

CE 435: Environmental Pollution Management

**January 2018 Semester
Level-4, Term II**

CN-7

**Department of Civil Engineering
Bangladesh University of Engineering and Technology
(BUET)**

Climate Change

CLIMATE CHANGE and IPCC

Much of the recent information on climate change comes from the studies and reports of IPCC, the Intergovernmental Panel on Climate Change.

The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to:

- Assess available scientific information on climate change,**
- Assess the environmental and socio-economic impacts of climate change, and**
- Formulate appropriate response strategies.**

CLIMATE CHANGE and IPCC

IPCC represents opinions of hundreds of world's best scientists in the field from over 60 countries. So far, IPCC has published 5 assessment reports:

- **First Assessment Report (1990), Supplement 1992**
- **Second Assessment Report (SAR, 1995)**
- **Third Assessment Report (TAR, 2001)**
- **Fourth Assessment Report (AR4, 2007)**
- **Fifth Assessment Report (AR5, 2013)**

AR5 Observations

Changes in Atmosphere:

In 2011, the atmospheric concentrations of the greenhouse gases CO₂, CH₄, and N₂O were 391 ppm, 1803 ppb, and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively.

| | <u>2005 (AR4)</u> | <u>2011 (AR5)</u> |
|------------------------|-------------------|-------------------|
| CO ₂ (ppm) | 379 | 391 |
| CH ₄ (ppb) | 1774 | 1803 |
| N ₂ O (ppb) | 319 | 324 |

Warming of the Planet:

The globally averaged combined land and ocean surface temperature data show a warming of 0.85 [Range: 0.65 to 1.06] °C, over the period 1880 to 2012.

Climate Change Trends in Bangladesh

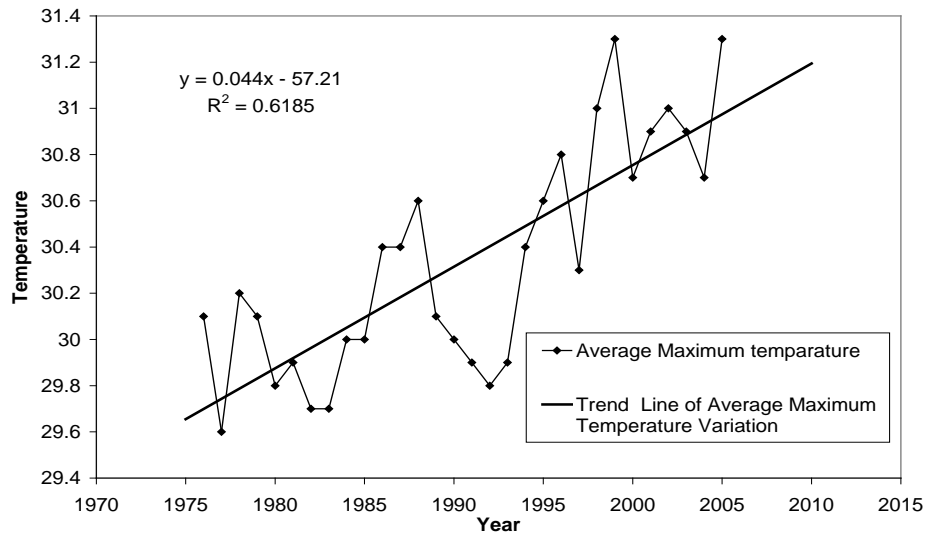
Changes in Temperature:

- Annual average maximum temperature increased by 0.58 °C during 1976-2005.
- Annual average minimum temperature increased by 0.46 °C during 1976-2005.

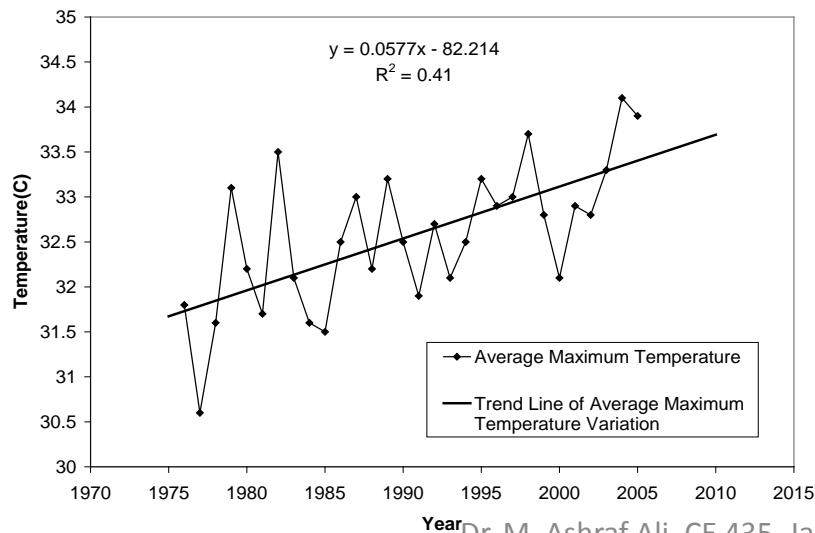
Changes in Precipitation:

- Majority of weather stations showed increasing trend of total rainfall during Monsoon (January to September) and Post-monsoon (October-November).
- Significant number of weather stations showed decreasing trend of total rainfall during Winter (December to February)

Climate Change Trends in Bangladesh



Variation of annual average maximum temperature in Chittagong



Variation of average maximum temperature in May in Cox's Bazar

Climate Change and Temperature

- The common definition of climate suggests that it is the prevailing or average weather of a place as determined by temperature and other meteorological conditions over a period of years.
- **“Average temperature” is one important measure of climate. Other important parameters include precipitation, winds, glaciations, and frequency of extreme events such as typhoons and hurricanes.**
- Long-term variation in average temperature is, however, the single most important attribute of climate change.

