology	• internationalization and economic integration
• trade	• rapid technological progress
• production and consumption patterns	• the emergence of a knowledge economy
• socio-cultural preferences	• improvement of transport systems
• population	• demographic development and transformations
• literacy	• cultural shifts
• equity	• international business strategies
• health	

The identified megatrends portray a global economy where Western patterns of energy-intensive production, modes of consumption and transport spread rapidly across countries (Box 1.3). The risk of further danger climate change is even greater if the global economy locks itself into this energy-intensive trajectory with high energy demand.

However, some megatrends contain the seeds of change. A shift is occurring in economic structures away from manufacturing towards the service sector. This transition in the developed world will gradually emerge in developing and transitioning countries as further economic development proceeds. The service economy is transforming into a knowledge economy and information society. There are indications that the knowledge economy will spread worldwide at a much faster pace that any previous technological trajectory[3]. These major transformations are supported by the promise that rising global

[2] *The Goldilocks Principle* or '*Goldilocks effect'* states that something must fall within certain margins, as opposed to reaching certain extremes. It is used, for example, in the Rare Earth hypothesis to state that a planet must neither be too far away nor too close to the Sun to support life (See: *http://en.wikipedia.org/wiki/Goldilocks_Principle*)

[3] "The continuing adoption of advanced information, communications technologies and of more open, market-based economic policies has led to further integration of the world economy, accelerating

Box 1.3 The Dynamics of World Energy Production

Industrialization, more goods and better living standards were only possible because new sources of energy became available. In 1860 the consumption of coal as an energy source represented about 100 million tons per year; today we use more than 5 billion tons of coal per year. In recent years, the world has seen a movement to a new path of rapid global growth, largely driven by the developing countries which are energy intensive and heavily reliant on the use of coal. It was anticipated that global coal use would rise by nearly 60% from 2000 to 2010. In 1870 world oil production was less than 1 million tons per year, whereas today it exceeds 3 billion tons. In 1938, world gas production was less than 60 billion m^3 per year; now it is more than 2 trillion m^3, and still on the rise. For each of these three primary energy sources a roughly exponential increase in consumption has been observed since the years 1800 (coal), 1860 (oil) and 1940 (gas). This increase practically matches an exponential increase in the world's population: about 1 billion in 1750, 1.5 billion in 1860, 2.6 billion in 1950, 5.5 billion in 1990, and more than 6.8 billion in 2010. It is likely that, without changes to the policies in place, global CO_2 emissions from fuel combustion will nearly double their 2000 level by 2020 and would continue to rise.

Source: Bennewitz, 2009; Sheehan *et al.*, 2008

welfare will lead to a greater emphasis and concern for the environment in the interest of future generations. The potential to fully make a shift to a knowledge economy on a worldwide level is impressive, but this potential still has to be realized. Developing this idea further, the IPCC in AR4 (IPCC, 2007a) also pointed out that if at the time of its Third Assessment Report (IPCC, 2001), in the late 1990s, information was mainly available to describe the anthropogenic climate change driver–impact–response linkages clockwise, i.e. to derive climatic changes and impacts from socio-economic information and emissions, then with increased understanding of these linkages it became possible to assess them counterclockwise, or to evaluate possible development pathways and global emissions constraints that would reduce the risk of future adverse impacts.

The current concentration of GHGs is the net result of past emissions into the atmosphere, partially compensated by chemical and physical removal processes. With the important exception of CO_2, it is generally the case that these processes remove a fraction of the total amount of a given gas, depending on its mean lifetime. In some cases, the removal rate may vary with the gas concentration or other atmospheric properties (e.g., temperature or background chemical conditions).

The contribution of each GHG to radiative forcing over a particular time period is determined by the change in its atmospheric concentration and its effectiveness in disturbing the radiative balance. Long-living GHGs, for example, CO_2, CH_4 and N_2O, are chemically stable and stay in the atmosphere over time scale ranging from a decade to centuries and longer. Because these gases are long-living, they are well and much faster mixing throughout the atmosphere. Given this ability, their global concentrations can be accurately estimated from data at a few locations. CO_2 does not have a specific lifespan because it is continuously cycled between the atmosphere, oceans and land biosphere, and its net removal from the atmosphere involves a range of processes with different time scales. Short-lived gases (e.g., sulfur dioxide and carbon monoxide) are chemically

technological change and sustained rapid growth in countries such as China and India. This is a well-documented process, often referred to as the rise of the new economy or of the global knowledge economy. Sustained, higher than expected global economic growth has produced much greater energy demand than markets, providers and analysts have anticipated" (Sheehan *et al.*, 2008)

Box 1.4 Treatment of uncertainty in IPCC AR4

Different approaches are used to describe uncertainties in the IPCC assessment outputs, each with a distinct form of language. Choices among and within these approaches depend on both the nature of the information available and the authors' expert judgment of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterized by providing a relative sense of the amount and quality of evidence and the degree of agreement through a series of self-explanatory terms such as: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence*; etc.

