UNDER PEER REVIEW

Refurbishment of Climate change relates to socio-economic consciousness and environmental pollution control

ABSTRACT

[Demand for energy, water, food and shelter for raising the standard of lifestyle are driving the environmental changes. Deforestation, CO2 emissions from fossil fuels such as coal and petroleum and incessant green house gas emissions are the main causes for climate change. Mechanisms that are needed to promote the capacity development of environment in this domain need more enthusiastic approach from all levels of state administrative and technical initiative with full autonomy towards implementation of environmental laws on the one hand and change of attitude of the country authority to safeguard the environment conditions for refurbishment of climate change. Socio-economic development with full consciousness among the people to nourish the environment may improve the climate change. The flaw of environmental laws is to be tightened and socio-culture is to be inculcated among citizens for full proof climate control.]

Introduction

The continuous improvement of human life style is helping the environment to be poured in with undesirable gaseous and micro particles besides toxic substances of fluid as well as non-fluid characteristics. In this connection the various parameters for climate change and researches undertaken to improve the environment and impacts at various regions of the globe have been reviewed by various researchers are noted below along with inputs for climate change incidents:

1. Graphical presentation of experimental data:

1.1. Sarajevo valley Environment and its effect on climate change

Sarajevo valley is surrounded by high Olympic Mountains: Bjelasnica, Igman,Jahorina, etc. Therefore, one of the main climate characteristics of Sarajevo's field is temperature inversion. It has influence in temperature gradient, in appearance fog, in air pollution, even it effects to middle temperature of the mounts, especially during winter period.

Last fifteen years had made possible a unique experiment: during the war, and

after the war, causes of air pollution suddenly stop working, so the presence of smog was important reduced. It made possible researching of the opposite influence: relations between air pollution and climate parameters mentioned before in the line. In this work used data of the meteorological station: Bjelave (630 meters), Butmir (518 meters), N.Sarajevo (535 meters) and Bjelasnica (2067 meters) over row 1975-2005.
The results of experiment showed the existence of high correlation between air pollution and temperature inversion (annual values - period April -March). Decrease of air pollution was followed by appropriate decrease of number of days with inversion and number of days with fog.
Graph 1 shows annual arithmetic means of concentration sulphur dioxide and black smoke during the period: 1974/75 – 2005/06, measured on station Sarajevo - Bjelave.
Graph 2 shows annual number of day with temperature inversion in Sarajevo valley, during the period: 1974/75 – 2005/06, measured on station Sarajevo – Bjelave, and Sarajevo –Butmir.
Visual correlation between these two graphs is obvious. Statistical correlation of these values is 0, 65, until year 2000. It is relatively high correlation, considering the fact that two different physical dimensions are compared.
However, correlation of these values until year 2006, is lower, about 0,36. This fact can be explained by using fig 1 and fig 2, and also graph 3. In last few years decrease of upper limit of inversion layer is obvious. Before the war, upper limit was about 900 meters, and after the war it is occasionally below the level of Bjelave station (about 600 meters). Latest measuring are taken at the another place of Sarajevo valley. (Station New Sarajevo – 535 m AMSL). Those results point out increase of air pollution at lover layer of Sarajevo's valley (graph 3 - parallel measurements for station Bjelave and New Sarajevo). It is caused by increase of traffic. In the year 2002, 120 thousand cars were registered in Sarajevo (mostly older than fifteen years). That explains increasing black smoke (soot) concentration in lower layer of atmosphere.

Lower correlation mentioned before is therefore result of decrease of upper limit of inversion layer below the Bjelave station. Because of the lack of adequate measurements on different spots, and especially aero sondage measurements, it is not adequate for analyses of the causes of this issue. Also, part of the solution could be related with climatic changes.
Answers should be sought with the help of complex model of temperature inversion and air pollution. It is important to notice that structure of particles of pollution before and after the war is different. Before the war it was industry, and today it is traffic. That fact significantly changes physical conditions and input parameters of the model.

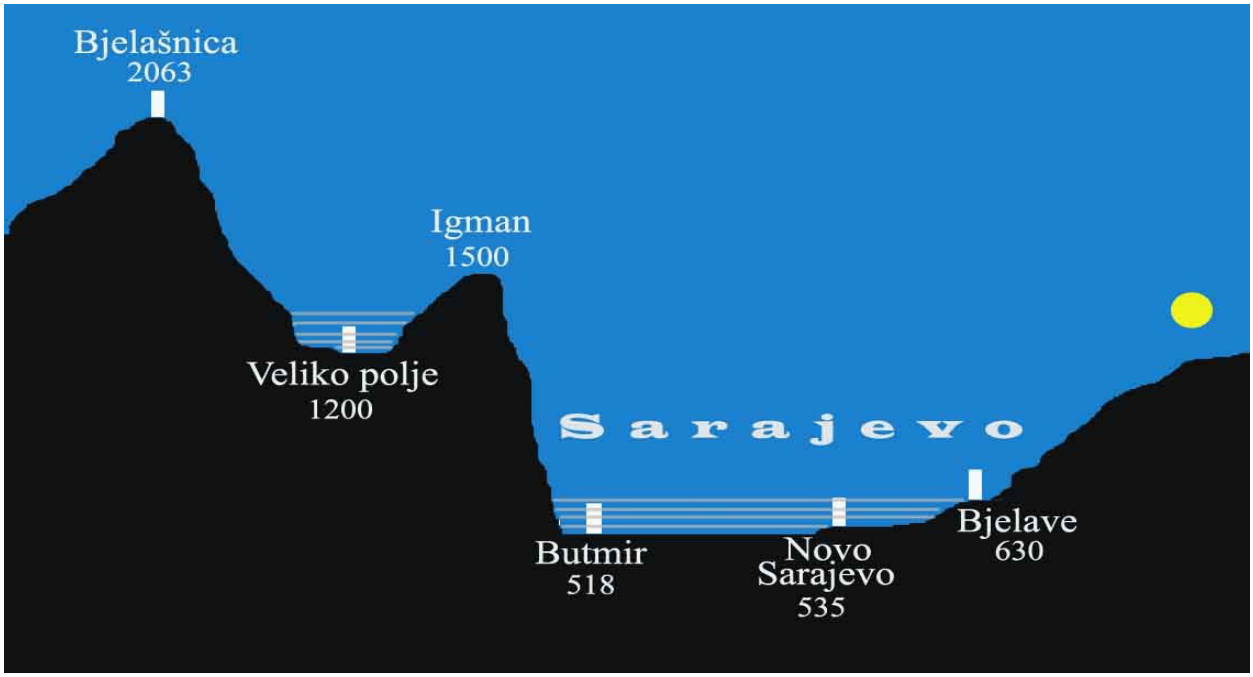
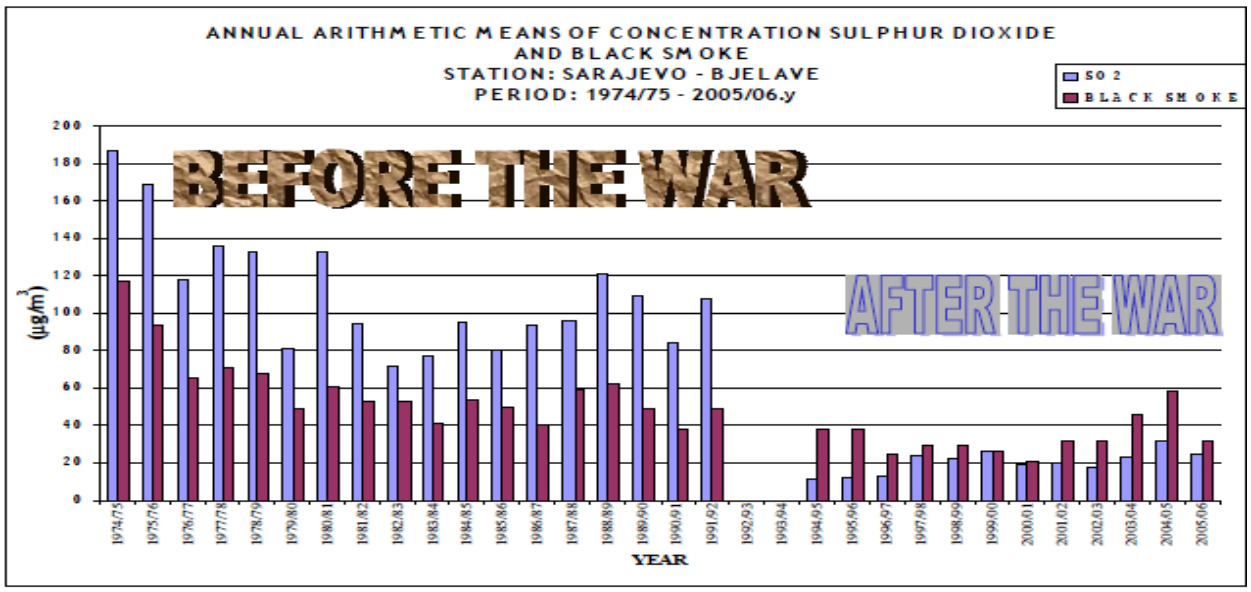
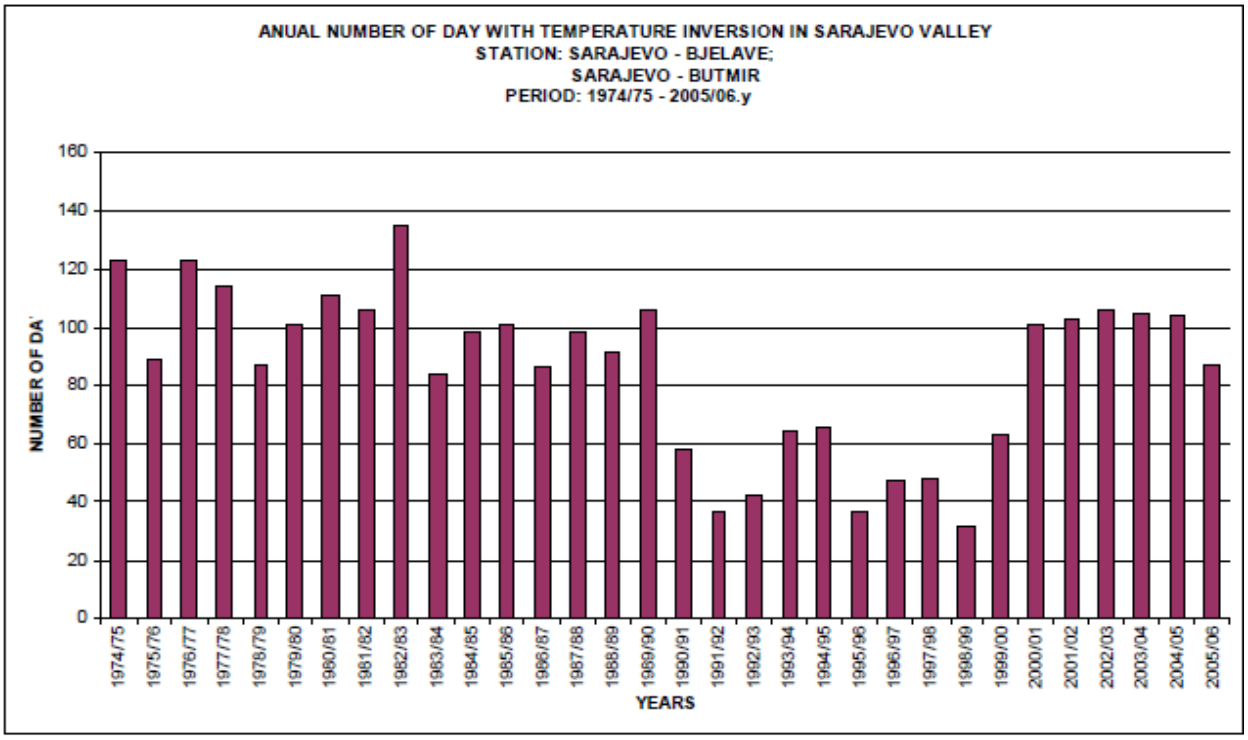


