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Review Article

Global warming-Present status of research and future strategies

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ABSTRACT
Increased fossil fuel combustion, land use changes and deforestation are contributing significant amount of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other greenhouse gases (GHGs) into the atmosphere. This has resulted in an increase of 0.6 ^{0}C in global mean surface temperature since the 19th century. Estimates show that at the present rate of GHG increase, this will further increase up to 1.4 ^{0}C - 5.8 ^{0}C by 2100. Surprisingly, in the past 100 years, the average temperatures in the Arctic region have increased at almost twice the global rate. It is estimated that combined effect of present increase in CO_2, N_2O and CH_4 would lead to an increase of atmospheric heating by 2.3 W m^{-2}. Calculations show that due to aerosol effect, the observed increase in global mean surface temperature over the industrial era is lesser by 40% of that expected from observed increase in concentrations of major GHGs. A significant part of heating is attributed to absolute nature of black carbon (BC) which contributes radiative forcing of the order of 0.3 to 0.5 W m^{-2}. At the same time, BC and other absorbing aerosols are reported to cause the dimming effect at the rate of ~6 W m^{-2} per decade over India. However, aerosol radiative forcing calculations have huge uncertainties which need to be corrected. Scientific evidences show that due to global warming, Indian region will experience severe consequences such as increased number of extreme events, sea level rise, melting of glaciers etc. Although per capita GHG emissions of India are very low, the total emissions, however, place India at 4th rank. It is to be noted that Indian initiatives to control GHG emissions and to share emission data with global community are highly appreciable. However, there is a great need of taking measures to control GHG emissions through mitigation and adaptation techniques. It is realized that Clean Development Mechanism (CDM) is the best adaptation option for developing countries to participate in emission reduction strategies.

HISTORY OF GLOBAL WARMING SCIENCE

Carbon dioxide induced global warming, which is being discussed at present as a global concern, was first demonstrated by the Swedish scientist Svante Arrhenius (Rodhe et al., 1997), who was awarded Noble prize in chemistry in 1903. More than hundred years ago, through a simple mathematical model, Arrhenius (1896) showed that a doubling of the atmospheric CO_2 concentration would lead to 4–5^{0}K warming of the earth surface due to greenhouse effect. But it was in 1963 when a breakthrough took place through a meeting on "Implications of Rising Carbon Dioxide Content of the Atmosphere", which was organized by `Conservation Foundation' where G. Plass and D. Keeling participated as the only experts of CO_2 research. Later in 1965, the issue was picked up by the Science Advisory Committee of US President. Subsequently, the number of researchers studying CO_2 and global warming continuously increased to record its effects on rising sea level, ecosystem changes and ice melting etc. Further, during UNEP/WMO/ICSU conference held in Villach in 1985, experts went on to call for policy initiatives and to mobilize an internationally coordinated effort to study policy options. This conference resulted in the establishment of International Panel on Climate Change (IPCC) in 1988 with Bert Bolin as its first chairman.

PRESENT UNDERSTANDING

Global warming due to CO_2

Recently, the 4 th Assessment Report of Intergovernmental Panel of Climate Change (AR4 IPCC) has reported that due to increased fossil fuel combustion, land use changes and deforestation, CO_2 concentrations are rising with other greenhouse gases causing an increase of 0.6 ^{0}C in global surface temperature since the 19th century (IPCC, 2007). Out of which around an increase of 0.3 ^{0}C was noticed only during the past 25 years. The global atmospheric concentrations of carbon dioxide have increased from 280 ppm (pre-industrial value) to 391 ppm in 2011, and the June2012 average of values at Mauna Loa observatory was 395.77 ppm, clearly indicating significant influence of human activities on the emissions of CO_2. In fact, on June 6th 2012, the CO_2 values hit 400 ppm mark over several places in the Arctic as reported by the monitoring stations across the region. This increase is definitely going to warm the earth's atmosphere. Based on six IPCC SRES "marker" scenarios, models predict that by the year 2100, the atmospheric concentration of CO_2 could range between 541 and 970 ppm, which is an increase of 90–250% as compared to the year 1750 (IPCC, 2001). Predictions show that global temperature will increase from 1.4 – 5.8 ^{0}C between 1990 and 2100.

Estimates reflect that the radiative forcing due to CO_2 has increased by 20% from 1995 to 2005, which is considered as the highest in any decade during last 200 years (IPCC, 2007). Increasing trends are seen in both daily maximum and minimum temperatures, with minimum temperatures increasing at a faster rate than maximum temperatures. It is very surprising to note that the average temperatures in the Arctic have increased at almost twice the global rate in the past 100 years.

Non-CO_2 greenhouse gases and global warming

Apart from CO_2, global warming is also caused by other greenhouse gases (GHGs) such as methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and surface ozone (O_3) (Ramanathan, 1975; Montzka et al., 2011). In the mid-1970s Ramanathan (1975) and Ramanathan et al (1985) reported that CFCs and other trace gases also contribute significantly to the global warming. These findings were important for the scientific community as until that time, CO_2 was thought to be the only gas contributing greenhouse effect and global warming. Such research encouraged other scientists to study about other GHGs.

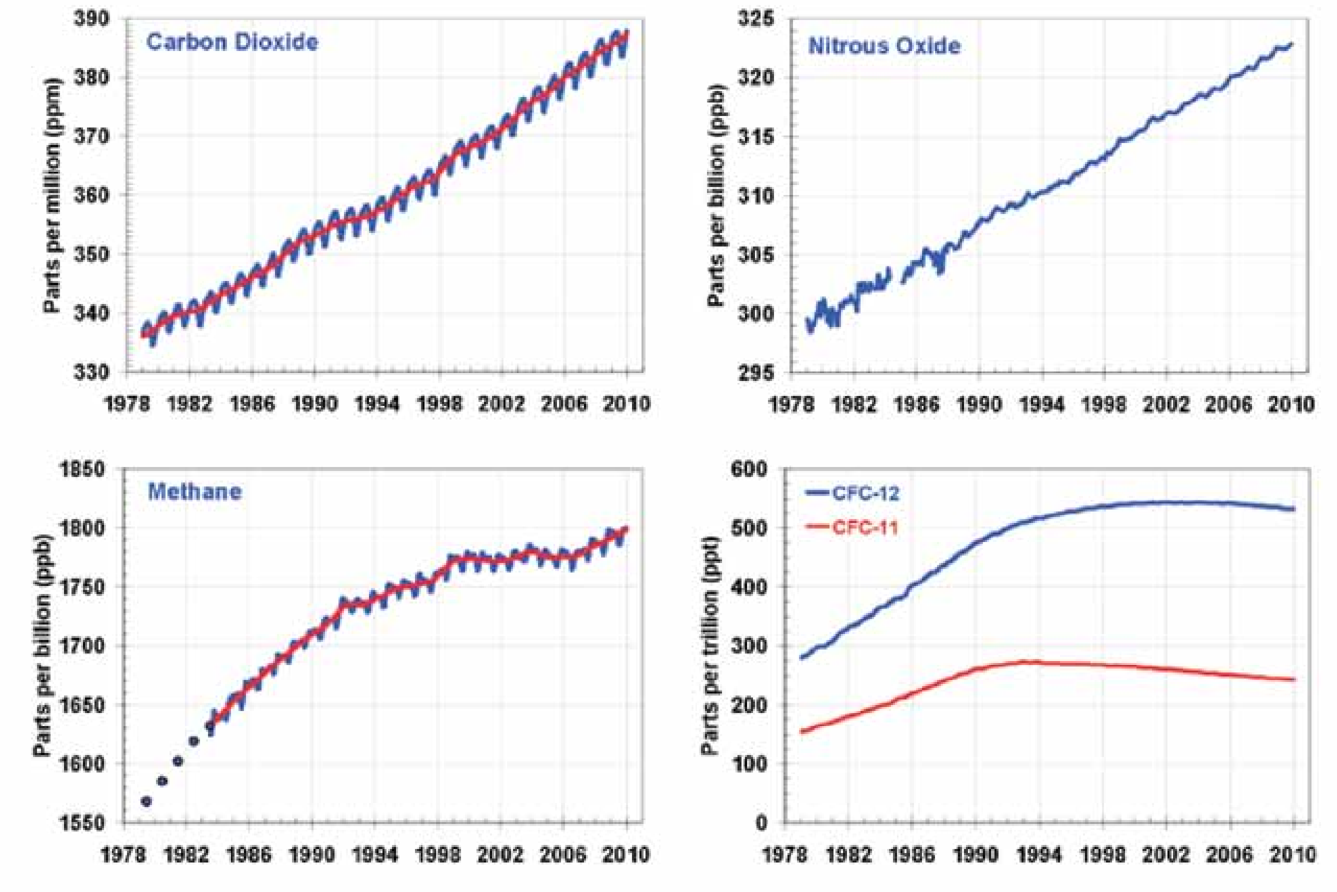
The global atmospheric concentrations of