The "Greenhouse Effect"

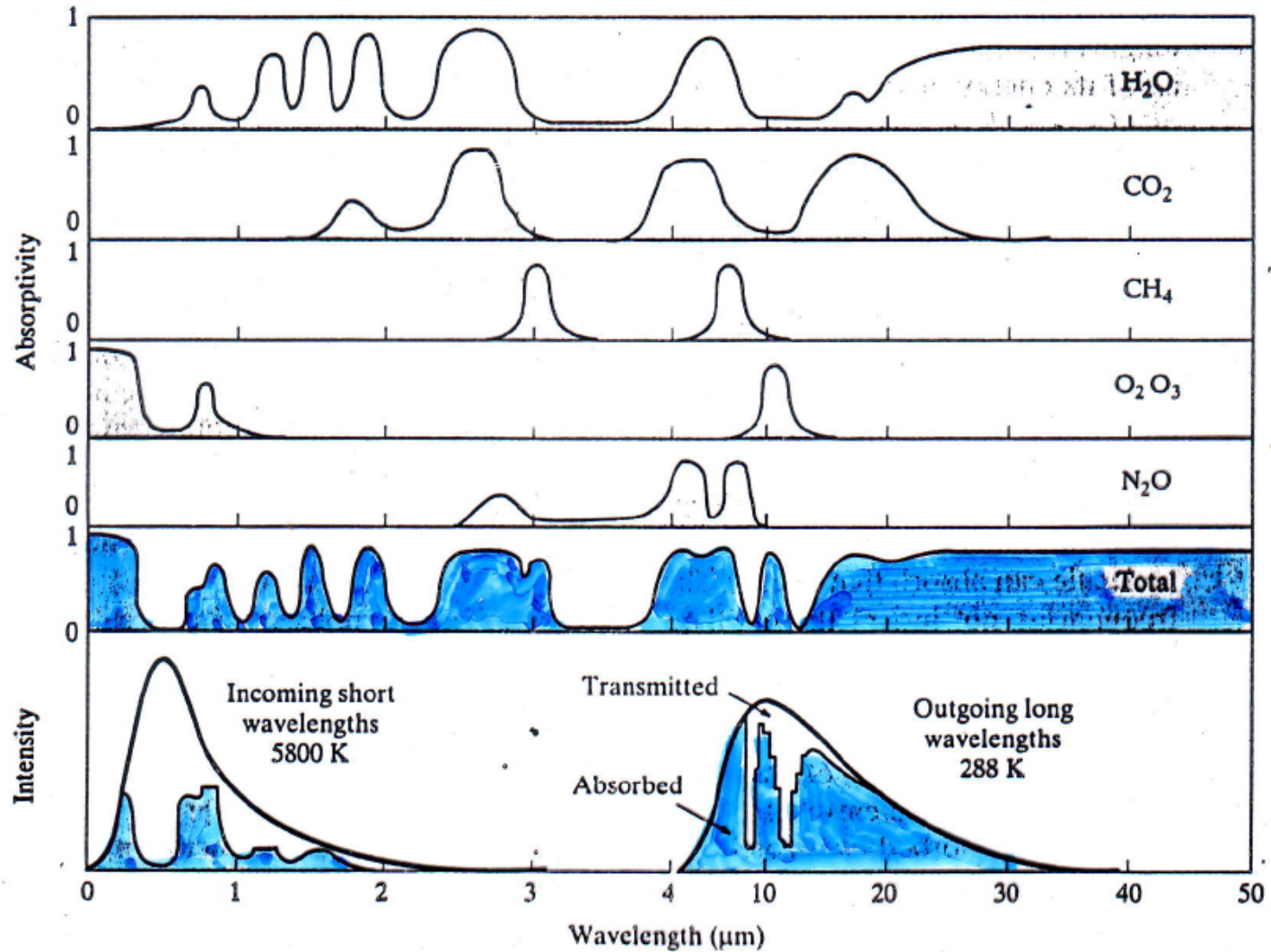


FIGURE 8.11 Absorptivity as a function of wavelength for water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), oxygen and ozone (O₂, O₃), and nitrous oxide (N₂O), and the total absorptivity of the atmosphere. Shown here are the spectra for incoming solar energy and outgoing thermal energy from the 288 K surface of the earth. Note the wavelength scale change at 4 μm . Dr. M. Ashraf Ali, CE 435, January 2017

The “Greenhouse Effect”

- Radiatively active gases that absorb wavelengths longer than $4 \mu\text{m}$ are called “greenhouse gases” or GHGs. This absorption heats the atmosphere, which in turn, radiates energy back to the earth as well as out to space, as shown in Fig. 8.12.