Figure. 1. Sarajevo valley – level of inversion early in the morning

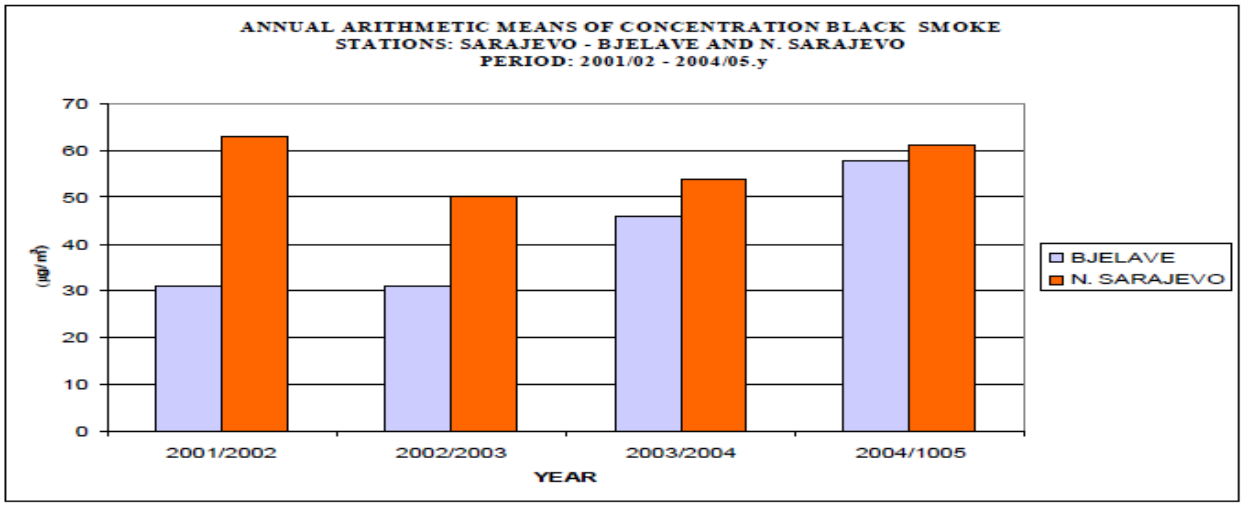
Figure 2. Sarajevo valley – level of inversion early afternoon



Graph 1



Graph 2



Graph 3

1.2.Effect of climate change on Environment in USA

Air pollution results from the combination of high emissions and unfavorable weather. Air quality managers seek to protect public health through emission controls. The resulting improvements in air quality may be modulated by changes in weather statistics, i.e., changes in climate. As we enter an era of rapid climate change, the implications for air quality need to be better understood, both for the purpose of air quality management and as one of the societal consequences of climate change. We review here current knowledge of this issue.

The two air pollutants of most concern for public health are surface ozone and particulate matter, and they are the focus of this review. Ozone is produced in the troposphere by photochemical oxidation of CO, methane and higher hydocarbons, and non-methane volatile organic (HOx) radicals. Ozone pollution is in general mostly a summer problem because of the photochemical nature of the source. Ozone production is usually limited by the supply of HOx and NOx, but can also be NMVOC-limited under highly polluted conditions and outside the summer season. The principal global sink for tropospheric ozone is photolysis in the presence of water vapor of the atmosphere. Uptake and transport on hemispheric scales in the free troposphere add atmospheric lifetime of ozone ranges from a few days in the boundary layer to weeks in the free troposphere. Ozone and its anthropogenic precursors ventilated from the source continents by vegetation (dry deposition) is also an important sink in the continental boundary layer (<2 km).Wet deposition is negligible as ozone and its major precursors have low solubility in water. The compounds (NMVOCs) by the hydroxyl radical (OH) in the presence of reactive nitrogen oxides (NOxhNOþNO2). NMVOCs, CO, and NOx have large combustion sources. Vegetation is a large NMVOC source. Methane has a number of biogenic and anthropogenic sources. OH originates mainly from atmospheric oxidation of water vapor and cycles in the atmosphere with other hydrogen oxide a significant back ground to surface ozone which is of increasing concern for meeting air quality standards (Holloway et al., 2003; United Nations Economic Commission for Europe (UNECE), 2007).

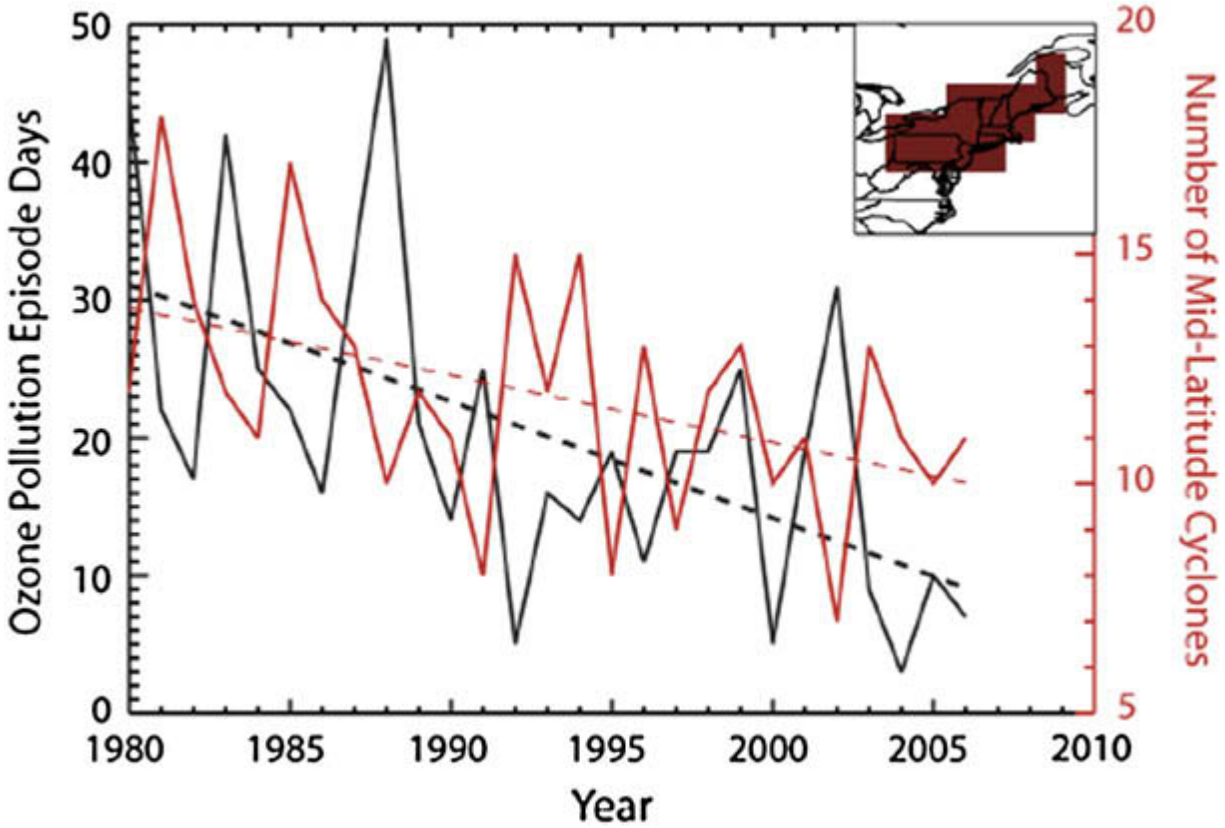


Fig. 1. 1980–2006 trend in the number of ozone pollution episodes (black) and the number of mid-latitude cyclones (red) in the northeastern U.S. in summer (Jun–Aug). Regression lines are also shown. The number of ozone pollution episode days for each summer is determined by averaging maximum daily 8-h average concentrations from a large number of monitoring sites over 2_ _ 2.5_ grid squares in the northeastern U.S. (inset), and tallying the number of grid-square days where this average exceeds 80 ppb. The number of cyclones is determined for each year from NCEP/NCAR Reanalysis data by tallying the westerly cyclone tracks passing through the eastern U.S.- Canada border region (40–50_N, 90-70_W), which are most important for ventilating the northeastern U.S. From Leibensperger et al. (submitted for publication).

Particulate matter (PM) includes as principal components sulfate, nitrate, organic carbon, elemental carbon, soil dust, and sea salt. The first four components are mostly present as fine particles less than 2.5 mm diameter (PM2.5), and these are of most concern for human health. Sulfate, nitrate, and organic carbon are produced within the atmosphere by oxidation of SO2, NOx, and NMVOCs. Carbon particles are also emitted directly by combustion. Nitrate and organic carbon exchange between the particle and gas phases, depending in particular on temperature. Seasonal variation of PM is complex and location-dependent; in general, PM needs to be viewed as an air quality problem year-round. PM is efficiently scavenged by precipitation and this is its main atmospheric sink, resulting in atmospheric lifetimes of a few days in the boundary layer and a few weeks in the free troposphere (similar to ozone). Unlike for ozone, however, export of PM from the source continents is limited by the precipitation scavenging that usually accompanies continental outflow. The PM background in the free troposphere is thus generally unimportant for surface air quality (Heald et al., 2006; UNECE, 2007). Exceptions are plumes from large dust

storms and forest fires which can be transported on intercontinental scales(Prospero, 1999; Forster et al., 2001).