Figure 1. Global averages of CO_2, CH_4, N_2O and CFCs since 1979.

	Pre-industrial (1750) concentrations	Recent concentrations	Lifetime (years)	GWP (100 year times horizon)	Increased radiative forcing W m^{-2}
CO_2	280 ppm	390.5 ppm	~100	1	1.79
CH_4	700 ppb	1871	12	25	0.50
N_2O	270 ppb	323 ppb	114	298	0.18
O_3	25 ppb	34 ppb	Hours to days	n.a.	0.35
SF_6	0	7.41 ppt	3200	22800	0.0029
CFC-11	0	241 ppt	45		
CFC-12	0	534 ppt	100		
HCFC-22	0	220 ppt	12	1810	0.041
CF-113	0	75 ppt	85	6130	0.024
HCFC 141b	0	22 ppt	9.3	725	0.0025
HCFC-142b	0	22 ppt	17.9	2310	0.0031
Halon 1211	0	4.3 ppt	16	1890	0.001
Halon 1301	0	3.3 ppt	65	7140	0.001
HFC-134a	0	64 ppt	14	1430	0.0055
CCl4	0	87 ppt	26	1400	0.012

(Source: http://cdiac.ornl.gov/pns/current_ghg.html) methane have increased from the pre-industrial values of 700ppb to about 1800ppb in January 2012 (actually it is 1871ppb in the Northern Hemisphere and 1750 ppb in the southern Hemisphere). The nitrous oxide concentrations have increased from a pre- industrial value of 270 ppb to 323 ppb in January2012. Estimates show that the combined effect of such increase in CO_2, N_2O and CH_4 would lead to an increase in irradiative forcing, by 2.3 W m^{-2}. Non- CO_2 greenhouse gases contribute about 37% of the total greenhouse gas forcing over the historical period. Recent findings suggest that CH_4 and N_2O gases may be contributing 20% higher than indicated warming effect (Gillet and Mathews 2010). Table.1 gives residence time, global warming potential and radiative forcing contributions of various GHGs.

Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), CFC-12 and CFC-11 are considered to be the major greenhouse gases. Fig. 1 shows that they are continuously increasing in concentration since1978. Interestingly, a major fraction (~96%) of the direct radiative forcing is contributed by these major greenhouse gases. Only a small fraction (~4%) is contributed by other gases as mentioned in Table 1. According to recent findings, temperature change is taking place not only in lower troposphere but also in mid troposphere and stratosphere. Radiosonde observations showed a warming of the atmosphere at a rate of 0.12°C per decade near the surface and 0.15°C per decade in the mid-troposphere, during 1958-2006 (NOAA, 2012). In the stratosphere (9-14 miles above the Earth's surface), atmospheric cooling has been observed, which has been found to be consistent with the depletion of observed stratospheric ozone concentrations and increased GHGs absorbing IR from Earth. Due to reduction in ozone concentrations, warming effect is reduced in the stratosphere (Karl et al., 2006).



(Source: http://www.esrl.noaa.gov/gmd/aggi/)

Figure 1. Global averages of CO_2, CH_4, N_2O and CFCs since 1979.

Aerosols and global warming

A significant amount of atmospheric aerosols is contributed by various anthropogenic activities. These aerosols contribute both direct and indirect radiative forcing. According to IPCC, sulphate aerosols, organic carbon (OC), black carbon (BC), nitrate and dust in the air together produce a cooling effect. They contribute a total direct radiative forcing of –0.5 W m^{-2} and an indirect cloud albedo forcing of –0.7 W m^{-2} (IPCC, 2007). Schwartz et al (2010) reported that the observed increase in global mean surface temperature (0.8 K) over the industrial era is less by 40% than that expected (2.1 K) from observed increase in long-lived greenhouse gases. This discrepancy is mainly due to uncertainty in climate sensitivity and/ or cooling forcing of aerosols.

Black carbon (BC) as potential source of global warming

Apart from CO_2 and non-CO_2 GHGs, black carbon contributes to global warming too. It is emitted due to incomplete combustion of fuels (dominated by fossil fuel) and thought to be the second largest contributor of global warming. Global distribution of BC is shown in Fig. 2 (Bond et al. 2004). Global BC emission estimates are provided by other workers also (Ito and Penner, 2004; Novakov et al., 2003) but the estimates reported by Bond et al (2004) seem more realistic. According to the estimates given by Bond and his co-workers, around 3000 Gg/y-1 BC is contributed by fossil fuel combustion while around 1500 Gg/ yr-1 by biofuel combustion. In the year 2000, BC emissions were almost 50% higher than that of 1950 matching with the energy demand patterns.