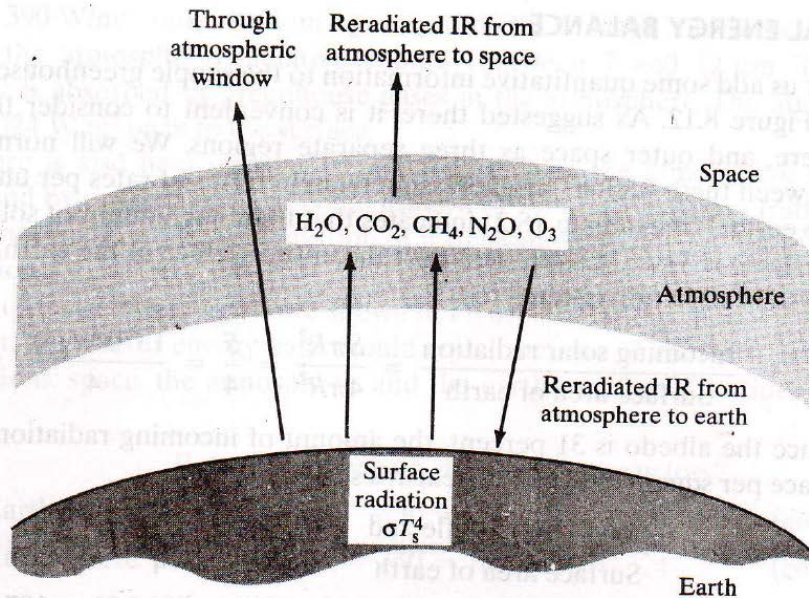


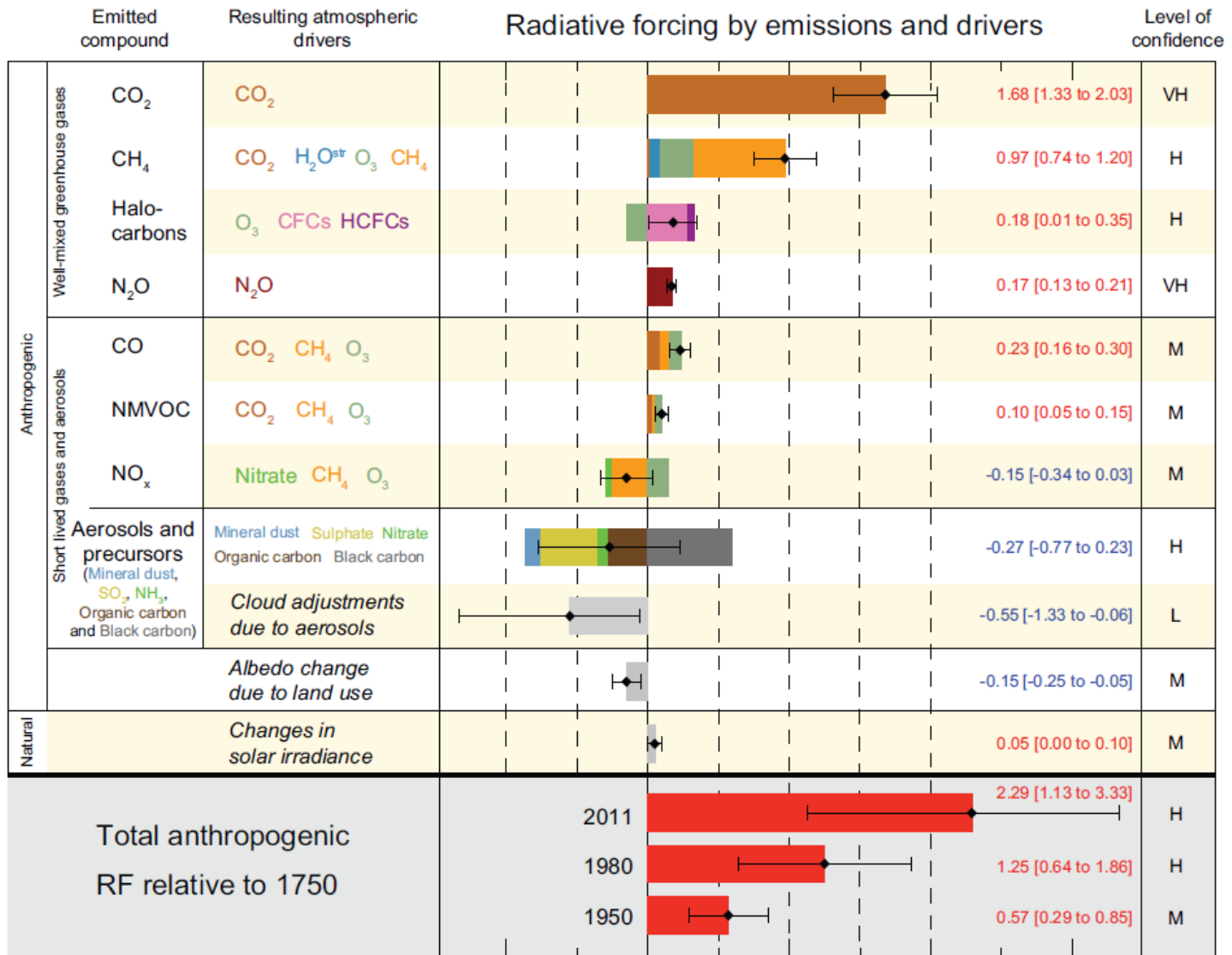
FIGURE 8.12 Most of the long-wavelength energy radiated from the earth's surface is absorbed by greenhouse gases in the atmosphere, but some passes directly through the atmospheric window. The atmosphere, in turn, radiates energy to space and back to the earth.