Changes in climate affect air quality by perturbing ventilation rates (wind speed, mixing depth, convection, frontal passages), precipitation scavenging, dry deposition, chemical production and loss rates, natural emissions, and background concentrations. The potential importance of this effect can be appreciated by considering the observed inter annual variability in air quality where besides 2.5 micron particles the increase in hydrocarbon in the water vapor cloud forming zone have been observed. Fig.1 shows a 1980–2006 record of the number of exceedances of the U.S. air quality standard for ozone (80 ppb, 8-h average) in the Northeast. There is a long-term decrease attributable to reductions in
anthropogenic emissions (NOx, NMVOCs), but also a large year to year variability due to weather. Ozone is strongly correlated with temperature (Cox and Chu, 1995). The summer of 1988 was the hottest on record in the Northeast and experienced a record high number of exceedances. The summer of 1992 was the coolest in the 1980–2006 record due to the eruption of Mt. Pinatubo and it had a low number of exceedances. The difference in the number of episodes between 1988 and 1992 in Fig. 1 is a factor of 10. If conditions like 1988 become more frequent as a result of global warming, the implications for air quality could be severe. Similar inferences can be made for Europe, where the summer 2003 heat wave was associated with exceptionally high ozone (Vautard et al., 2005, 2007; Guerova and Jones, 2007; Solberg et al., 2008).

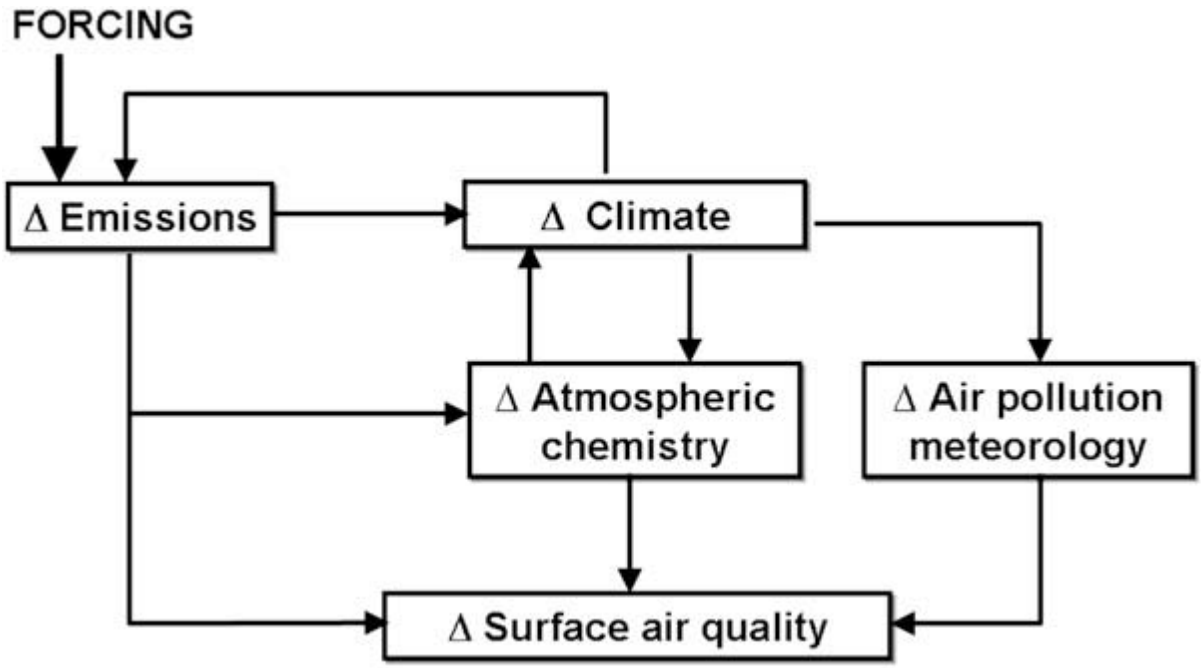


Fig. 2. Effect of climate change on surface air quality placed in the broader context of chemistry-climate interactions. Change is forced by a perturbation to anthropogenic emissions resulting from

socio-economic factors external to the chemistry-climate system. This forcing triggers interactive changes (D) within the chemistry-climate system resulting in perturbation to surface air quality.

Ozone and PM interact with solar and terrestrial radiation and as such are recognized as important climate forcing agents (Forster et al., 2007). Because of this dual role, the effect of climate change on surface air quality is often framed in the broader context of chemistry-climate interactions (Giorgi and Meleux, 2007; Gustafson and Leung, 2007), as shown diagrammatically in Fig. 2. In this diagram, an external forcing from change in anthropogenic emissions triggers interactive changes within the chemistry climate- emissions system, and the perturbation to surface air quality is a consequence of these interactive changes. Examples of forcings include anthropogenic emissions of CO2 (driving change in climate), NOx (driving atmospheric chemistry), or elemental carbon (driving change in climate as well as direct change in air quality). Change in atmospheric chemistry affects air quality (ozone and PM) and climate (ozone, PM, methane). Change in climate affects natural emissions (biosphere, dust, fires, lightning) with implications for air quality. Chemistry-climate interactions involve a number of possible feedbacks, as illustrated in Fig. 2, and these are in general poorly understood (Denman et al., 2007).

This review is made with a discussion of the effect of climate change on air pollution meteorology, i.e., the regional meteorological conditions that have a general effect on air quality. Then the examinaion and comparison of results from different approaches used to probe the effects of climate change on ozone, PM and hydrocarbon in air quality: observed correlations with meteorological variables, perturbation studies in chemical transport models (CTMs), and CTM simulations driven by global climate models (commonly called general circulation models or GCMs). We discuss the implications of these results for air quality management, and speculate on the possible implications of climate change for mercury as this is an emerging issue for air quality managers.

2. Effect of climate change on air pollution meteorology

The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) presents mean regional climate projections for the 21st century from an ensemble of about 20 GCMs (Christensen et al., 2007). Fig. 3 shows the projections of changes in annual mean surface temperature and precipitation in North America, Europe, and Asia for 2080–2099 vs. 1980–1999. The projections are based on the A1B scenario for greenhouse gas emissions from the IPCC Special Report on Emission Scenarios

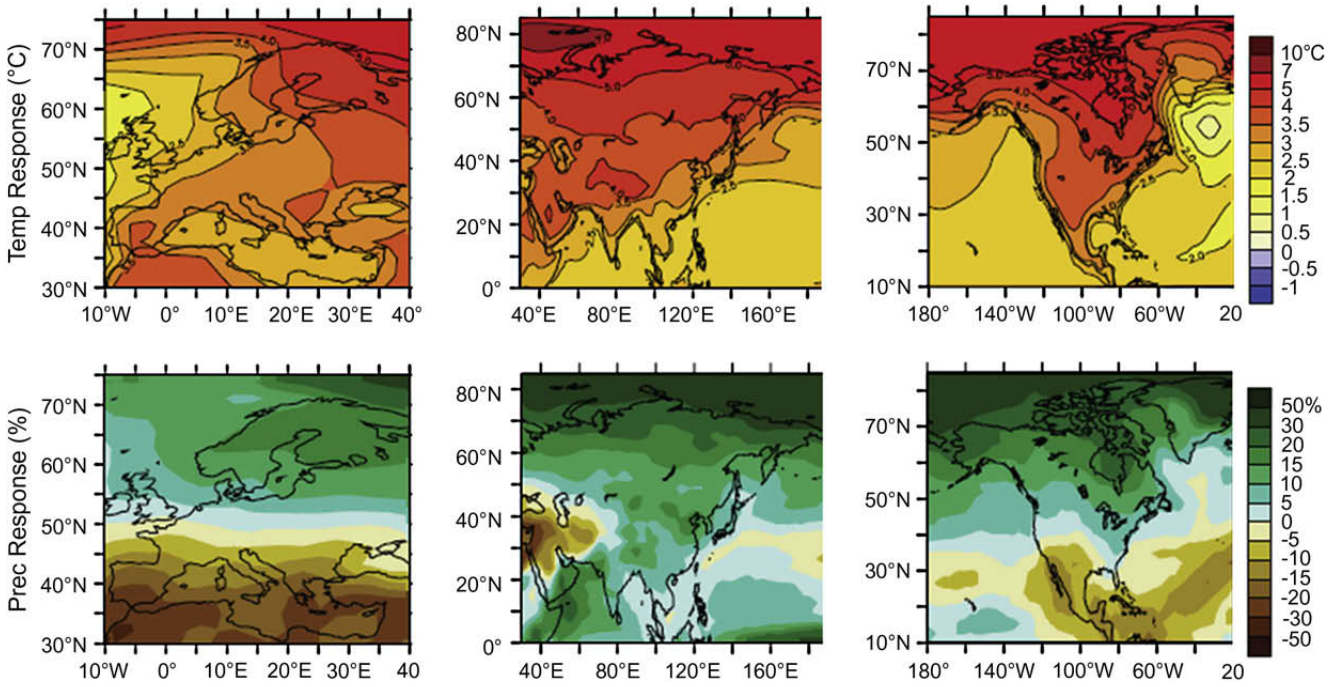


Fig. 3. Differences in annual mean surface air temperatures and precipitation in Europe, Asia, and North America for 2080–2099 vs. 1980–1999, averaged over an ensemble of about 20 GCMs contributing to the IPCC 4th assessment. Adapted from Christensen et al. (2007).

(SRES) [Nakicenovic et al., 2000]. Results from a subset of models indicate that the general spatial patterns of warming and precipitation are similar for the other SRES scenarios, with a _30% difference in warming relative to A1B depending on the scenario (B1 coolest, A2 warmest). The trends are roughly linear in time, so that the results in Fig. 3 can be interpolated to shorter time horizons. The patterns of Fig. 3 can be viewed as depicting our general understanding of 21st-century climate change, with the caveat that great uncertainty needs to be attached to regional climate projections.

Fig. 3 shows a strong warming over the northern mid-latitude continents, generally increasing in magnitude with increasing latitude. No area experiences cooling. The frequency of heat waves increases in all areas (Christensen et al., 2007). Global precipitation increases slightly due to enhanced evaporation from the oceans but there is considerable regional variability. Precipitation increases in the northern parts of North America and Europe but decreases in the southern parts. It increases in northern Asia but decreases in the Middle East. Models agree in general that high latitudes will become wetter and subtropical latitudes drier. There is a w10_ transitional band of latitudes centered at about 35_N in North America, 50_N in Europe, and 25_ N in East Asia where the model ensemble mean shows little change in precipitation (Fig. 3), but which really reflects disagreement between models as to whether the future climate will be wetter or drier (Christensen et al., 2007).