Black carbon, being absorbing in nature contributes surface solar dimming and positive forcing. The dimming has a surface cooling effect and decreases evaporation of moisture from the surface. The radiative forcing of black carbon is estimated to be 0.3 to 0.5 Wm^{-2}. Studies show that the surface solar dimming is increasing in India. Based on the 1981-2006 data, Kumari and Goswami (2010) have reported that the absorbing aerosols caused dimming at the rate of ~6 W/m^2 / decade over India. BC studies are very important especially in a country like India where urban air is dominated by carbon aerosols (Kulshrestha et al., 2005). Ramanathan and Feng (2009) noticed that global warming is linked with regional air pollution phenomenon. Earlier, air pollution was thought as local or urban problem but new findings suggest that air pollution is a global phenomenon transported across continents and ocean basins. The occurrence of such global air pollution plumes is termed as Atmospheric Brown Clouds (UNEP, 2008). Black carbon is an integral component of Atmospheric Brown Cloud (ABC) and has regional as well as global impacts. ABC and black carbon

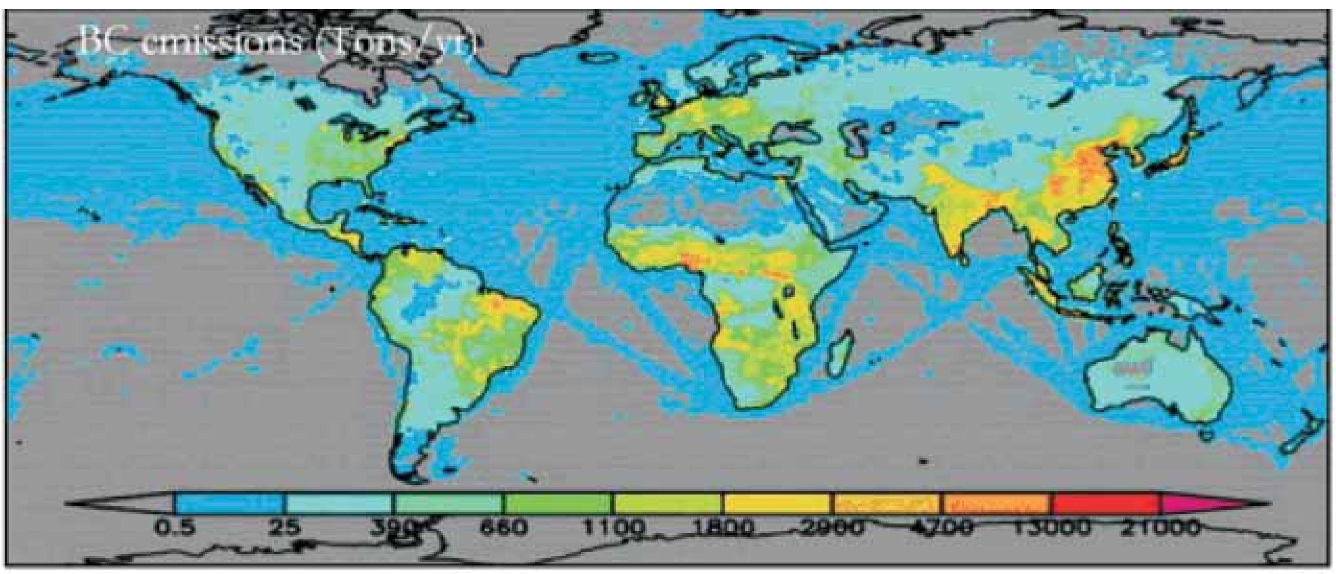


Figure 2. Global emissions of black carbon (Bond et al., 2004). Reprinted with permission.

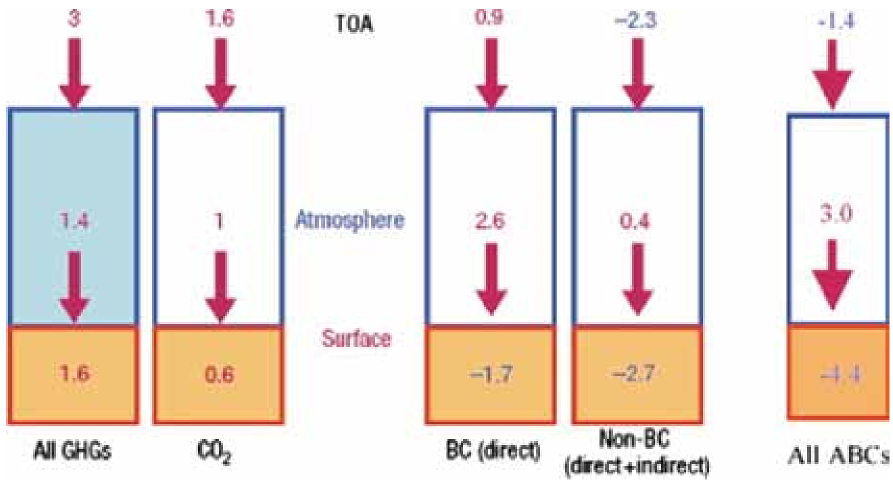


Figure 3. Global average radiative forcing of ABCs at the surface (brown box), in the atmosphere (blue box), and at the top of the atmosphere (on the top), compared with the forcing of greenhouse gases (GHGs). Positive and negative forcing are shown in magenta and blue colors, respectively (Reprinted from the permission from Ramanathan and Feng, 2009).

have direct and indirect effects, which include atmospheric heating, reflection, radiation, absorption, evaporation, change in monsoon circulation and precipitation etc. (Satheesh and Ramanathan, 2000; Babu and Moorthy 2001). Global average forcing due to ABC has been shown in Fig.3. In Indian region, a significant amount of BC is also contributed by biomass burning (Stone et al., 2010; Venkatraman et al., 2005) together with the emissions of organic carbon (OC). Chronology of Indian studies on carbon aerosols show that the first study on carbonaceous aerosols was reported by Sarkar et al (2001), where total carbonaceous aerosols were found to be dominated by organic carbon (OC). It is to be noted that the warming effect depends on the source-type of plumes (fossil fuel dominated/ biomass burning dominated). Based on surface and aircraft-based measurements, Ramana et al (2010) studied the warming effect due to black-carbon (BC) aerosols with reference to their combustion source and the ratio of black carbon to sulphate. These workers noticed more warming effect (100%) due to fossil-fuel-dominated BC plumes, as compared to bimomass-burning dominated plumes. Babu et al (2002) noticed very high concentrations of BC over Bangalore (11% of total mass and 23% of submicron mass), indicating very low values of single scattering albedo. These workers estimated a heating of 0.8K day^{-1} for cleaner periods and 1.5 K day^{-1} for less cleaner periods.

Thermal pollution induced global warming

Heating due to fossil fuel combustion and nuclear power also contributes to global warming. Earth's thermal equilibrium is maintained when net outflow is equal to the geothermal heat flow. Nordell (2003) found that in Sweden, net heating was about three times greater than the geothermal heat flow. According to calculations, in 1880, the net heat outflow was equal to the geothermal heat flow. Over the years, additional heating is contributed by non- renewable energy sources. Such heating will continue to contribute to global warming up to 1.8^0C of further rise in Earth's temperature, until thermal equilibrium is attained.

CONSEQUENCES OF GLOBAL WARMING

It is to be noted that the net effect of global warming will be region specific. Different local and regional geographical and meteorological factors will play important role in determining the net consequences of global warming and climate change. For example, North America, Canada and Europe will be the most affected regions from the direct effects of global warming while near equator regions will be most affected by the indirect effects of global warming. The impact of global warming in the latter regions will lead to change in precipitation, more floods, sea level rise, frequent cyclones, human health effects, crop yield change, increase in extreme events etc (Chandrappa et al., 2011).

Increase in extreme events

In most of the studies reported so far, global warming effect on average rainfall has not been obvious. In spite of sudden increase in global mean temperature, the average rainfall during summer monsoon has been almost stable during past 100 years (Houghton et al., 2001; Mann et al., 1999).