Between 7 and $12 \mu\text{m}$ there is a relatively clear sky for outgoing thermal radiation, referred to as the *atmospheric radiative window*.

“Radiative Forcing” Since Pre-industrial Times

- “Radiative forcing” can be both positive (contribute to global warming) or negative (tend to cool the earth).
- Gases and particulate matter added to atmosphere can exert both direct and indirect radiative forcing effects.
- Example 1: Aerosols have a direct effect on forcing when they absorb or reflect sunlight; aerosols can also cause an indirect effect when they induce changes in the albedo of clouds.
- Example 2: Halocarbons have a direct effect on forcing when they absorb long-wave radiation from earth; they also cause an indirect effect by destroying ozone in the stratosphere.

Drivers of Climate Change: Radiative Forcing (AR5)



-1 0 1 2 3
 Radiative forcing relative to 1750 (W m⁻²)
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 Semester

Direct Forcing by “Greenhouse Gases (GHGs)”

- Principal GHGs are **CO₂, CH₄, N₂O** and **Halocarbons** (compounds containing carbon plus fluorine, chlorine and/or bromine).
- Figure 8.16 shows relative importance of principal GHGs in terms of changes in their radiative forcings (from 1850 to 1995). Of the total 2.45 W/m² of forcing since the pre-industrial period, carbon-dioxide accounts for 64%, methane 19%, halocarbons 11%, and nitrous oxide 6%.

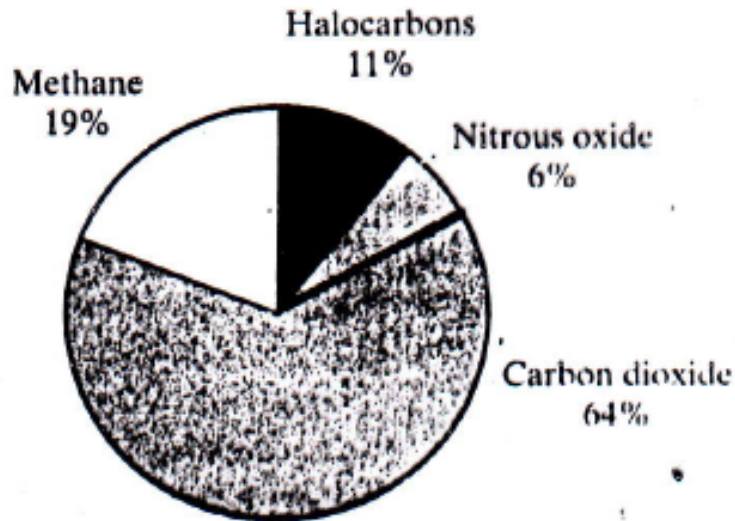
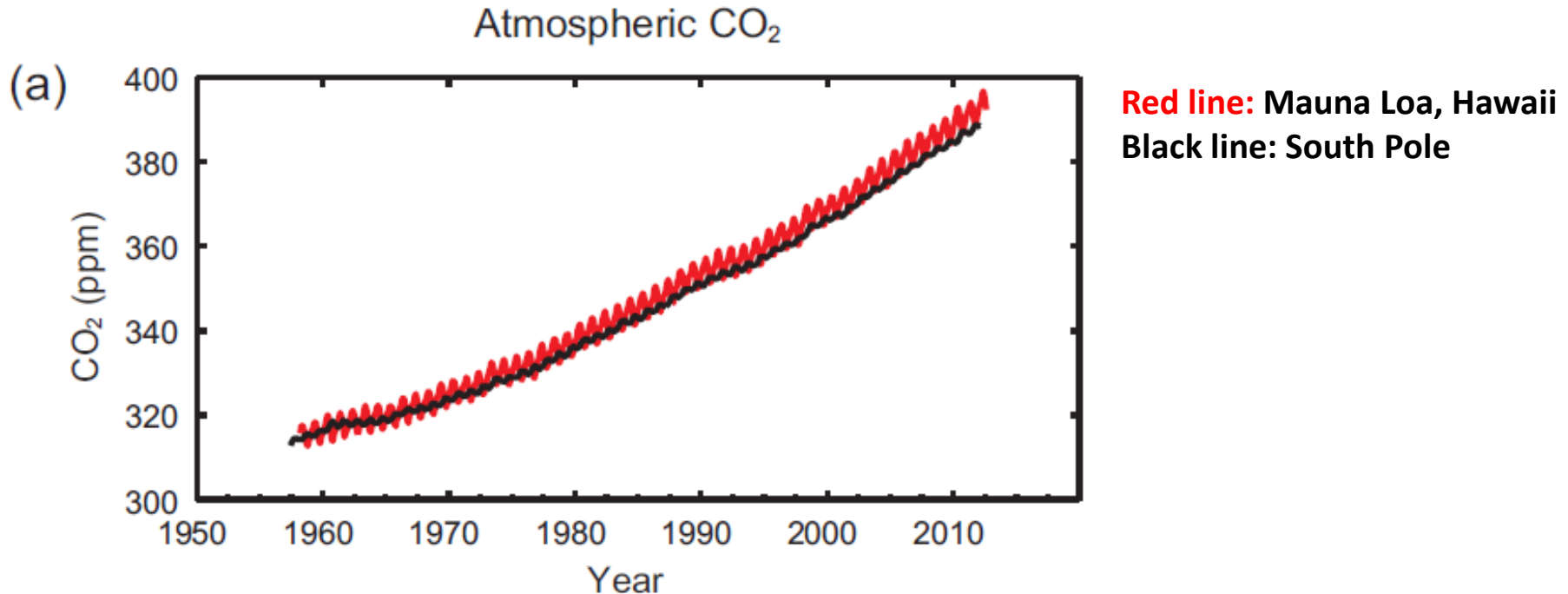