Other aspects of the hydrological cycle important for air quality (humidity, cloudiness, wet convection) follow qualitatively the precipitation projections of Fig. 3. On a global average basis, specific humidity will increase due to increased evaporation from the oceans, while relative humidity is not expected to change significantly (Held and Soden, 2000), but large regional variations are expected. Forkel and Knoche (2006) and Meleux et al. (2007) draw attention to the expected reduction in cloud cover over southern and central Europe in summer as an important factor promoting ozone formation. Trends in wet convective ventilation vary greatly between models, as the destabilizing effects of higher water vapor and sensible heat in the boundary layer are compensated by the stabilizing effect of latent heat release in the free troposphere (Rind et al., 2001; Wu et al., 2008a). Most GCMs find an increase oflightning in the future climate (Hauglustaine et al., 2005; Brasseur et al., 2006; Wu et al., 2008b), as convection is deeper even if it is less frequent.

Cold fronts spawned by mid-latitudes cyclones are major agents of pollutant ventilation in eastern North America, Europe, and eastern Asia (Cooper et al., 2001; Liu et al., 2003; Li et al., 2005; Ordonez et al., 2005; Leibensperger et al., submitted for publication). Fig.1 shows a strong interannual correlation between cyclone frequency and the number of high-ozone episodes in the northeastern U.S., illustrating the importance of frontal passages for pollutant ventilation. A consistent result across GCMs is that mid latitude cyclone frequency will decrease in the 21st-century climate and the prevailing cyclone tracks will shift pole ward (Lambert and Fyfe, 2006; Christensen et al., 2007). These changes will decrease the frequency of cold frontal passages in polluted mid-latitude regions and hence increase the frequency and duration of stagnation episodes (Mickley et al., 2004; Forkel and Knoche, 2006; Murazaki and Hess, 2006; Wu et al., 2008a). Climatological data for 1950–2000 indeed indicate a decrease and poleward shift of northern mid-latitude cyclones (Zishka and Smith, 1980; McCabe et al., 2001). Leibensperger et al. (submitted for publication) find a decreasing 1980–2006 cyclone trend for eastern North America in summer in the NCEP/NCAR Reanalysis (Fig. 1), as well as in a GCM simulation forced by increasing greenhouse gases, although the trend is not present in the NCEP/ DOE Reanalysis.

The effect of climate change on mixing depth is uncertain. GCM simulations for the 21st century find increases and decreases of mixing depths in different regions with no consistent patterns (Hogrefe et al., 2004; Mickley et al., 2004; Leung and Gustafson, 2005; Murazaki and Hess, 2006; Chen et al., submitted for publication; Lin et al., 2008a; Wu et al., 2008a). Murazaki and Hess (2006) find that trends in mixing depth vary greatly between two versions of the same GCM with different resolutions, implying that the trends are not robust.

3. Observed correlations of air quality with meteorological variables

Statistical correlation of pollutant concentrations with meteorological variables has been an active area of study for over three decades, with three principal purposes: (1) to remove the effect of meteorological variability in analyses of long-term trends of air quality, (2) to construct empirical models for air quality forecasts, and (3) to gain insight into the processes affecting pollutant concentrations. They are useful for our purpose as an observational basis for diagnosing and understanding the sensitivity of pollution to weather.

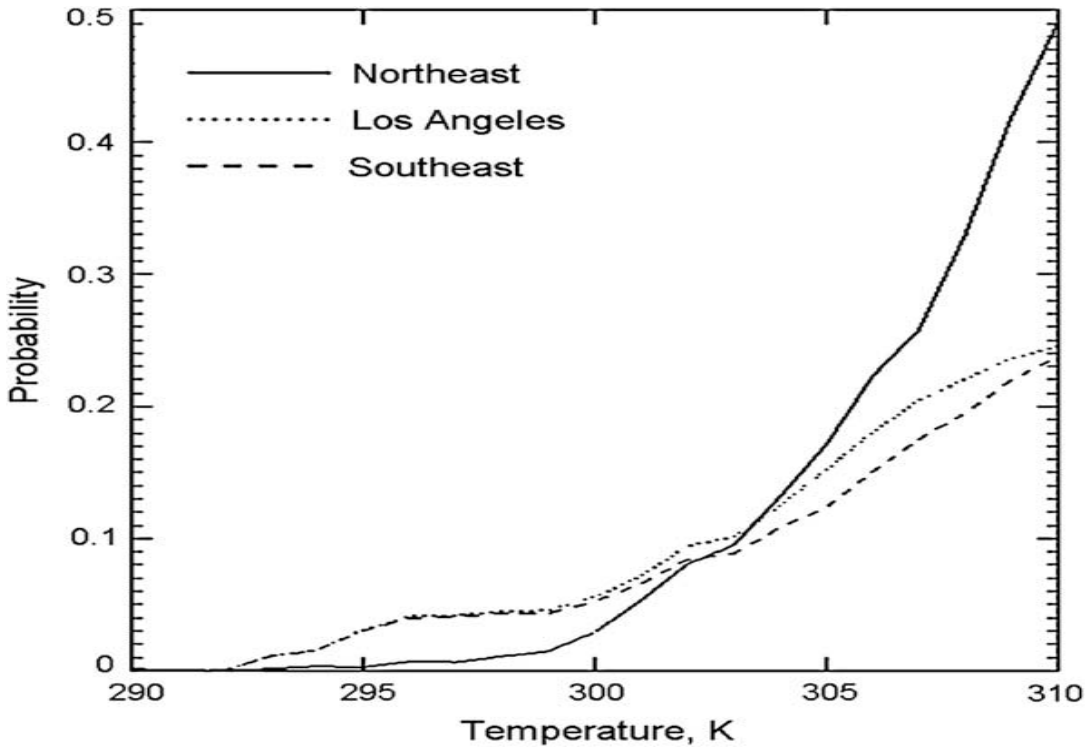


Fig. 4. Observed probability that the maximum daily 8-h average ozone will exceed 80 ppb for a given daily maximum temperature, based on 1980–1998 data. Values are shown for the Northeast U.S., the Los Angeles Basin, and the Southeast U.S. Adapted from Lin et al. (2001).

3.1. Ozone

Two recent studies in Europe (Ordonez et al., 2005) and the U.S. (Camalier et al., 2007) present systematic regional-scale analyses of the correlation of ozone with a large number of candidate meteorological variables. Ordonez et al. (2005) find that the dominant predictor variables for ozone at sites in Switzerland in summer are temperature, morning solar radiation, and number of days since last frontal passage. Camalier et al. (2007) find that as much as 80% of the variance in the maximum daily 8-h average ozone in the eastern U.S. can be explained by a generalized linear model with temperature (positive) and relative humidity (negative) as the two most important predictor variables. Temperature is most important in the Northeast and relative humidity is more important in the Southeast. Wind speed and direction are important for only a small subset of sites. Studies for different regions indicate that

correlations with mixing depth are weak or insignificant (Rao et al., 2003; Ordonez et al., 2005; Wise and Comrie, 2005).

Strong correlation of elevated ozone with temperature is a ubiquitous feature of observations in polluted regions, even in prevailingly hot climates such as the southwestern U.S. (Wise and Comrie, 2005) and Egypt (Elminir, 2005). The correlation is generally limited to polluted conditions, i.e., ozone in excess of about 60 ppb; lower ozone concentrations more representative of background show no correlation with temperature (Sillman and Samson, 1995). Fig. 4 shows the probability of ozone exceeding the 80 ppb U.S. air quality standard as a function of daily maximum temperature for three U.S. regions, based on 1980–1998 data. In the Northeast, the probability can double for a 3 K increase in temperature, illustrating the potentially large sensitivity to climate change.

Table 1:Dependence of surface air quality on meteorological variables

Variable	Ozone	PM
Temperature	++	−
Regional stagnation	++	++
Wind speed	−	−
Mixing depth	=	− −
Humidity	=	+
Cloud cover	−	−
Precipitation	=	− −

A few studies have used observed correlations of high-ozone events (>80 ppb) with meteorological variables, together with regionally downscaled GCM projections of these meteorological variables, to infer the effect of 21st-century climate change on air quality if emissions were to remain constant. A major assumption is that the observed present-day correlations, based on short-term variability of meteorological variables, are relevant to the longerterm effect of climate change. Cheng et al. (2007) correlated ozone levels at four Canadian cities with different synoptic weather types, and used projected changes in the frequency of these weather types (in particular more frequent stagnation) to infer an increase in the frequency of high-ozone events by 50% in the 2050s and 80% in the 2080s. Lin et al. (2007) applied the relationship of Fig. 4 for the northeastern U.S. to infer a 10–30% increase in the frequency of high-ozone events by the 2020s and a doubling by 2050. Wise (in press) projected a quadrupling in the frequency of high-ozone events in Tucson, Arizona by the end of the 21st century.

3.2. Particulate matter

Observed correlations of PM concentrations with meteorological variables are weaker than for ozone (Wise and Comrie, 2005). This reflects the diversity of PM components, the complex coupling of PM to the hydrological cycle, and various compensating effects discussed in Section 4. No significant correlations with temperature have been

reported in the literature to our knowledge. Aw and Kleeman (2003) report that peak nitrate concentrations in the Los Angeles Basin decrease with increasing temperature but the data are very noisy. Strong correlation of PM with stagnation is still expected as for ozone and is reported by Cheng et al. (2007) in their study of four Canadian cities. Koch et al. (2003) report a negative correlation of sulfate with cloud cover in Europe over synoptic time scales, which they interpret as reflecting in part the correlation of clouds with precipitation and in part a decrease of SO2 photochemical oxidation, more than compensating for the role of clouds in promoting aqueous-phase production of sulfate. Wise and Comrie (2005) find a negative correlation of PM with relative humidity in the southwestern U.S, reflecting the importance of dust as a PM source in that region.

4. Pollutant transport Models

4.1.Perturbation studies in chemical transport models

A number of studies have investigated the sensitivity of ozone and PM air quality to climate change by perturbing individual meteorological variables in regional CTMs. These studies are useful for understanding the important processes affecting pollutant concentrations, complementing the empirical approach described in Section 3. They also provide a diagnostic tool for more complex GCM–CTM simulations. General results from perturbation studies in the literature are summarized in Table 1. They are not always consistent with the correlation analyses described in Section 3, likely reflecting covariances between meteorological variables as discussed below.

Model perturbation studies consistently identify temperature as the single most important meteorological variable affecting ozone concentrations in polluted regions (Morris et al., 1989; Aw and Kleeman, 2003; Sanchez-Ccoyllo et al., 2006; Steiner et al., 2006; Dawson et al., 2007a). This is consistent with the strong observed correlation of ozone pollution episodes with temperature. The model dependence of ozone on temperature is due to two principal factors (Jacob et al., 1993; Sillman and Samson, 1995): (1) the temperature-dependent lifetime of peroxyacetylnitrate (PAN), a major sequestering reservoir for NOx and HOx radicals even at high temperatures; and (2) the temperature dependence of biogenic emission of isoprene, a major VOC precursor for ozoneformation under high-NOx conditions. Model slopes (v½O3_=vT) are typically in the range 2–10 ppb K_1, with maximum values in urban areas having high ozone formation potential (Sillman and Samson,1995; Baertsch-Ritter et al., 2004; Steiner et al., 2006). They tend to be lower than the observed ozone-temperature regression slopes (d[O3]/dT) (Sillman and Samson, 1995). Jacob et al. (1993) find in a CTM simulation that this can be explained by the correlation of high temperature with stagnation and sunny skies, not accounted for in simple perturbation studies. Perturbation studies diagnose the partial derivative, while observed correlations diagnose the total derivative.