However, there are studies which report increased number of heavy rainfall events (Goswami et al.,2006; Allen and Ingram, 2002). This is probably due to the fact that increased temperature will result in increased moisture content in the atmosphere leading to heavy rainfall. Goswami et al (2006) have reported significant rising trends in the frequency and the magnitude of extreme rain events in Indian region during 1951-2000, together with a significant decreasing trend in the frequency of moderate events over central India. Fig. 4 shows temporal variation in the variance of daily anomalies during summer monsoon seasons from 1951 to 2000. Fig. 5 shows temporal variation in the number (N) of heavy, moderate and very heavy rain events during monsoon season over central India during1951 to 2000 as reported by Goswami et al (2006).

Sea level rise

Globally, around 600 million people live 10 m below the average sea level. Since 1950, the sea level is rising at the rate of 1.7 mm/year and from 1993 to 2009, the rising rate is 3 mm/ year (Nicholl et al., 2010). Glacier ice melt and the expansion of warm ocean have contributed to the rise in sea level. Studies in Indian region also show a rise in sea level due to global warming. Unnikrishnan and Shankar (2012) have estimated an average sea level rise of 1.29 mm yr^{-1} in Arabian Sea and Bay of Bengal.

These estimates are in accordance with global sea level rise of 1.8 mm yr^{-1} (Douglas, 2001) and 1.7 $\pm$ 0.4 mm yr^{-1} (Holgate and Woodworth, 2004). However, it is not clear whether these rates will be followed in future on long term basis.

Melting of Glaciers

According to various reports published worldwide, it is now confirmed that glaciers are receding due to global warming (Wagnon et al., 2001; Vuille et al., 2008) including Himalayan glaciers. Earlier, in a report published by Ministry of Environment and Forest (Raina, 2009), Indian scientist Dr V K Raina claimed that "Himalayan glaciers, although shrinking in volume and constantly showing a retreating front, have not in any way exhibited, especially in recent years, an abnormal annual retreat, of the order that some glaciers in Alaska and Greenland are reported". But IPCC report made a claim of catastrophic retreat of Himalayan glaciers by 2035 (IPCC, 2007). However, later, UN's climate science body admitted that the claim was unfounded. A recent satellite study reported by Indian Space Research Organization (ISRO) also reveals that most of the Himalayan glaciers are retreating. On an average the retreat is about 3.75 km during the 15 years (Ghosh, 2011), which is based on the study of 2,190 glaciers from 1989 to 2004. Similarly, a glaciology study reported by Azam et al (2012) revealed that though Himalayan glaciers are receding these are not going to disappear. Not only melting, glacier regions are having faster weathering problem. Hasnain (2000) noticed excessive chemical erosion in the glacierised catchments of the Himalaya. Studies of International Center for Integrated Mountain Development (ICIMOD) showed that the Himalayan glaciers are retreating at the rate of 10 - 60 m/year (UNEP, 2011). Retreating rate of Trakarding glacier is recorded as 66 m/year during 1957-2000. Imja and Lhotse Sar glaciers are found to be retreating at the rate of 41 m/year from 1962 - 2001. It is to be noted that the rate (74 m/year) of retreat was alarming during 2001-2006. The reason for faster melting of glaciers is thought to be due to the black carbon embedded in snow, in addition to general global warming. Higher deposition of black carbon creates accelerated heating of snow and ice (Ming et al., 2008; Menon et al., 2010).

Ocean acidification

Recently, it has been realized that due to rising concentrations of CO_2, ocean chemistry is

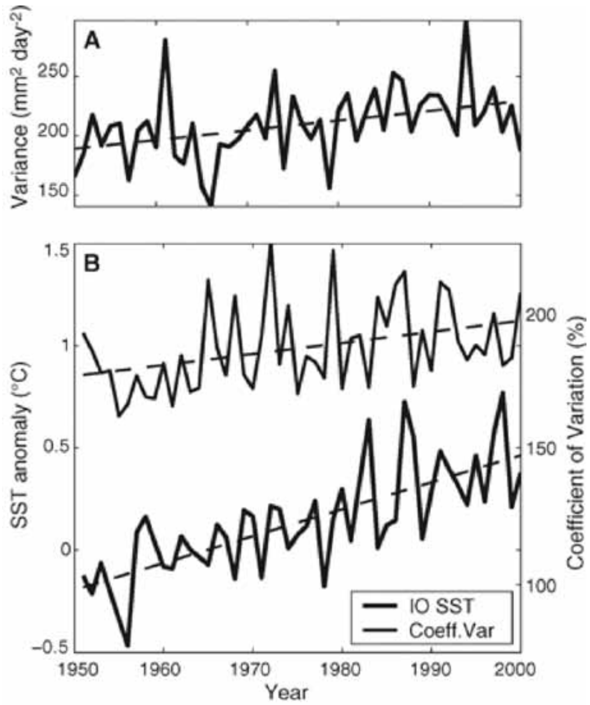


Figure 4. Temporal variation in the variance of daily anomalies during summer monsoon seasons during 1951-2000 together with its linear trend (dashed line). B. Coefficient of variability of daily precipitation during summer monsoon season and its trend (thin line) together with JJAS SST anomalies averaged over tropical IO and their trend (bold line). Reprinted with permission from Goswami et al (2006).

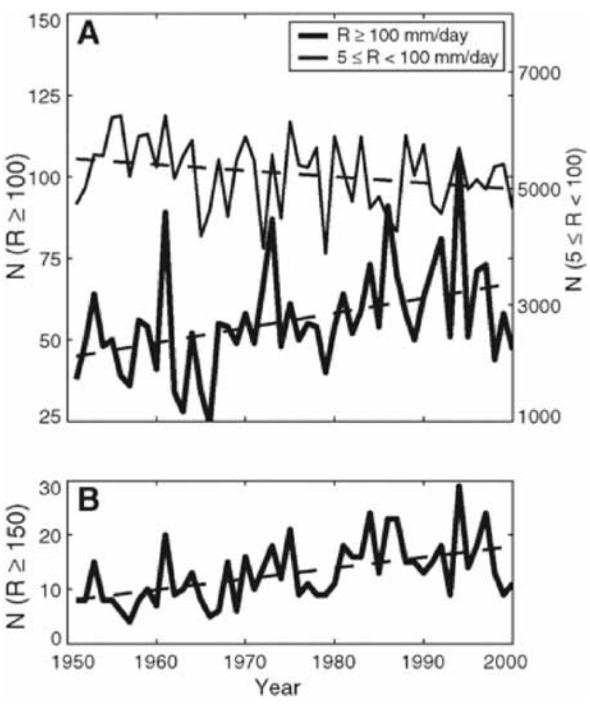


Figure 5. Temporal variation in the number of (A) heavy ($R \geq 100$ mm/day, bold line) and moderate ($5 \leq R < 100$ mm/day, thin line) daily rain events and (B) very heavy events ($R \geq 150$ mm/day) during the summer monsoon season over Central India during 1951-2000. Reprinted with permission from Goswami et al (2006).

changing very rapidly creating the problem of ocean acidification. According to "Monaco Declaration", "the pH levels of ocean water are changing 100 times faster than natural variability (http://www.ocean-acidification. net/)". Scientists feel that within a few decades most of the oceanic regions will be inhospitable to coral reefs. Apart from CO_2 increase, acidification of ocean can also take place by acid rain and dry deposition of acidic gases such as SO_2 and NOx. Acid rain contains excess sulphate and nitrate, which can contribute to the acidification of oceanic water (Kulshrestha, 2009a). In regions such as north America, Canada and Europe, rain water is reported having pH as low as 3, which contributes significant amount of protons (1000 micro equivalent per litre of H^+) that on long term basis, can give rise to lower pH of oceanic water. Apart from wet deposition, dry deposition of SO_2 and NOx can also give rise to sulphuric and nitric acids, which further contribute to acidity of oceanic waters.