FIGURE 8.16 Direct radiative forcing due to changes in greenhouse gases from pre-industrial times to the present day as presented in Table 8.3. The total direct forcing is estimated to be 2.45 W/m². The overall forcing of halocarbons is actually less than 11 percent when the indirect effects are included.

(1) Carbon-di-oxide (CO₂)

First continuous, precise and direct measurement of atmospheric CO₂ began in 1957 at the South Pole, and in 1958 at Mauna Loa, Hawaii.



Anthropogenic CO₂ emissions are located predominantly in the northern hemisphere, but the mixing of northern and southern hemisphere air is sufficiently complete that the concentrations of CO₂ are only few parts per million higher at Mauna Loa than at the South Pole.

(1) Carbon-di-oxide (contd.)

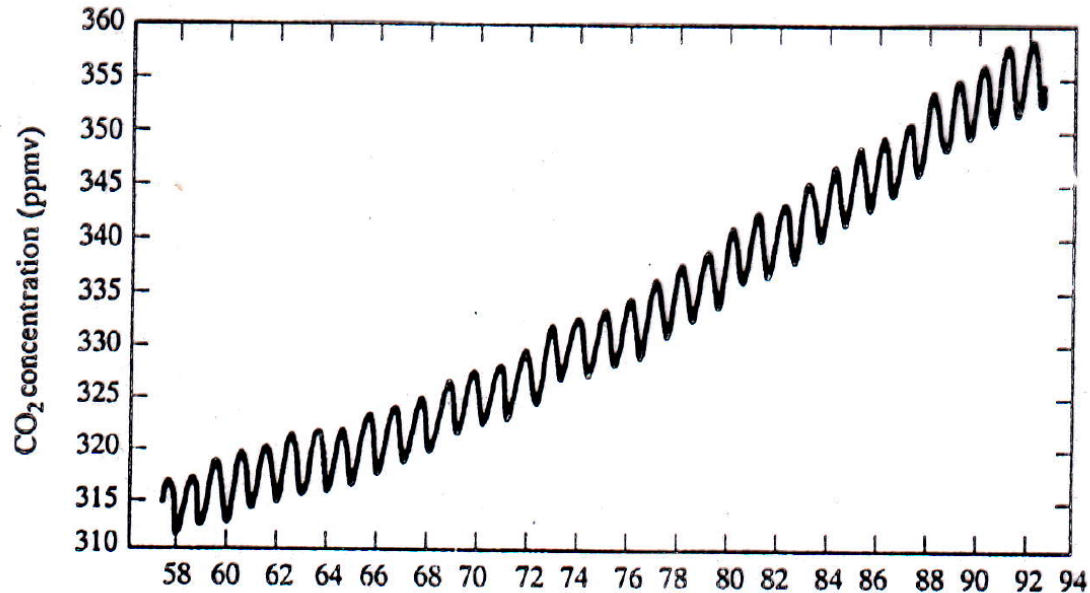
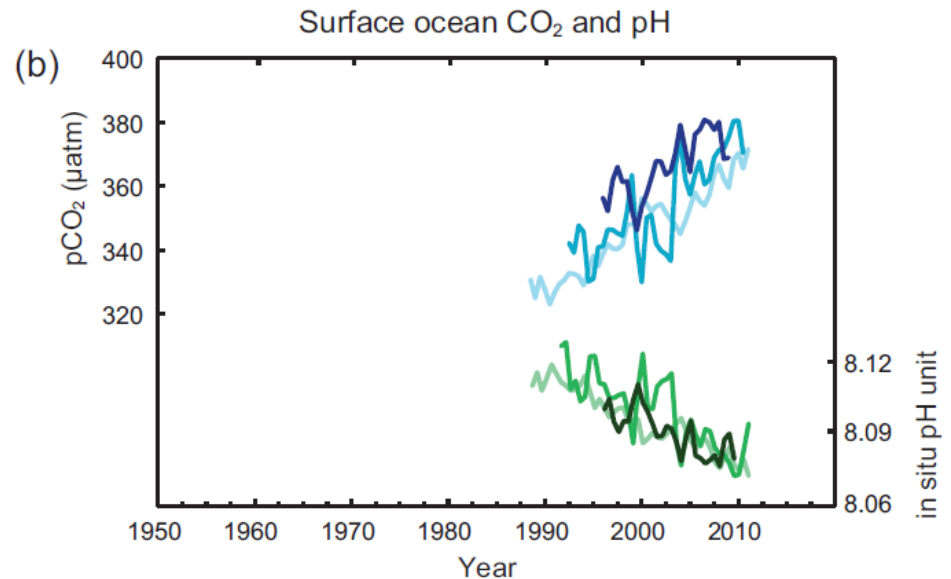


FIGURE 8.17 Carbon dioxide concentrations at Mauna Loa, Hawaii since 1958 showing trends and seasonal cycle. (Source: IPCC, 1995)

The oscillations shown in the Mauna Loa data (Fig. 8.17) are caused by seasonal variation in the rates of photosynthesis and respiration. During spring and summer, when plants are growing their fastest, atmospheric CO₂ levels drop, tending to reach their lowest point in the northern hemisphere in about October (see details in handout). Carbon thus moves continually from the atmosphere to food chain during photosynthesis and returns to the atmosphere during respiration.