Where uncertainty is assessed more quantitatively, using expert judgment of the correctness of underlying data, models or analyses, then the following scale of ***confidence levels*** is used to express the assessed chance of a finding being correct: *very high confidence* – at least 9 out of 10 chance*; high confidence* – about 8 out of 10; *medium confidence* – about 5 out of 10; *low confidence* – about 2 out of 10; and *very low confidence* – less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), then the following ***likelihood*** ranges are used to express the assessed probability of occurrence/outcome: *virtually certain* – >99% probability of occurrence; *extremely likely* – >95%; *very likely* – >90%; *likely* – >66%; *more likely than not* – > 50%; *about as likely as not* – 33% to 66%; *unlikely* – <33%; *very unlikely* – <10%; *extremely unlikely* – <5%; *exceptionally unlikely* – <1% probability.

Working Group II has used a combination of *confidence* and *likelihood* assessments, while Working Group I has predominantly used *likelihood* assessments.

Unless otherwise stated, the numerical ranges, usually given in square brackets, indicate 90% uncertainty intervals (i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range). Uncertainty intervals are not necessarily symmetric around the best estimate.

Source: IPCC, 2007a

reactive and generally are removed by natural oxidation processes in the atmosphere, their removal at the earth's surface or by washout during precipitation; as a result, their concentrations vary significantly.

New observations and related modeling of GHG emissions, solar activity, land surface properties and some aspects of aerosols have led to improvements in the quantitative estimates of radiative forcing (IPCC, 2007b). Given the colossal amount of work completed by international researchers on this subject, it is not necessary to 'retell' their work. The following is a brief summary of the IPCC's principal conclusions, as well as their uncertainties (Box 1.4) based on the *Summary for Policymakers of the Contribution of Working Group I* to AR4.

On the whole, it has shown that as a result of human activities, global atmospheric concentrations of long-living GHGs have increased markedly relative to pre-industrial conditions, defined as of 1750, and now far exceed values determined from ice core samples spanning many thousands of years. In particular:

- The atmospheric concentration of CO_2 has increased from a pre-industrial level of about 280 ppm[4] to 379 ppm in 2005. The latter exceeds by far the natural range over

[4] *ppm* (parts per million) or *ppb* (parts per billion) is the ratio of the number of GHG molecules to the total number of molecules of dry air

the last 650,000 years (180 to 300 ppm). The annual CO_2 concentration growth rate was larger during the last 10 years (1995–2005 average: 1.9 ppm per year) than it has been since the beginning of continuous direct atmospheric measurements (1960–2005 average: 1.4 ppm per year), although there is year-to-year variability in the rates of growth. The primary source of this increased concentration results from fossil fuel use; land-use change provides another significant but smaller contribution.

- The global atmospheric concentration of CH_4 has increased from a pre-industrial value of about 715 ppb to 1774 ppb in 2005, also exceeding by far the natural range of the last 650,000 years (320 to 790 ppb). It is *very likely* that the observed increase is due to anthropogenic activities, predominantly agriculture and fossil fuel use, but relative contributions from different source types have not been well determined.
- The global atmospheric N_2O concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The growth rate has been approximately constant since 1980; more than a third of all nitrous oxide emissions are anthropogenic and primarily due to agriculture.
- The combined radiative forcing due to increases in these three gases is +2.30[+2.07 to +2.53]W m^{-2}, and the rate of increase during the industrial era is *very likely* to have been unprecedented in more than 10,000 years. CO_2 radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years.
- Significant anthropogenic contributions to radiative forcing come from several other sources. Tropospheric ozone changes due to emissions of ozone-forming chemicals contribute +0.35[+0.25 to +0.65]W m^{-2}. Changes in surface albedo, due to land cover changes and deposition of black carbon aerosols on snow, exert average respective forcings of –0.2 and +0.1 W m^{-2}.

1.1.2 Evidences of the recent climate change

1.1.2.1 The Global Picture

The most principal AR4 conclusion is: *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level"* (IPCC, 2007b, p.5). Progress in understanding how climate is changing has been gained through improvements and expansion of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties and a wider variety of measurements.

In particular, it was stated by IPCC (2007a) and in recent publications that:

1. In addition to observed changes in global average surface temperature shown in Fig. 1.2, twelve of the last thirteen years (1995–2007) rank among the thirteen warmest years in the instrumental record of global surface temperature since 1850. A century (1906–2005) linear trend of 0.74[0.56 to 0.92]°C is larger than the corresponding trend of 0.6[0.4 to 0.8]°C in 1901–2000. The trend over the second part of 1906 to 2005 period (0.13°C per decade) is nearly twice that for the first 50 years. Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least