Change in demographic patterns

Since, the global warming is expected to affect temperate as well as tropical regions severely; it is likely that global climate change may change the present demographic distribution in coming centuries. This may be primarily because of decrease in ground water table due to climate change. Drying of rivers has added to this effect by making recharging of ground water very poor. The situation may be highly vulnerable, forcing rural population to leave agricultural dependency. Such situation may result in migration of rural people to urban centers to find out alternate sources of income. Continuity of such migration may further encourage inter-continental migration. As predicted, global warming will lead to increase in green cover in certain regions such as Scandinavia. The green land will need more people and labor. In Scandinavia where the population is very less, rich migrants as well as climate refugees from developing world may find suitable place to settle (Umesh Kulshrestha, 2009). In other words, after internet, global warming and climate change will bring whole globe more closer by breaking the geographical boundaries of the nations, which will probably result in a real Global Village.

Reduction in income

Economic estimates of Ng and Zhao (2011) showed an adverse impact of global warming on the income of the people. They estimated that the income for the G-7 nations could be decreased by 3% due to 1°C rise in temperature. However, in the opinion of other researchers, the relationship of temperature and income depends on the method of income calculations (Nordhaus, 2006).
Also, this will become non-linear for temperature increases beyond 3 or 4°C.

GLOBAL AND INDIAN INITIATIVES

Kyoto Protocol and other global treaties for GHG emission reduction

There have been several global negotiating efforts to reduce GHG emissions. The Kyoto Protocol is a well known treaty on climate change. This is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC) to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (http://unfccc. int/kyoto_protocol/items/3145.php). At present, 191 signatories have ratified the protocol except United States of America. Under the Protocol, 37 industrialized countries, which are also termed as 'Annex I' countries commit themselves to reduce greenhouse gas emissions by 5.2% during 2008-2012, as compared to their emissions in 1990. The Protocol allows 'Annex I' countries to reduce their emission share by mechanisms such as emissions trading, the clean development mechanism (CDM) and joint implementation. Subsequently, Bali Roadmap was an outcome of the climate conference (COP 13) held in December 2007 in Bali, Indonesia. Bali negotiations resulted in the adoption of the Bali Action Plan, where parties established the mandate to focus on mitigation, adaptation, finance, technology and a shared vision. The Bali Roadmap set a deadline for concluding the negotiations in Copenhagen in December 2009. But Copenhagen Summit 2009 (COP 15) witnessed only limited number of signatories of the accord (http://unfccc.int/meetings/ copenhagen_dec_2009/

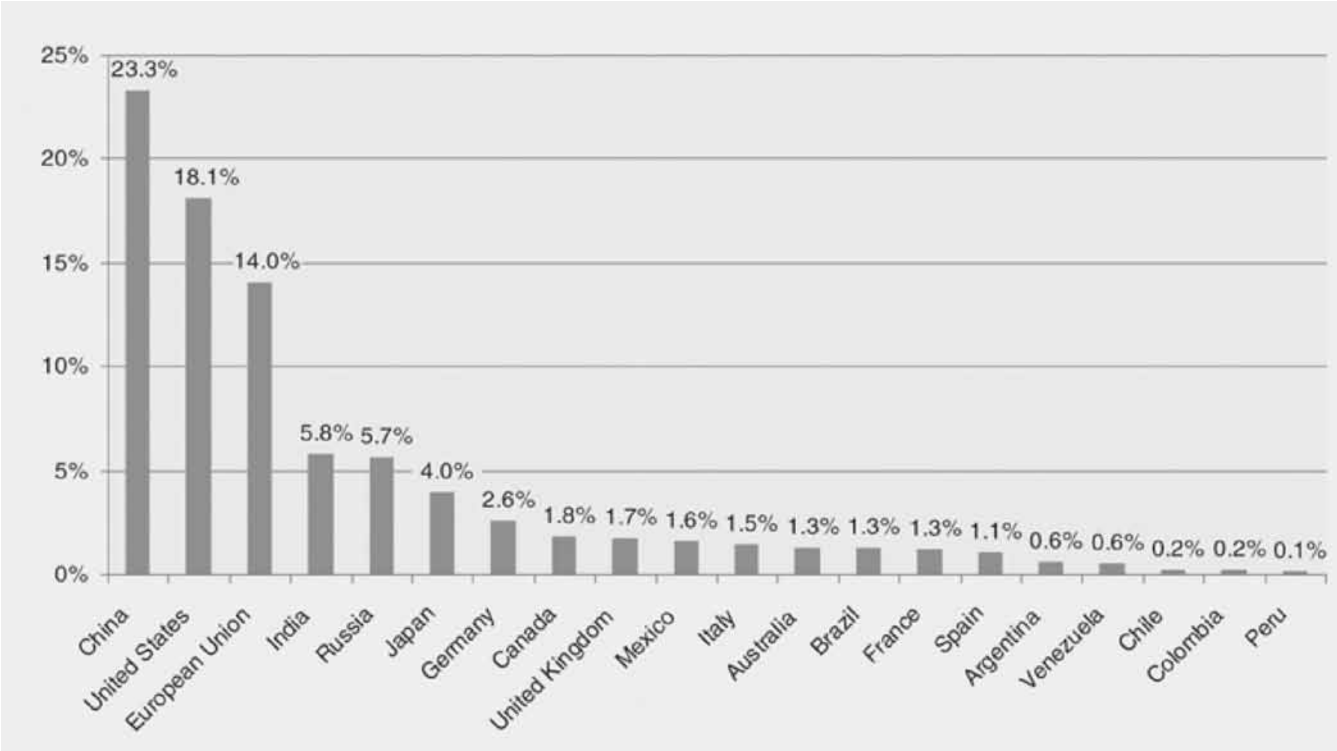


Figure 6. Percent CO2 contribution of different countries in 2008 (Rudnic et al., 2012).

meeting/6295.php). Further, Cancun Climate Change Conference (COP 16) held in Mexico in 2010 highlighted legally bindings agreement. But India and China refused to subject themselves to any legally binding curbs on their emissions. Recently, Durban conference (COP 17) held in November-December 2011 in South Africa has been a breakthrough, where parties agreed to work towards universal legal agreement on climate change before 2015. During Durban conference, India raised its concern to include the concept of equity.