(1) Carbon-di-oxide (contd.)

- From 1750 to 2011, estimated total anthropogenic emission of CO₂ is 555 GtC (470 -640 GtC)
- Of this amount, 240 GtC has accumulated in the atmosphere; 155 GtC has been taken up by the Ocean, and 160 GtC has been accumulated in natural terrestrial ecosystem.
- Ocean acidification is quantified by decreases in pH. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (high confidence), corresponding to a 26% increase in hydrogen ion concentration.



(2) Methane (CH₄)

- Concentration of CH₄ in the atmosphere was about 700 ppbv for many hundreds of years before it began its rapid climb in the 1800s. In 1992 it reached 1714 ppbv (increase of almost 250% over pre-industrial period); in 2011 it reached 1803 ppbv.

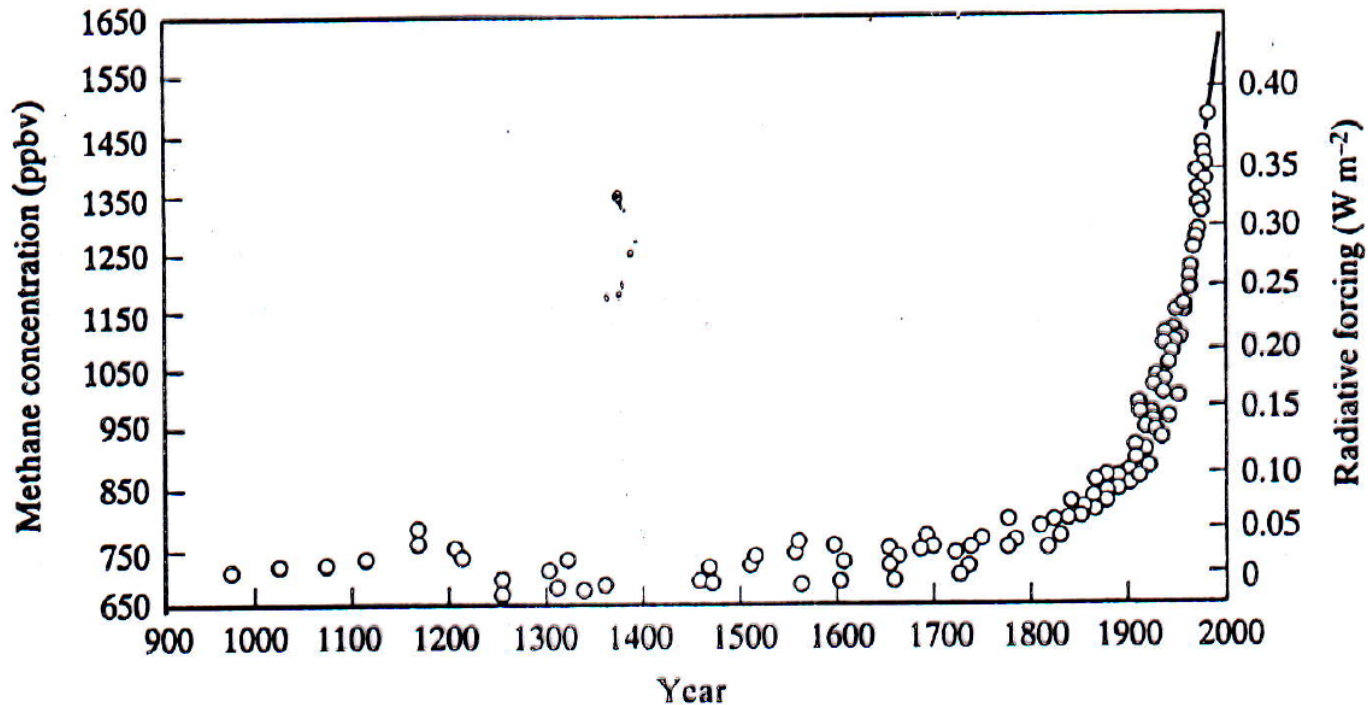


FIGURE 8.19 Methane concentrations from Antarctic ice cores combined with more recent direct measurements (smooth line). Radiative forcing is also shown. (Source: IPCC, 1995)

(2) Methane (CH₄) (contd.)

- Methane is a potent greenhouse gas (direct radiative forcing) and also one of the precursors of tropospheric ozone (O₃) (considered an indirect radiative forcing), and thus contributes to both climate change and air pollution.
- Major sources of CH₄ include:
 - Wastewater (including fecal sludge),
 - Flooded rice cultivation,
 - Livestock and poultry,
 - Municipal solid waste,
 - Coal mines, and
 - Natural gas production and transmission.