Water vapor has compensating effects on ozone. Increasing water vapor increases ozone loss by the reaction sequence where (R2) competes with reaction of the excited oxygen atom O(1D) withN2 orO2, stabilizing O(1D) to the ground-state atomO(3P) which eventually reacts with O2 to return ozone. Because of (R2), models

$$O_3 + h\nu \rightarrow O_2 + O(^1D) \quad (R1)$$

$$O(^1D) + H_2O \rightarrow 2OH \quad (R2)$$

find that background tropospheric ozone decreases with increasing water vapor (Johnson et al., 1999). Under polluted conditions the effect is more complicated, because theOHradicals produced by (R2) react with VOCs and CO to produce ozone, while also converting NO2 to nitric acid to suppress ozone formation. Model perturbation studies thus find that the sensitivity of ozone towater vapor is weak and of variable sign under polluted conditions, reflecting these compensating effects (Awand Kleeman, 2003; Baertsch-Ritter et al., 2004; Dawson et al., 2007a). Some of the correlation of ozone with relative humidity seen in theobservations, as inCamalier et al. (2007) could reflect a joint association in polluted air masses rather than a cause-and-effect relationship. An additional effect under very dry conditions is drought stress on vegetation, which can suppress stomatal uptake of ozone and hence dry deposition; this effect is generally not included in models but appears to have been a significant factor contributing to the high ozone over Europe in the summer of 2003 (Vautard et al., 2005; Solberg et al., 2008).

Increasing solar radiation in model perturbation studies causes an increase of ozone, but the effect is weak (Sillman and Samson, 1995; Dawson et al., 2007a). This reflects similar complexities as in the case of increased water vapor, i.e., the increased UV flux stimulates both ozone production and loss. The observed correlation of ozone with solar radiation seen in some studies such as Ordonez et al. (2005) could reflect in part the association of clear sky with high temperatures.

Simple investigation of the sensitivity of ozone to ventilation has been conducted in models by perturbing wind speeds or mixing depths. Weaker wind speeds in polluted regions cause ozone to increase, as would be expected simply from a longer reaction time and increased aerodynamic resistance to dry deposition (Baertsch-Ritter et al., 2004; Sanchez-Ccoyllo et al., 2006; Dawson et al., 2007a). Mixing depths have a more complicated effect, reflecting the ambiguity seen in the observational analyses (Section 3). Ozone concentrations in the lower free troposphere at northern mid-latitudes are typically about 60 ppb (Logan, 1999), so that increasing mixing depth entrains relatively high-ozone air; in addition, diluting NOx in a deeper mixed layer increases its ozone production efficiency (Liu et al., 1987; Kleeman, 2007). The model

sensitivity study by Dawson et al. (2007a) for the eastern U.S. finds a positive dependence of ozone on mixing depth where surface ozone is low and a negative dependence where it is high, consistent with the above arguments. Sanchez-Ccoyllo et al. (2006) find a decrease in simulated ozone for the Sao Paulo metropolitan area as the mixing depth increases, reflecting the low ozone background there. Aw and Kleeman (2003) find little sensitivity of ozone to mixing depth in model simulations of the Los Angeles Basin, which may reflect ozone enrichment of the lower free troposphere due to diurnal pollutant venting. Additional Los Angeles Basin simulations by Kleeman (2007) show both positive and negative ozone responses to increases in mixing depth.

4.2. Particulate matter

Model perturbation studies find that the effect of temperature on PM depends on the PM component. Sulfate concentrations increase with temperature (Aw and Kleeman, 2003; Dawson et al., 2007b; Kleeman, 2007), due to faster SO2 oxidation (higher rate constants and higher oxidant concentrations). In contrast, nitrate and organic semi-volatile components shift from the particle phase to the gas phase with increasing temperature (Sheehan and Bowman, 2001; Tsigaridis and Kanakidou, 2007). Model sensitivity studies indicate large decreases of nitrate PM with increasing temperature, dominating the overall effect on PM concentrations in regions where nitrate is a relatively large component (Dawson et al., 2007b; Kleeman, 2007). Awand Kleeman (2003) and Dawson et al. (2007b) find mean nitrate PM decreases of 7 and 15% K_1 in Los Angeles and the eastern U.S. respectively. Both studies find much weaker sensitivities of organic PM to temperature, reflecting the weaker temperature dependences of the gas-particle equilibrium constants. Overall, Dawson et al. (2007b) find mean negative dependences of total PM2.5 in the eastern U.S. of 2.9% K_1 in January and 0.23% K_1 in July, the larger effect in winter reflecting the greater abundance of nitrate. Some sulfate-rich regions in their simulation exhibit a positive dependence in summer.

PM concentrations decrease with increasing precipitation as wet deposition provides the main PM sink. The critical variable is precipitation frequency rather than precipitation rate, since scavenging within a precipitating column is highly efficient (Balkanski et al., 1993). Dawson et al. (2007b) perturbed precipitation areas and rates in their CTM and find a high PM sensitivity in summer, when events tend to be convective and small in scale, vs. a low sensitivity in winter when synoptic-scale storms dominate. This is consistent with precipitation frequency being the dominant factor Changes in ventilation (wind speed, mixing depth) have stronger effects on PM than on ozone because of the lower PM background concentrations. PM concentrations typically decrease by an order of magnitude between polluted regions and the diluting background air, whereas for ozone the decrease is typically less than a factor of 2 and

concentrations may actually increase with altitude. Dawson et al. (2007b) and Kleeman (2007) find that increasing ventilation rates in their models has a simple diluting

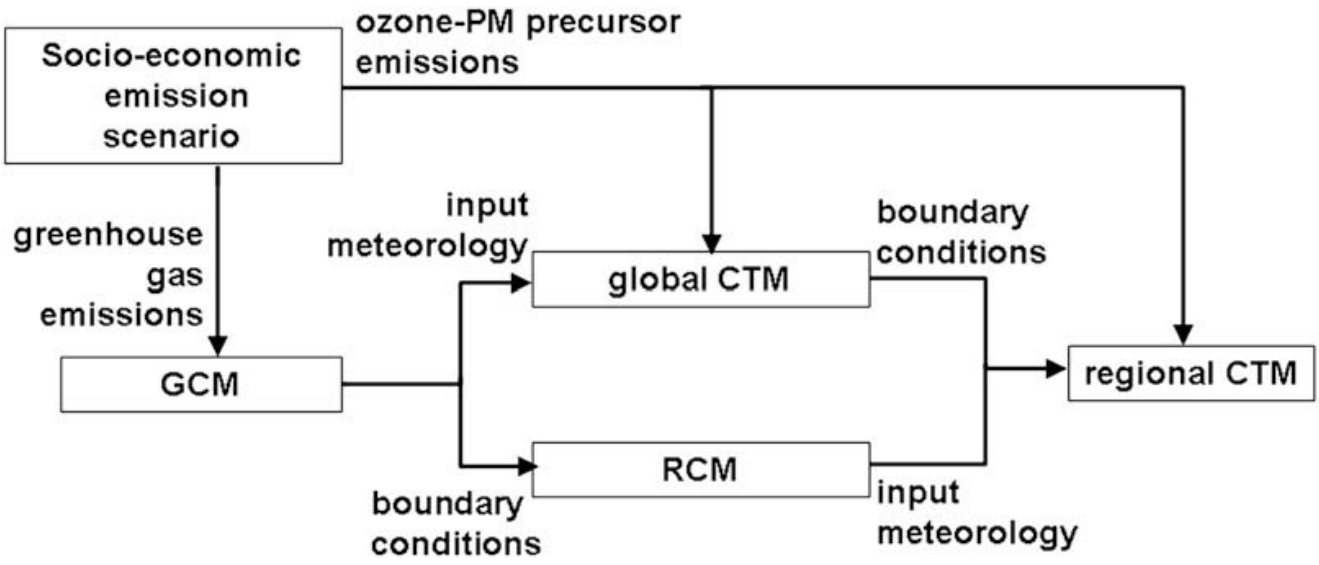


Fig. 5. General GCM–CTM architecture for investigating the effect of climate change on air quality. The socio-economic emission scenario driving the simulation is equivalent to the forcing of Fig. 2. GCMhgeneral circulation model; CTMhchemical transport model; RCMhregional climate model. The CTM simulations are represented here as conducted offline from the parent meteorological model (GCM or RCM), but they can also be conducted on-line (see Section 5.1).

effect on PM. Pye et al. (in press) point out that increasing mixing depth in the future climate is generally associated with a decrease in precipitation, representing a compensating effect.

Changes in humidity and cloudiness also affect PM. Increasing relative humidity increases the PM water content and hence the uptake of semi-volatile components, mainly nitrate and also possibly organics. Dawson et al. (2007b) find in their model perturbation studies a large sensitivity of nitrate PM to humidity, but little sensitivity of other PM components. They find little sensitivity to changing cloud cover or liquid water content, despite the importance of clouds for sulfate production by aqueous-phase oxidation of SO_2. A likely explanation is that cloud frequency, i.e., the frequency for processing of air through cloud, is the critical variable since aqueous-phase SO_2 oxidation by H_2O_2 in cloud takes place on a time scale of minutes. This processing frequency and more generally the simulation of aqueous-phase sulfate formation in clouds is difficult to parameterize adequately in either mesoscale or global models (Koch et al., 2003).

5. GCM–CTM studies

5.1. General approach

Empirical correlations and model perturbation studies as described in the previous

sections cannot capture the complex coupling between meteorological variables involved in climate change nor the parallel change in anthropogenic emissions. A CTM driven by future-climate GCM fields is required. Fig. 5 shows the general architecture of the GCM–CTM approach. A scenario of future greenhouse gas emissions drives a GCM simulation of global climate change. The GCM provides input to a CTM that simulates atmospheric composition on a global scale. Changes in the global anthropogenic emissions of ozone and PM precursors consistent with the greenhouse scenario may also be input to the CTM, or not if one wishes to isolate the effect of climate change. The GCM can provide boundary conditions to a regional climate model (RCM) for finer-scale resolution of climate change over the region of interest.
The air quality simulation is then done with a regional CTM using meteorological input from the RCM, chemical boundary conditions from the global CTM, and (if one wishes) future pollutant emissions.