Indian emissions, control initiatives and demand of equity

As far as global warming and climate science policy is concerned, India has come out as a very responsible nation. Indian scientists and gover nment have reported several studies on greenhouse gas emissions time to time, which include GHG emissions from various sectors such as fossil fuel, rice and animals (Mitra, 1991), transport, rice, coal and livestock (Mitra, 1992; Parashar et al., 1998), all India methane emissions from rice paddy field (Parashar et al, 1994, 1997), biomass, cement, oil and natural gas, manure, crop residue, MSW, soils, rice including organic and non organic, soils and other all sources (Garg et al 2001; NATCOM 2004). It is worth mentioning here that methane campaign of India has been a success story. According to reports, USEPA projected methane emissions from Indian paddy as 37.8 Tg per year. Later, based on a nationwide campaign led by National Physical Laboratory, New Delhi (a CSIR lab), it was corrected to 4.3 Tg per year (Parashar et al., 1994). Reddy and Subbaraya (2005) have documented a number of studies reported on global warming and climate change in India. Several other researchers have also reported GHG measurements at various sites in India (Padhy and Varshney, 2000; Mitra and Bhattacharya, 2002; Mitra et al., 2004; Singh et al., 1998; Garg et al., 2001; Gupta et al., 2009; Verma et al., 2002; Purkait et al., 2005; Parashar et al., 1991; 1998; Naqvi and Noronha, 1991; Lal et al., 1993). Vertical distribution of N_2O and other GHGs has also been reported in India by Lal and Sheel (2000). Recently, under National Action Plan on Climate Change 2008, India has developed a programme called Indian Network for Climate Change Assessment (INCCA). Recently, greenhouse gas

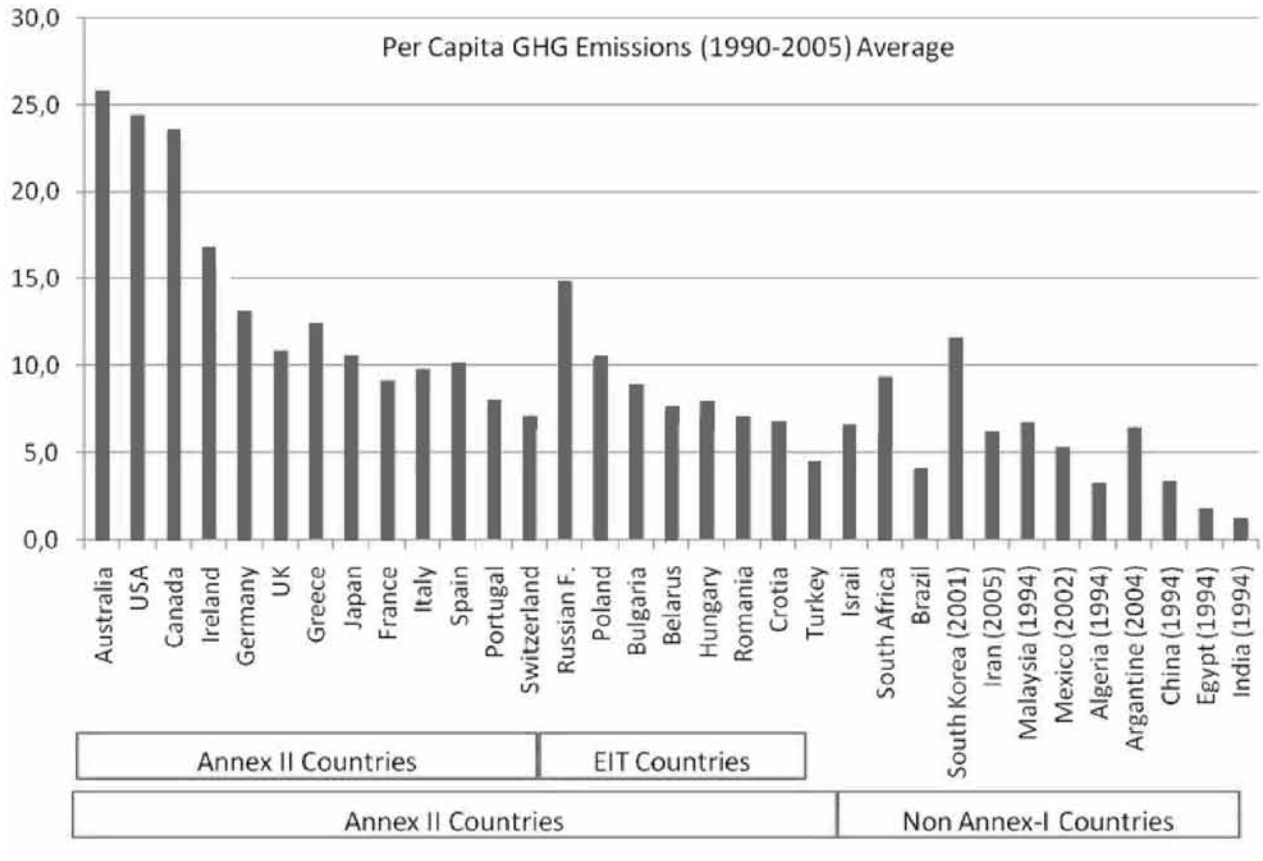


Figure 7. Per Capita Greenhouse Gas Emissions (Ton CO2 Equivalent / Person)(Source: (Rudnic et al., 2012).

emissions 2007 report has been published by Ministry of Environment and Forests (INCCA, 2010). With this release, India has become first of non-Annex countries to share its greenhouse emissions globally. According to INCCA (2010), India's emissions are 1727 million tones of carbon dioxide equivalent in 2007 as compared to 1228 million tons in 1994. After United States, China, the European Union and Russia, India falls fifth in GHG emitter 's list. However, current estimates place India in fourth place ahead of Russia (Fig. 6). It is interesting to note that United States and China emit four times higher than that of India. Energy sector is the biggest contributor of CO_2. India emits 1497 million tons of CO_2, out of which around 58% is contributed by energy sector. Total methane emissions are 20.56 million tons, out of which major contribution comes from agriculture sector (77.1%). Within the agriculture sector, live stock enteric fermentation contribution of CH_4 is the highest (56.6%). Total Indian N_2O emissions are 0.23 million tons. Most of N_2O is contributed by agriculture sector , which is 60% of the total N_2O. Fig. 7 shows a comparison of per capita GHG emissions worldwide. The list of countries shown in Fig.7 reveals that the per capita GHG emissions of India are the least suggesting a room to increase the emissions in order to attain a global equilibrium. Such low figures for per capita GHG emissions highly support Indian demand for opting equitable emission model. In this direction, India can opt for a liberal approach of sustainable development, which allows expansion of urban and industrial activities in a regulated manner. Apart from very low per capita emissions, India has natural benefit of its unique atmospheric environment. Atmospheric soil-dust, which is rich in calcium carbonate, significantly removes sulphur dioxide from the atmosphere eliminating the threat of acid rain (Kulshrestha, 2012). Most of the sulphur dioxide is contributed by coal combustion process. The dominance of soil-derived atmospheric, dust further opens up the scope of burning of coal without contributing to atmospheric acidity. It is possible for India to go for sustainable development, by utilizing its coal under stringent emission control norms. It goes with out saying that India has already shown its responsibility towards global warming control. Additional Indian commitments are seen recently, when it released its second National Communication to the United Nations Framework Convention on Climate Change report (NATCOM, 2012).