(3) Nitrous oxide (N₂O)

- Almost 2/3 of anthropogenic emissions are result of tropical agriculture. Other sources include 3-way catalytic converters in cars, combustion of fossil fuels containing nitrogen, and a variety of industrial processes.
- Apparently there is no tropospheric sinks for N₂O, and it is only slowly degraded in the stratosphere by photolysis. Its atmospheric lifetime is about 120 years, indicating its long-lasting effects.

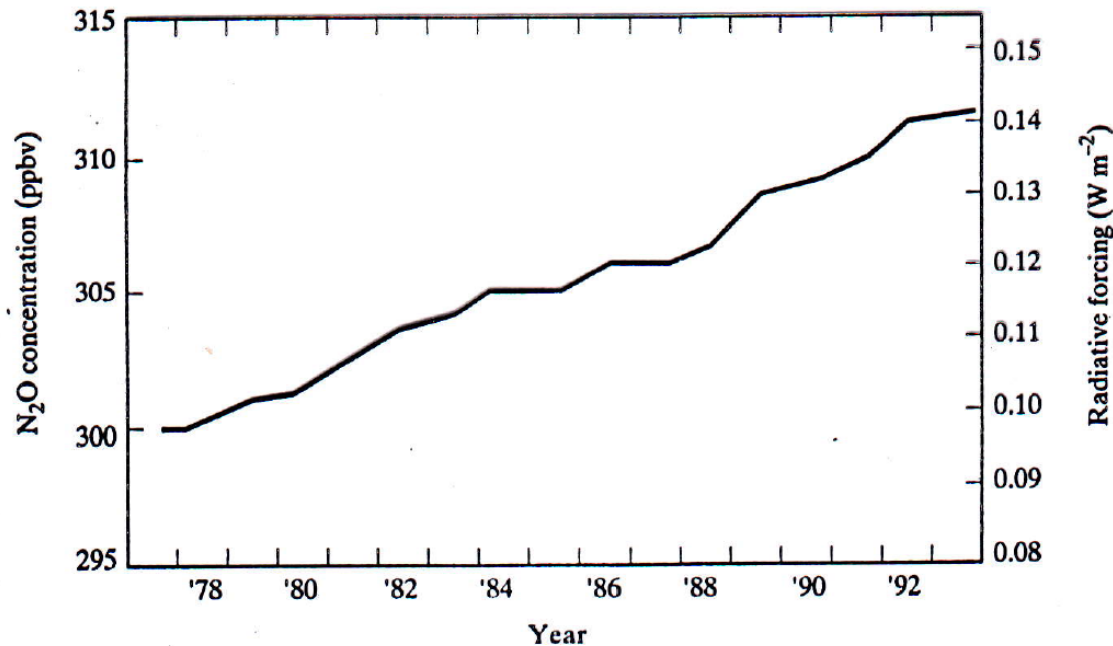


FIGURE 8.21 Increasing concentration of nitrous oxide and corresponding radiative forcing. (Source: IPCC, 1995)

(4) Halocarbons

- Halocarbons are carbon-based molecules that have **chlorine, fluorine, or bromine in them**. They not only contribute to global warming, but also chlorine and bromine atoms that find their way into the stratosphere have the ability to destroy ozone catalytically.
- Sub-categories of halocarbons:
 - Chlorofluorocarbons (CFCs): C + F + Cl
 - Hydrochlorofluorocarbons (HCFCs): H + C + F + Cl
 - Hydrofluorocarbons (HFCs): H + C + F
 - Halons: C + F + Br ± Cl
 - Others: CCl₄, methyl chloroform (CH₃CCl₃), methyl bromide (CH₃Br)

(4) Halocarbons (contd.)

Chlorofluorocarbons (CFCs):

- Non-toxic, non-flammable, non-reactive, and not water soluble; hence have long atmospheric residence times.
- Only removal mechanism is photolysis by short-wavelength solar radiation, which occurs after the molecules drift into the stratosphere.
- Chlorine freed during this process destroys the stratospheric ozone layer

Halons:

- Like CFCs, halons (which contain bromine) have no tropospheric sinks and their only removal mechanism is also photochemical decomposition in the stratosphere, which releases ozone-depleting bromine.

(4) Halocarbons (contd.)

Hydrochlorofluorocarbons (HCFCs):

- HCFCs are being used as replacements for CFCs. Because of hydrogen molecule, they are more reactive and can be destroyed in the troposphere.
- However, they still have some potential to deplete ozone layer and they are still potent greenhouse gases.

Hydrofluorocarbons (HFCs):

- HFCs have no chlorine atoms, so they are better than HCFCs. They are becoming the refrigerant of choice for automobile air conditioners and refrigeration equipment.
- However, HFCs have relatively long atmospheric residence times, which contribute to their global warming potential.

(4) Radiative Forcing of Halocarbons

- Halocarbons account for about 11% (0.28 W/m^2) of the direct radiative forcings of the GHGs.
- Of that, CFC-11 and CFC-12 account for about 71%; while others (CCl_4 , HCFC-22, and CFC-113) account for the remaining.
- Since halocarbons induce a loss of ozone in the lower stratosphere, and ozone is a greenhouse gas, the net forcing of halocarbon is reduced by about 0.1 W/m^2 .

(4) Ozone

While O_3 is an important greenhouse gas, it has proven to be difficult to understand.