The CTM simulation can be integrated on-line within the GCM/RCM (Giorgi and Meleux, 2007), but is more often conducted off-line using archived GCM/RCM meteorological fields (e.g., Liang et al., 2006). The off-line approach has more computational flexibility but it requires a separate transport code to replicate that of the GCM/ RCM as well as customized archival of GCM/RCM meteorological data affecting the air quality simulation (such as convective mass fluxes, boundary layer turbulence, vertical distribution of precipitation).We refer here to GCM-CTMs as chemical simulations driven by GCM meteorology, whether the CTM is on-line or off-line.

The GCM–CTM approach offers a general and flexible framework for investigating the effect of climate change on air quality, but it is computationally expensive. Consider an investigation of 2000–2050 climate change. This requires a continuous GCM simulation for the 50-year period with time-dependent radiative forcing of climate. The reference point for the air quality simulation must be the GCM year 2000, not the observed meteorological year 2000; the two are different since the GCM is not forced by observations and thus can only simulate a hypothetical year consistent with 2000 climate. Because of natural interannual variability in the GCM (a consequence of chaos in the equation of motion), one cannot simply compare CTM simulations for GCM year 2050 vs. GCM year 2000 to diagnose the effect of climate change. It could be for example that these particular GCM years are anomalously cool or warm. In the same way that multiple years of observations are needed to generate air quality statistics for the present-day climate, it is necessary to conduct several years of CTM simulations centered around the target GCM years (here 2000 and 2050) in order to separate the effect of climate change from interannual variability. Downscaling to the regional scale compounds the computational challenge. To reduce cost and complexity, GCM–CTM studies in the literature often omit some of the components in Fig. 5. Some omit the

regional components and diagnose change in air quality from the global CTM simulation (with spatial resolution of a few hundred km). Others omit the global CTM component and hence ignore climate-driven changes in background concentrations

5.2. Ozone

A large number of global GCM–CTM studies have investigated the effect of 21st-century climate change on the global tropospheric ozone budget and the surface ozone background; they are reviewed by Wu et al. (2008b) and are not discussed in detail here since our focus is on regional ozone pollution. The most important climate variables affecting tropospheric ozone on a global scale are stratosphere-troposphere exchange, lightning NOx, and water vapor. These three variables are all expected to increase in the future climate; the first two cause an increase in ozone and the third a decrease. Different models thus project changes in the global tropospheric ozone burden over the 21st century ranging from _5% to þ12% (Wu et al., 2008b). Despite this disagreement in sign, the models agree that climate change will decrease the ozone background in the lower troposphere where the water vapor effect is dominant (stratosphere-troposphere exchange and lightning are more important in the upper troposphere). An ensemble analysis of 10 global GCM-CTMs by Dentener et al. (2006) indicates a decrease of annual mean surface ozone in the northern hemisphere by

Table 2
GCM–CTM studies of the effect of climate change on ozone air quality.[a]

Reference	Domain[b]	Scenario[c]	Time horizon[d]	Metric reported	Surface ozone change (ppb)[e]
Hogrefe et al. (2004)	Eastern U.S.	A2	2080 vs. 1990	JJA MDA8[f]	50 eastern U.S. cities: +4.4 (2050)[g] Eastern U.S.: +2.7 (2020), +4.2 (2050), +5.0 (2080)
Liao et al. (2006)	Global	A2	2100 vs. 2000	July mean	Northeastern U.S.: +4–8 Central Europe: +2–6
Murazaki and Hess (2006)	Global	A1	2090 vs. 1990	JJA MDA8	Eastern U.S.: +2–5 Western U.S.: insignificant
Racherla and Adams (2006)	Global	A2	2050 vs. 1990	Summer mean	Eastern U.S.: +1–5
Kunkel et al. (2007)	Global/ northeastern U.S.	A1FI, B1	2090 vs. 1990	JJA MDA8	Northeastern U.S.: +10–25% (A1FI), +0–10% (B1)
Tagaris et al. (2007)	U.S.	A1B	2050 vs. 1990	JJA MDA8	Midwest U.S.: −2.5% Northeastern U.S.: +2.8%
Jacobson (2008)	Global/urban		Present vs. preindustrial CO_2	Jul–Nov means	Mean U.S.: +0.12[h] Los Angeles: +5
Lin et al. (2008a)	Global	A1FI, B1	2090 vs. 1990	JJA MDA8	U.S.: +3–12 (A1FI), +3–6 (B1) Eastern China: +3–12 (A1FI), +1–5 (B1)
Nolte et al. (2008)	Global/U.S.	A1B	2050 vs. 2000	JJA MDA8[i]	Texas, eastern U.S.: +1–8 Midwest, northwestern U.S.: −1–3
Wu et al. (2008a)	Global	A1B	2050 vs. 2000	JJA MDA8	Midwest, northeastern U.S.: +2–5 Southeastern U.S.: insignificant
Avise et al. (submitted for publication)	U.S.	A2	2050 vs. 2000	July MDA8	Northeastern U.S.: +4 Southeastern U.S.: −6
Langner et al. (2005)	Europe	IS92a[j]	2060 vs. 2000	Apr–Sept MDA[k]	South-central Europe: +0–12% Scandinavia: −0–4%
Forkel and Knoche (2006, 2007)	Europe	IS92a	2030 vs. 1990	JJA MDA	N. Italy: +10 S. Germany, E. France: +5–7
Meleux et al. (2007)	Europe	A2, B2	2085 vs. 1975	JJA MDA	West-central Europe: +10–18 (A2), +2–8 (B2)

a- Effect of climate change only, holding anthropogenic emissions of ozone precursors constant.

b- Slashes indicate nesting of global and regional CTMs.

c -Socio-economic scenario for 21st-century greenhouse gas emissions from the IPCC Special Report on Emission Scenarios (Nakicenovic et al., 2000): A1 (rapid economic growth and efficient introduction of new technologies), A2 (very heterogeneous world with sluggish economic growth), B1 (convergent world with rapid introduction of clean and efficient technologies), B2 (focus on sustainability, intermediate economic development). The A1 scenario further distinguishes three sub-scenarios (A1FI, A1T, A1B) by technological emphasis.

d- Climate change is computed from a transient GCM simulation over the indicated time horizon (except for Liao et al. (2006), who used equilibrium climates). Most studies simulate several years around the target year to resolve interannual variability.

e- Selected results; more information is given in the original reference. Some results are given as % increases or decreases.

f- June–July–August maximum daily 8-h average.

g- Result presented in Bell et al. (2007).

h- þ0.72 ppbv for areas with surface ozone > 35 ppbv.

i -Results for September–October indicate in general larger increases.

j -Older scenario from the IPCC 2nd Assessment Report, with CO2 climate forcing comparable to the A1B scenario.

k Maximum daily ozone, averaging time not specified.

0.8 - 0.7 ppb for 2000–2030 climate change, with the standard deviation describing the spread between models.

Table 2 lists the GCM–CTM studies in the literature that have examined the effect of climate change on regional ozone pollution. Almost all have targeted North America or Europe. The only targeted study of eastern Asia is that of Lin et al. (2008a). The results in Table 2 indicate that polluted regions at northern mid-latitudes will experience higher surface ozone as a result of 21st-century climate change, despite the decrease in the surface ozone background. The projected increases are typically in the 1–10 ppb range and are found to be driven primarily by temperature, consistent with the correlative and model sensitivity analyses discussed in Sections 3 and 4. Decreases are found only in relatively clean areas where ozone is largely determined by its background (Lin et al., 2008a; Nolte et al., 2008; Wu et al., 2008b), and in areas projected by the specific GCM/RCM to experience increased cloudiness and little warming: Scandinavia in Langner et al. (2005), the Midwest U.S. in Tagaris et al. (2007) and Nolte et al. (2008) (who used the same driving meteorological fields), the southeastern U.S. in Avise et al. (submitted for publication). Nolte et al. (2008) find

larger increases (3–8 ppb) over the central U.S. in September–October than in summer, which might reflect a seasonal shift to NMVOC-limited conditions more sensitive to isoprene emission (Jacob et al., 1995).

A general finding among models is that the ozone increase from climate change is largest in urban areas where present-day ozone is already high (Bell et al., 2007; Jacobson, 2008; Nolte et al., 2008). This is consistent with the model perturbation studies reviewed in Section 4 and reflects the high ozone production potential of urban air. Most models also find that the sensitivity of ozone to climate change is highest during pollution episodes (Hogrefe et al., 2004; Tagaris et al., 2007;Wu et al., 2008a), although some studies do not find such an effect (Murazaki and Hess, 2006; Lin et al., 2008a). For pollution episodes (i.e., at the high end of the ozone probability distribution), Wu et al. (2008a) and Hogrefe et al. (2004) find increases of up to 10 ppb by 2050 and up to 17 ppb by 2080 respectively. Wu et al. (2008a) argue that the higher sensitivity during episodes reflects a similar trend in temperature, i.e., the temperature rise during heat waves is larger than that of mean temperature.

Significant ozone increases in the northeastern U.S. are found in all the models of Table 2. This likely reflects the strong sensitivity of ozone in that region to temperature and to the frequency of frontal passages, for which climate projections are consistent across GCMs. Significant increases are also found in all models for southern and central Europe, where future climate projections consistently show large warming and decreased cloudiness in summer (Christensen et al., 2007). Other regions show less consistency between models. Racherla and Adams (2006) and Tao et al. (2007) find large ozone increases in the southeastern U.S. whileWu et al. (2008a) find little effect there and Avise et al. (submitted for publication) find a large decrease. Wu et al. (2008a) find a large ozone increase in the Midwest due to increased stagnation while Tagaris et al. (2007) and Nolte et al. (2008) find a decrease there due to increased cloudiness. Murazaki and Hess (2006) find no significant increase in the western U.S. due to the effect of the reduced ozone background, but Tao et al. (2007) find large increases there.