Apart from greenhouse gas measurements and inventory initiatives, India has launched a very ambitious programme called Black Carbon Research Initiative under National Carbonaceous Aerosols Programme (NCAP), as part of Indian Network for Climate Change Assessment (INCCA, 2011). This programme includes field experiments through network stations and aircrafts. As per the action plan, the network measurements of five years will include installation of aethalometers over entire Indian region. Approximately, 60 instruments will be deployed covering most parts of the country. Scientific findings of NCAP will be helpful to understand the role of BC/OC in radiative forcing of this region.

RECENT IMPRO VEMENTS IN OUR UNDERSTANDING

Our understanding of global warming at present is satisfactory. Earlier, there were several issues related to measurements and modeling of global warming and climate change parameters. Recent research has shown that several of these issues have been resolved such as Errors identified in the satellite data and other temperature observations have been corrected (USEPA, 2012). It is now clear that the observed temperature change is because of human influences on the climate system due to changes in greenhouse gases, aerosols and stratospheric ozone. Unlike earlier, at present, there is no discrepancy in the rate of surface air temperature increase with higher levels in the atmosphere. Hence, present scientific contributions have increased confidence in the understanding of observed climate changes and their causes. Only the unresolved issue is related to the rates of warming in the tropics where models and theory predict greater warming in the atmosphere than at the surface. This needs to be resolved through thorough investigations. Latest data show that warming is continuing. According to the World Meteorological Organization report, 2001-2010 decade was the warmest having 0.46° C higher temperature, as compared to the temperature recorded during 1961-1990 and 0.21° C higher than 1991-2000 decade indicating consistent long term warming (WMO, 2011). Also, year 2010 was the warmest year. According to NOAA National Climate Data Center, in March 2012, global average land surface temperature was 0.73°C higher than 20th century average marking it 18th warmest March on record (NOAA, 2012). In the same month, the global average ocean temperature was 0.35°C higher than the 20th century average marking 14th warmest March on record tied with the years 1988 and 1990. NOAA (2011) record shows that out of the 13 warmest years since 1880, 11 were recorded between 2001 and 2011. Year 2011 was the warmest La Niña year between 1950 and 2011. So far, per capita Indian contributions of greenhouse gases are very small as compared to global. Presently, India is ranked at 120th place in terms of per capita emissions; Qatar, Kuwait and UAE holding No.1, 2 and 3 position respectively (http://pdf.wri.org/navigating_numbers_chapter4.pdf). But the total CO_2 emissions place India at 4th rank (Fig. 6).

NONGOVERNMENTAL INTERNATIONAL PANEL ON CLIMATE CHANGE (NIPCC) AND GLOBAL WARMING

Organizations such as the liberty Institute, conservative commentators, and ExxonMobil have challenged IPCC climate change scenarios. So called Non-governmental International Panel on Climate Change (NIPCC) considers solar cycle as major source of present global warming trends. According to NIPCC, IPCC conclusions are ill defined. IPCC infers that "most of the observed increase in global average temperatures since the mid twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations", which very likely be at least 90%. NIPCC argues how this figure of 90% has been derived. NIPCC also argues that the IPCC ignored the fingerprints from the best available observations. Very sophisticated GHG models actually conclude that the anthropogenic GHG contribution to global warming is minor. The U.S. Climate Change Science Programme (CCSP) confidently claims that the 'fingerprints' or patterns of warming observed in the twentieth century differs from the patterns predicted by global climate change models, designed to stimulate carbon dioxide induced global warming. All greenhouse gas models show an increasing trend of warming with a peak at around 10 km , at roughly twice the surface value. However, the temperature data from balloons gives opposite results. NIPCC also challenges the alarm raised by the IPCC, about melting and eventual disappearance of glaciers in the near future. Kieffer et al (2000) state that of the 160,000 glaciers presently known to exist, only 67,000 (42%) have been inventoried to any degree. Probably, some of the questions of NIPCC will be answered in the forthcoming report of IPCC (AR5). However, these arguments of NIPCC open huge scope of future research in the area of global warming and climate change.

SCOPE OF FUTURE STRATEGIES

Global perspective

Disclosure of emission data

Data dissemination is very important in policy making. It will be a great help if the information of emission is disclosed and shared globally. Usually, more data on pollution and emission are disclosed by the nations, which have ratified the Kyoto Protocol as compared to other nations (Freedman and Jaggi, 2005). Also, it has been observed that larger companies disclose more data than smaller companies. If the data are shared consistently by all the countries and companies, it will be easier to make effective policies.

Need to develop a regional alliance

Indian region has very high population density. Countries of the region such as India, Pakistan, Nepal, Sri Lanka, Bhutan, Nepal, Bangladesh and Myanmar fall under developing nations category, which means the region will have growing energy demand to meet people's requirements in future. Growing population and energy needs will be adding more emissions of GHGs and BC in the region. Hence, a joint action plan needs to be formulated consisting of all the countries of the region to implement GHG management policies. Various scientists, foresters, international agencies and climate experts, who can help in bringing out strategic policies to protect from global warming, can be part of the alliance. Similarly, apart from respective ministries, international agencies and NGOs can also be included in GHG mitigation teams.

Future scope of research in Indian region

In India, emissions of GHGs are not very high for its population but the rate of increase needs attention. It is realized that BC is relatively a major threat to global warming in Indian region. Controlling BC emissions is really a challenging task in Indian perspective. We have to keep in mind that the carbon emissions in urban areas can be controlled by stringent regulations, efficient public transport system such as Metro rail and better power supply. But in rural areas, we need to have an alternative to traditional cooking stoves and better management of agriculture residue. Soft approaches, which can change the public mind set for adaptation are also necessary for effective carbon and GHG emission reduction. The need of the hour is to use renewable energy resources, provide energy efficient domestic devices in rural areas, find out the solution for agriculture waste burning in villages, keep check on deforestation and have very well planned land use pattern changes. As part of future strategies, Indian scientists/engineers need to focus upon- i) development of eco-friendly cost effective technologies, ii) generation of quality controlled data through systematic measurements, iii) development of high quality modeling capabilities, iv) organization of multi-dimensional field campaigns and v) spreading awareness regarding environment and climate change.

Some of the important areas where India needs to focus are discussed below-

Study of hydroxyl radical

Hydroxyl radical (OH) which effectively reacts with methane forming CO_2 is abundant in tropics. Hydroxyl radical concentrations increase from higher latitude towards tropics due to increase in water vapour concentrations and sunlight intensity (Uherek, 2012). OH concentrations highly depend upon solar irradiation, latitude, altitude, temperature, water vapour, CO, O_3, NOx etc. Since, OH abundance is region specific, photochemical fate of methane in tropical regions needs to be investigated thoroughly. Conversion of CH_4 into CO_2 contributes less to global warming as GWP of CO_2 is much less than CH_4.