Tropospheric Ozone:

- Unlike other greenhouse gases, O_3 is not well-mixed in the atmosphere. Hence, tropospheric O_3 concentrations are higher in the northern hemisphere (urban areas). However, concentrations vary seasonally, with sunnier summer months promoting more ozone formation.
- IPCC (1996) tentatively puts the radiative forcing of O_3 between 0.2 and 0.6 W/m^2 .

(4) Ozone

Stratospheric Ozone:

- In the stratosphere, O₃ concentrations are decreasing as a result of the attacks by chlorine and bromine released by UV-exposed CFCs and halons.
- These O₃ losses vary by geographic location and by season, as the annual appearance of the ozone hole over Antarctica in September and October demonstrates.
- It has been estimated that stratospheric O₃ loss has a globally averaged negative forcing of about -0.1 W/m^2 .
- As emission of CFCs and halons into the atmosphere are being curtailed, it is expected that O₃ will begin to recover in the early part of the twenty-first century, so the negative forcing will diminish.

(5) Aerosols (Particulates)

Aerosols can affect earth's energy balance in a number of ways:

- (1) They can reflect incoming solar radiation back into space, which increases the earth's albedo (direct effect);**
- (2) They can provide cloud condensation nuclei, which increase cloud reflectivity and cloud life, and those also increase albedo (indirect effect);**
- (3) Carbonaceous particles such as soot from fossil fuel burning can increase atmospheric absorption of incoming solar energy (direct effect).**

(5) Aerosols (Particulates)

Direct (both positive and negative) and indirect (negative) effect of aerosol: Increasing of albedo and cloud reflection yields negative radiative forcing, which is counteracted to some extent by the positive forcing due to solar absorption of soot. **“Global cooling” due to aerosols is offsetting an estimated half of the “global warming” caused by GHGs.**

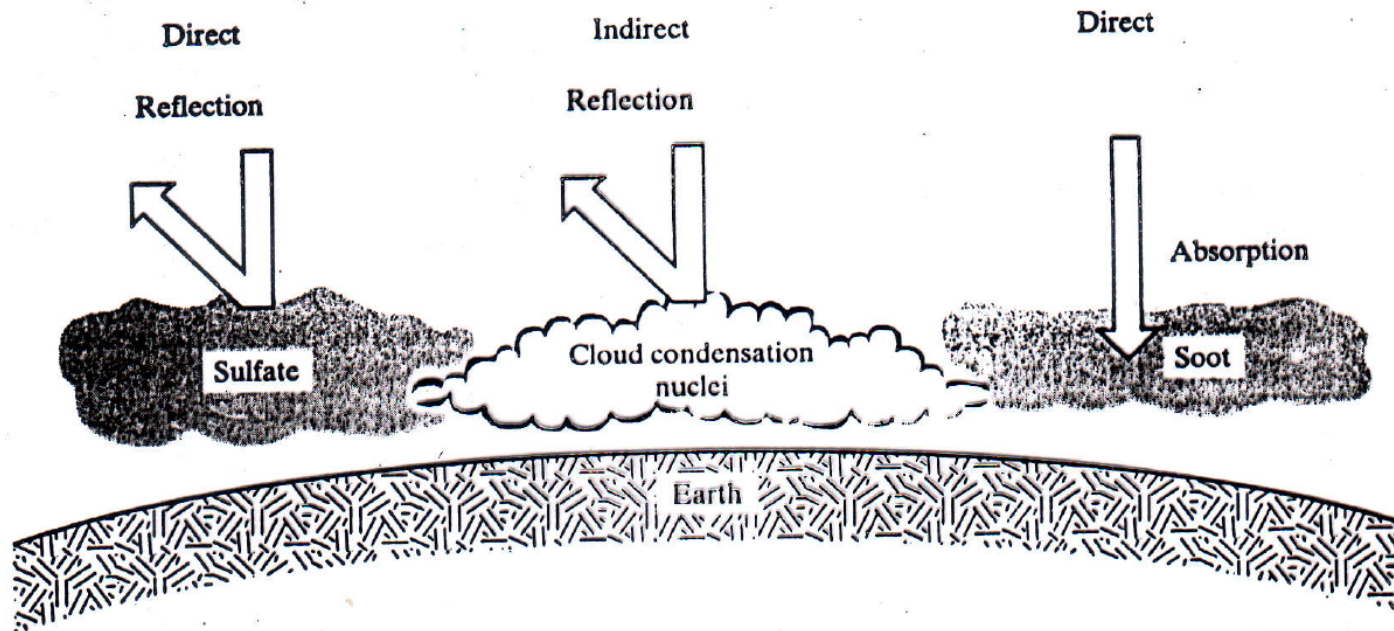


FIGURE 8.23 Aerosols provide negative radiative forcing by reflecting sunlight and by enhancing cloud formation, which also increases reflection. Carbonaceous particles (soot) can provide negative forcing by absorbing sunlight. Aerosol absorption and reflection are direct effects; cloud formation and reflection is an indirect effect.

(5) Aerosols (Particulates)

Apart from these (as discussion earlier under PM), Black Carbon (BC) particles also have climate impacts:

- (1) When deposited on ice/snow, BC reduces albedo of these surfaces, increasing both atmospheric warming and melting rate caused by increased absorption of heat by the darker snow/ice around the world. This affects the water cycle and increases the risks of flooding.**
- (2) Black carbon aerosols have a large impact on regional circulation and rainfall patterns (e.g., monsoon) as they cause significant asymmetry in heating patterns over a region.**