Table 3
GCM–CTM studies of the effect of climate change on PM air quality.[a]

Reference	Model	Scenario[b]	Time horizon[c]	Metric reported	Surface PM change ($\mu g\,m^{-3}$)[d]
Liao et al. (2006); Racherla and Adams (2006)	Global	A2	2100 vs. 2000	Annual mean	Central Europe: +1 (sulfate), +0.5–1 (carbonaceous) Eastern U.S.: +1 (sulfate)
Tagaris et al. (2007)	U.S.	A1B	2050 vs. 2000	Annual mean	U.S.: −10% ($PM_{2.5}$)
Unger et al. (2006)	Global	B1	2030 vs. 1990	Annual mean	Southern Europe: +0.1–1 (sulfate)
Heald et al. (2008)	Global	A1B	2100 vs. 2000	Annual mean	Eastern U.S.: +0.5 (secondary OC)
Jacobson (2008)	Global/urban		Present vs. preindustrial CO_2	Jul–Nov mean	U.S.: +0.065 ($PM_{2.5}$)
Spracklen et al. (submitted for publication)	Global	A1B	2050 vs. 2000	JJA mean	Western U.S.: +0.5 (carbonaceous)[e]
Pye et al. (in press)	Global	A1B	2050 vs. 2000	Annual mean	U.S.: −0.3 to +0.3 (sulfate), −0.2 to 0 (nitrate)
Avise et al. (submitted for publication)	U.S.	A2	2050 vs. 2000	July mean	U.S.: −1 ($PM_{2.5}$)

a- Effect of climate change only, holding anthropogenic emissions of PM and precursors constant.
b -See footnote in Table 2.
c -See footnote in Table 2.
d -Selected results; more information is given in the original reference. Some results are given as % changes.
e- Climate-driven increase in wildfires accounts for 70% of this increase.

Differences in air pollution meteorology between GCMs/RCMs are a major cause of the above discrepancies (Kunkel et al., 2007). Differences between CTMs in the parameterizations of natural emissions, chemistry, and deposition also play a role. Wu et al. (2008a) point out that model differences in isoprene oxidation mechanisms have significant implications for sensitivity to climate change in regions where NOx is relatively low and isoprene is high, such as the southeastern U.S. Oxidation of isoprene by OH produces organic peroxy radicals RO2, which react with NO by two branches:

$$RO_2 + NO \rightarrow RO + NO_2 \qquad (R3a)$$

$$RO_2 + NO + M \rightarrow RONO_2 + M \qquad (R3b)$$

(R3a) goes on to produce ozone by NO2 photolysis, while (R3b) produces isoprene nitrates and can be a major sink for NOx (Liang et al., 1998). Isoprene nitrate chemistry is highly uncertain, as reviewed by Horowitz et al. (2007). Isoprene nitrate yields R3b/(R3aþ R3b) range in the literature from 4 to 15%, and the fate of these nitrates (in particular whether they recycle NOx or represent terminal sinks) remains largely unknown (Giacopelli et al., 2005). A recent chamber study by Paulot et al. (2008) finds a 11% yield of isoprene nitrates with 50% regeneration of NOx upon subsequent

oxidation. There may also be substantial production of isoprene nitrates from oxidation of isoprene by the nitrate radical but this is even less understood (Horowitz et al., 2007).Wu et al. (2008a) find that their assumed isoprene nitrate yield of 12%, with no NOx recycling, is responsible for their lack of sensitivity of ozone to climate change in the southeastern U.S. Racherla and Adams (2006) did not include isoprene nitrate formation in their model and find by contrast a large ozone sensitivity to climate change in that region.

Another major factor of uncertainty is the sensitivity of isoprene emission to climate change. All the models in Table 2 use similar parameterizations for isoprene emission in which the main dependence is on temperature, with roughly a doubling of emissions per 4 K temperature increase (Guenther et al., 2006). But it is not clear that this standard model dependence, based on short term observations for the present climate, is relevant to the much longer time scales involved in climate change. In addition, there is evidence that increasing CO2 causes plants to decrease isoprene emission (Centritto et al., 2004; Arneth et al., 2007; Monson et al., 2007), and this is not accounted for in the models of Table 2 (except for Lin et al. (2008a), who assume a very weak dependence). A study by Heald et al. (in press) of 2000–2100 change of isoprene emission for the A1B climate (717 ppm CO2 in 2100) finds a global 37% increase in emission when only temperature is taken into effect, a 8% decrease when both changes in temperature and CO2 are considered, and a doubling when changes in net primary productivity (NPP) and land cover are also considered. The response of land cover to climate change is very uncertain, and forest dieback in regions subjected to drier climates would cause isoprene emission to decrease (Sanderson et al., 2003).

5.3. Micro Particulate matters

Table 3 lists the GCM–CTM studies that have examined the impact of 21st-century climate change on surface PM concentrations in polluted regions. Projected changes are in the range _0.1– 1 mgm_3. This represents a potentially significant effect but there is little consistency between studies, including in the sign of the effect. Racherla and Adams (2006), Tagaris et al. (2007), and Avise et al. (submitted for publication) emphasize the importance of changing precipitation in modulating the PM sink. Tagaris et al. (2007) find a 10% decrease in PM2.5 throughout the U.S. due to increased precipitation in the future climate. Racherla and Adams (2006) find a global decrease in PM2.5, as would be expected from the global precipitation increase, but a regional increase in the eastern U.S. due to lower precipitation there. Differences between GCM/RCMs in the regional precipitation response to climate change are a major cause of discrepancy in the PM response (Racherla and Adams, 2006; Pye et al., in press). From the IPCC ensemble of models (Fig. 3), one may expect changes in precipitation to drive PM increases in southern North America and southern Europe, but decreases in most other continental regions of northern midlatitudes.

Factors other than precipitation are also important in driving the sensitivity of PM to climate change. Liao et al. (2006), Unger et al. (2006), and Pye et al. (in press) point out that higher water vapor in the future climate leads to higher concentrations of H2O2, the principal SO2 oxidant, thus increasing sulfate concentrations. Liao et al. (2006) find that increased stagnation in the future climate causes PM to increase in polluted regions. A study of secondary organic PM by Heald et al. (2008) finds a positive response to rising temperature in continental regions due to increasing biogenic NMVOC emissions.

Increasing frequency of wildfires from droughts in the future climate could be yet another important factor driving PM increases. The anomalously hot summer 2003 in Europe was associated with record wildfires that significantly degraded air quality for both PM and ozone (Vautard et al., 2007; Solberg et al., 2008). The GCM– CTM study of Spracklen et al. (submitted for publication) including projection of climate-driven increase in wildfires finds a 0.5 mgm_3 increase in carbonaceous PM in the western U.S. in summer.

6. Effect of climate change on mercury

The effect of climate change on mercury cycling has received no attention to date but is a potentially important issue. Increased volatilization of mercury from ocean and land reservoirs as a result of climate change would transfer mercury between ecosystems via atmospheric transport, re-depositing it in a more mobile and presumably more toxic form. Volatilization of mercury from the ocean is directly affected by warming (lower solubility of elemental mercury) and would also be affected by changes in ocean biology and circulation (Strode et al., 2007; Sunderland and Mason, 2007). Increased volatilization of soil mercury could potentially be of considerable importance, as the amount of mercury stocked in soil (1.2_106 Mg) dwarfs that in the atmosphere (6 _103 Mg) and in the ocean (4 _104 Mg) (Selin et al., 2008). Soil mercury is mainly bound to organic matter (Ravichandran, 2004). Future warming at boreal latitudes could release large amounts of soil organic matter to the atmosphere as CO2, both through increased respiration (Raich and Schlesinger, 1992) and increased fires (Spracklen et al., submitted for publication). It is not known whether organic-bound mercury is emitted or retained in the soil when the carbon is respired. Boreal peatland fires may have very high mercury emissions from burning of the peat (Turetsky et al., 2006).

7. Implications for air quality management

There is consistent evidence from models and observations that 21st-century climate change will worsen ozone pollution. The effect on PM is uncertain but potentially significant. When assuming business-as-usual future scenarios without significant

emission reductions beyond current regulations, models find that the combined effects of emissions changes and climate change in the U.S. will result in increased ozone pollution (Hogrefe et al., 2004; Steiner et al., 2006; Tao et al., 2007; Chen et al., submitted for publication). Simulations that assume emission reductions far beyond the full implementation of current regulations indicate that climate change will partly offset the benefit of the emissions reductions (Tao et al., 2007; Tagaris et al., 2007; Nolte et al., 2008). Wu et al. (2008a) refer to this 'climate penalty' as the need for stronger emission controls to achieve a given air quality standard. In an example for the U.S. Midwest, they find that an air quality objective attainable with a 40% NOx emission reduction for the present climate would require a 50% NOx reduction in the 2050 climate. They find that this climate penalty decreases as anthropogenic NOx emissions decrease, thus providing additional return on NOx emission controls.

The work of Leibensperger et al. (submitted for publication) using 1980–2006 ozone data for the northeastern U.S. (Fig. 1) highlights the potential importance of climate change for air quality managers. By using the observed interannual correlation between cyclone frequency and exceedances of the ozone air quality standard, Leibensperger et al. (submitted for publication) conclude that the ozone air quality standard would have been met in the northeastern U.S. by 2001 were it not for the decreasing trend in cyclone frequency indicated by the NCEP/NCAR Reanalysis. There is uncertainty as to the actual long-term cyclone trend in the 1980– 2006 record, but the point here is that climate change can significantly affect the accountability of air quality management decisions on a decadal time scale.

An important issue is whether climate change could affect the dependence of ozone on NOx and NMVOC emissions in a way that would compromise the effectiveness of current emission control strategies. Liao et al. (2007) examined this issue for the U.S. with the model of Tagaris et al. (2007) and found no significant effect, implying that emission control strategies designed for the present climate should still be successful in the future climate. Model simulations by Baertsch-Ritter et al. (2004) for the Milan urban plume show increased ozone sensitivity to NMVOCs as temperature increases, due to the reduced thermal stability of PAN and hence higher concentrations of NOx. By contrast, model simulations by Cardelino and Chameides (1990) for the Atlanta urban plume show increased ozone sensitivity to NOx as temperature increases, due to increasing isoprene emission and supply of HOx radicals. The opposite responses of the Milan and Atlanta plumes likely reflect regional differences in biogenic NMVOC emissions, but the point from both studies is that sensitivities of ozone to NOx and NMVOC emissions could be affected by climate change.

Pollutant emissions are also expected to respond to climate change. Higher temperatures increase the demand for air conditioning in summer when ozone and

PM concentrations are highest. Evaporative emissions of anthropogenic NMVOCs also increase, although the effect determined for mobile sources is relatively weak, in the range 1.3–5% K_1 (Cardelino and Chameides, 1990; Rubin et al., 2006). The ozone background is likely to become an increasingly important issue for air quality managers as air quality standards become tighter. This background is likely to increase in the future because of global increase in methane and NOx emissions (Fiore et al., 2002). Climate change may provide some relief, at least in summer. Wu et al. (2008b) find that the U.S. policy-relevantbackground (PRB), defined by the U.S. Environmental Protection Agency (EPA) as the surface ozone concentration in the absence of North American anthropogenic emissions, will decrease by up to 2 ppb in summer as a result of 2000–2050 climate change. Lin et al. (2008b) obtain similar results. Wu et al. (2008b) project that climate change will fully offset the effect of rising global anthropogenic emissions on the PRB in the eastern U.S. in summer, though there will still be a 2–5 ppb increase in the PRB in the west. Seasons outside summer will experience less benefit from climate change in terms of decreasing the ozone background, while experiencing stronger intercontinental transport of pollution (Fiore et al., 2002).