Study of radiative forcing due to atmospheric dust- GHG mixture

Global warming studies are carried out for individual gases and their GWP. But the atmosphere is a complex system having GHGs, aerosols, mineral dust, carbon aerosols and active trace gases. Indian atmospheric environment is unique due to the presence of soil dust (Kulshrestha et al., 2003). The soil-dust acts as natural geo -engineering tool to combat acidification and climate change in Indian region (Kulshrestha, 2009a). Transfor mations happening in atmosphere are also very complex which take place at local or regional time scale (in terms of residence time of species). Schwartz et al (2010) also noticed the discrepancy between observed heating and expected heating to be mainly due to uncertainty in radiative forcing, due to atmospheric aerosols. Hence, comprehensive experimental efforts are needed to understand the role of complex mixture of gases and particles in radiactive forcing, which will definitely help in minimizing uncertainties.

Development of solar and wind energy technologies

Solar and wind powers are the ultimate source of energy for tropical regions for sustainable development. Serious efforts are needed to develop cost effective energy technology affordable by common man. Wind industry very effectively helps in reducing CO_2 emissions. A single 1.5 MW turbine can produce over 4,491 MW of electricity per year, reducing over 3,000 tons of CO_2 emissions (Tanti, 2012). Apart from reduction in CO_2 emissions, it creates jobs also. Every megawatt of new wind capacity creates 15 jobs on a direct and indirect basis.

Finding out the solution for agriculture waste burning

Global estimates show that developing world including Asia, Africa and Latin America produced around 2060 Tg biomass fuel in 1985, out of which 66% was burned in Asia (Yevich and Logan, 2003). 33% of biofuel supply comes from agricultural waste. Out of total use, 39% is used in Asia (Indian and China sharing 41% and 51% respectively). Out of the total biomass fuel, crop residue accounted for 400 Tg, which is burned in the fields. Biofuel and field residue burning emit around 0.9 Pg C as CO2, which is around 1/6 of CO_2 emissions from fossil fuel and industry (5.3 Pg C).

India is an agriculture based country, where huge amount of crop residue is left over and burnt in fields. According to Sarkar (2007), India produced 388 Tg crop residues. The burning of the agricultural waste and crop residue contribute emission of GHGs. Sahai et al (2011) have reported that 253 Tg of dry crop residue was generated in 2010 in India, out of which 63Tg accounted for field burning (which contributed 4.86 Tg carbon dioxide equivalent of greenhouse gases). According to the report, major field burning is practiced in the states of Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Maharashtra, Tamilnadu, Karnataka, Andhra Pradesh, Bihar and West Bengal. Hence, it is the need of the hour to develop technology to utilize the waste for energy production. Already biogas plants are set up in certain states, but there are difficulties related to their effective utilization. I think we need to find out the alternate option to incinerate the waste or use it to produce energy at Block and Tehsil levels, which requires detailed planning and involvement of farmers and social volunteers.

Development of cost effective device for domestic and winter-time heating

Wood burning for domestic heating and winter-time heating is common in India, which emits huge amount of GHGs. There is an urgent need to develop user friendly devices, which can provide domestic heating and winter-time heating to poor people sleeping on roads and farmers in villages (so called 'Tapne Ke Liye Saadhan'). This device will be very useful to reduce GHGs and health problems associated with wood burning. It will reduce wood consumption also. Project Surya (www.projectsurya. org) is such a step forward , where efforts are being made to replace traditional cooking stoves with improved and efficient stoves.

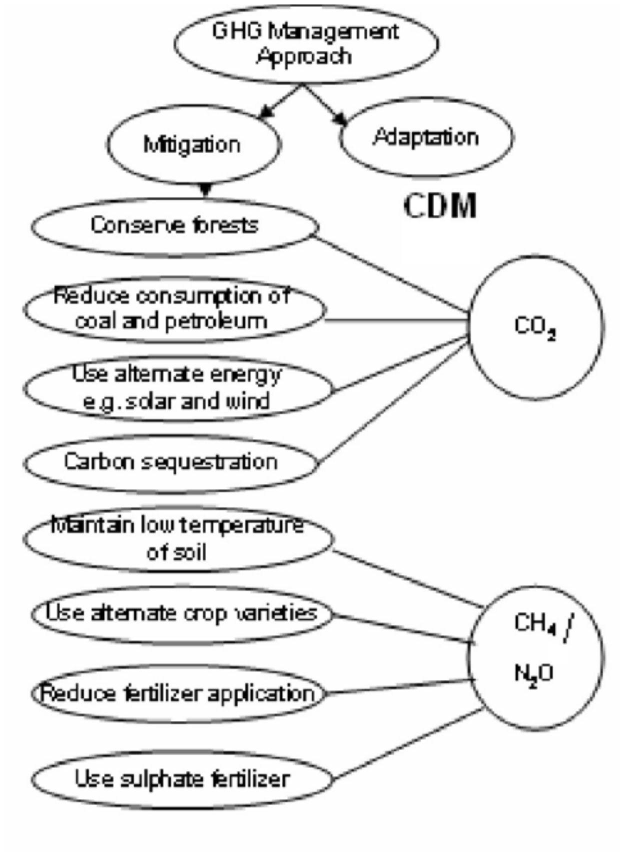


Figure 8. Flow chart showing GHG management approaches.

GHG Management through Carbon trading

GHG management involves both mitigation and adaptation. As shown in Fig. 8, various mitigation steps can be opted to control the emissions of CO_2, CH_4 and N_2O (Kulshrestha, 2009b). Under adaptation, Clean Development Mechanism (CDM) is a very effective mechanism for developing countries, which allows to earn carbon credits (http://cdm. unfccc.int/). India has around 20% share in global business of carbon trading. Mechanism of carbon trading and the companies utilizing this new process of trading are also described by Kulshrestha and Gupta (2010).

SUMMARY

Present estimates show that with the current rate of increase of GHGs, the average surface temperature will increase from 1.4 - 5.8 ^{0}C between 1990 and 2100. Total Indian GHG emissions have grown from 1228 million tons in 1994 to 1727 million tons of carbon dioxide equivalent in 2007, ranking India as 4th largest emitter. United States, China, the European Union are ahead in the list of biggest polluters. However, if European Union is split, country-wise India is Number 3 in total emission. According to recent studies, radiative forcing due to atmospheric aerosols needs to be calculated comprehensively in order to minimize uncertainties in the calculations.

The role of aerosols becomes more important in a region like Indian sub-continent, where soil-derived aerosols play a significant role in various atmospheric processes and act as effective natural geo-engineering tool to combat acidification and climate change. Apart from soil-dust, black carbon emissions from biomass burning are very huge in Indian region, which need to be controlled. Studies predict that in Indian region, global warming will result in very severe consequences such as increased number of extreme events, sea level rise, melting of glaciers etc. However, science of global warming has huge scope of future research to validate these predictions and projections.

Scientists need to carry out their research involving some important topics such as studies on hydroxyl radicals and their role in methane destruction and radiative forcing due to mixture of aerosols and gases etc. Our efforts should also be focused upon development and implementation of solar and wind power technologies. We should not forget that the opportunity of earning carbon credits through Clean Development Mechanism (CDM) has great benefits for developing countries. It is worth mentioning that Indian initiatives on GHG control, data disclosure and sharing are highly appreciated, which have projected India as a responsible nation.

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