Finally, as the world moves forward to develop energy and transportation policies directed at mitigating climate change, it will be important to factor into these policies the co- or dis-benefits for regional air pollution. Energy policy offers an opportunity to dramatically improve air quality through transition to nonpolluting energy sources. By contrast, a switch to biofuels would not necessarily benefit air quality and could possibly be detrimental (Jacobson, 2007).

9. Greenhouse gas emissions:

Scientific arguments about human induced climate change to respond appropriately, social workers ought to understand the science of climate change. Climate change refers to that complex articulation of greenhouse gas emissions, including carbon dioxide, methane,higher hydrocarbons and other gases that have caused temperatures of climate to rise. Known as carbon emissions, these are associated with the processes of industrialisation, especially the use of fossil fuels to produce energy for domestic and industrial processes connected to urbanised living (IPCC, 2007). Knowledge about climate change is not new. In 1865 in the UK, John Tyndall suggested that gases like water vapour and CO2 retain heat (Ungar, 1992).

Svante Arrhenious in Sweden warned in 1896 that CO2 from burning fossil fuels would lead to global warming (Sample, 2005). Its genesis in the industrialisation of Western countries has labelled the West responsible for climate change and, as polluter, liable the costs to deal with its consequences and limit temperature rises. In this scenario, the rest of the world is portrayed as the victim of the West's intransigence, i.e., failure to limit its own emissions and share renewable energy technologies (Third World Network

[TWN], 2010). Sharing green technologies developed primarily in the West (Löscher, 2009) can play key roles in reducing emissions. Social workers can mobilise communities to facilitate technology sharing and emission reduction by using their mediation skills to bring groups in dispute together.

Industrialization processes treat the atmosphere as a carbon sink by emptying gaseous pollutants straight into it. Population growth, sedentary materialistic lifestyles associated with industrialization, centralization in cities and commuting communities associated with urbanization have added pressure on the earth's finite fossil fuel resources. Global demand for energy is predicted to increase by 60 per cent between now and 2030 (Löscher, 2009) while the atmosphere is rapidly approaching its limits in absorbing emissions. Scientists on the IPCC calculate that to keep temperature rises within 20C, a total of 1,400 billion tonnes of carbon emissions can be absorbed by the atmosphere between 2000 and 2050 (IPCC, 2007).

There were 280 ppm of carbon emissions in the air before the Industrial Revolution. Today, this figure stands at 430 ppm and is likely to rise to 550 ppm by 2035 if reduced emissions are not forthcoming (Stern, 2006). Environmental stress will be exacerbated if methane currently locked in the permafrost of Siberia and Northern Canada is released because methane causes more atmospheric heating per unit than carbon dioxide (Löscher, 2009). The world is warming at an alarming rate. Most of the rise has occurred since 1970. There is 40 per cent more CO2 in the atmosphere now than 200 years ago.

Addressing climate change has to take account of the physical limit to the amount of carbon emissions that can be spewed into the air. The threatened growth in carbon levels makes it imperative for individuals and countries to reduce emissions and become carbon neutral. Unless urgent action curbs greenhouse gas emissions, the planet and all living things will be seriously endangered along with legitimate demands amongst industrialising countries to eradicate poverty (TWN, 2010). This means that the polluter-victim analogy has to be replaced with a problem-solving approach that supports all nations in a common purpose, namely that of addressing climate change for the benefit of all peoples and their environments.

Failure to reduce carbon emissions impacts substantially on everyone and has resulted in 1998 being the hottest year in the warmest decade in the warmest century for one thousand years. A heat wave in Europe in 2003 killed over 30,000 people. A drought in the Amazon region in 2005 turned the Amazonian Rainforest – a natural carbon sink absorbing carbon – into a source of carbon emissions and endangered indigenous livelihoods. By 2007, Arctic ice had melted by significant amounts; 2009 was the fifth warmest year since 1850; and 2010 has broken a number of records for extreme weather events. The earth's natural defences are eroding because rising carbon emissions have impacted deleteriously upon natural carbon sinks – rainforests and oceans. Both tropical and temperate rainforests lose capacity to absorb carbon emissions as temperature rises.

Additionally, rainforests are being destroyed for crops, wood, biofuels and human shelters at alarming rates, except for places like Costa Rica that are reforesting.

The oceans are losing capacity to absorb carbon, becoming more acidic as water temperature rises. Greater acidity threatens their flora and fauna with extinction.

10.Shifting patterns of energy consumption

Binary discourses of 'Polluters'(West) and 'Non-Polluters' (Global South) position the West as the perpetrator of catastrophic events and the others as victims bearing a disproportionate share of the effects of climate change. The West is blamed for unfairly consuming fossil fuels, extensively polluting land, air and water and producing climate change. These constitute a historical legacy and moral obligation to reduce its own emissions and pay for industrialising nations to 'catch-up' in their development by funding clean air technologies (Averchenkova, 2010). Unfortunately, the blame game has produced an intractable impasse in negotiations about who caused the damage, who will pay for undoing it and who is suffering and resulted in an impasse in negotiations around the Kyoto Protocol (TWN, 2010).

The West's dominance as polluter is changing as emissions from industrialising countries in the Global South rise. For example, South Korea's emissions nearly doubled from 298 million tonnes in 1990 to 594 tones in 2005. Emissions in China rival those of Germany at 6.4 tons of HCU per capita GDP. China's use of energy is less efficient because 3.5 times more energy than the global average is consumed to generate each unit of GDP (Löscher, 2009). The largest consumers of energy in 2005 included industrialised and rapidly industrialising countries (percentage in brackets): USA (20.5%); China (15.0%); Russia (5.7%); Indonesia (4.7%); Japan (3.0%); Germany (2.4%); France (2.4%); Canada (2.4%); the UK (2.0%); South Korea (1.9%). China emits 6.1 billion tons of CO2 yearly, while 250 million people live in poverty. Its emissions are set to rise to 10 billion by 2020 (Löscher, 2009). China overtook the USA as the single largest polluter in 2006 and is likely to retain that position for the foreseeable future. Together, they produce 40 per cent of global carbon emissions to be absorbed by the same atmosphere and biosphere inhabited by all living things (Löscher, 2009). China's emissions will continue to rise because it is opening a coal-fired power station every few days to feed its industrialisation drive.

Coal, the dirtiest fossil fuel, could be substituted by renewable energies if the green technologies associated with them were better shared and emissions recycled more effectively. More global technological cooperation would enable the Chinese government to expand its existing renewable energy programme and accelerate the search for alternative solutions, a development its policymakers are keen to progress. Rapid population growth, highest in the Global South, will intensify pressures on resources available to meet ever growing needs (UNDP, 2009). The changing picture in energy use requires a more equitable sharing of resources and clean energy technologies than is occurring. Social workers can advocate for this to happen.

Individual contributions to climate change are differentiated according to class and geographic region. Rich individuals contribute most, if lifestyle activities are counted. These include private jets, consumerism and, if Sir Richard Branson succeeds, day trips to outer space for US$200,000 per passenger (Allen, 2009). These decisions are made privately. Individuals can disregard carbon footprints and their impact upon the earth's entire population. In contrast, a homeless person in a rich country would have a small personal carbon footprint. Wars and terrorist bombs contribute carbon emissions that are usually discounted. The 'good-time toys' that people enjoy in groups, for example fireworks to celebrate New Year, or Guy Fawkes Day, add to the total carbon emissions that planet earth has to absorb. When do we think of the consequences of these behaviours and ask if alternatives are available or can be created?

The impact of climate change will be variable as weather events become more extreme. Some countries will sink. Small island nations in the Pacific like Tuvalu might disappear altogether. Others might rise. Climate migrants will pose another issue to be addressed (UNDP, 2008). The 1951 Geneva Convention on Refugees does not apply to climate migrants (Meo, 2009; Sanders, 2009). New protocols are necessary to cover their needs (UNDP, 2008). Humanitarian aid currently cannot meet demands for food, shelter and medicines by climate refugees in drought stricken Somalia, Kenya and Ethiopia. Social workers can advocate for increases in aid and help develop appropriate services and policies.

These complex realities are compelling the West to rethink its strategy towards climate change, reject the Polluter–Non-Polluter binary and tackle barriers in negotiations. However, its ambivalence in reducing emissions is impeding progress (TWN, 2010).
Public responses to climate change'Sceptics' claim that people play a minimal role as Mother Nature causes climate change. The 'greens' emphasise people's contributions and call for reductions in greenhouse gas emissions to limit temperature rises to 20C, stabilise the world's climate and reduce damage caused by humans. These debates have been distorted by media assertions that data collected by British scientists at the Centre for Climate Change at the University of East Anglia were fabricated. The veracity of these allegations has been discredited by three enquiries (Adams, 2010; Russell, 2010). A substantial amount of other evidence supports the view that people induced climate change is real and having deleterious effects on the livelihoods and well-being of countless people (Dessler & Parsons, 2009).

One-half of British voters are sceptical about the relevance of climate change to their lives (Hennessy, 2009). Their numbers encompass distinguished persons, including Nigel Lawson, former Chancellor in the UK, who deems policies to reduce carbon emissions 'extremely damaging and harmful'. The twofold categorisation of participants in the climate change debate as 'sceptics' and 'greens' is crude. A DEFRA study in the UK refined this classification in a survey that clustered people's responses around:
•Positive greens: They comprise 18 per cent of respondents and will do as much as

possible to limit their impact on the environment;
•Waste-watchers: Covering 12 per cent of respondents, this group considers thrift part of their lifestyle and recycles extensively;
•Concerned consumers: Forming 14 per cent of those replying, they felt they were already doing a lot and unlikely to do more;
•Sideline supporters: Making up 14 per cent of those surveyed, they acknowledged climate change as a problem, but refused to alter current lifestyles;
•Stalled starters: This group has little information about climate change, wanted an affluent lifestyle, but could not afford it;
•Honestly disengaged: These respondents lacked interest in the issue, seeing it as irrelevant to them.

Only 23 per cent of Britons deemed climate change the world's most worrying problem; 58 per cent think it is one of several serious issues. Low levels of outright support hinder the removal of 20 billion tonnes of carbon from Britain's atmosphere by 2020 (Hennessy, 2009). Getting everyone on board is crucial as 40 per cent of emissions in the UK come from domestic sources (Giddens, 2009). Engaging sceptics in well-informed dialogues about climate change could be part of these efforts. Social workers can contribute to this task by raising awareness and mobilising communities through community social work if they understand the science behind these debates.

11.Contribution of social work on climate change

Climate change has become shorthand for one of the most important challenges facing contemporary societies. It encompasses the idea that the world's climate is changing as a result of greenhouse gas or carbon emissions caused by human activities. Greenhouse gases include water vapor, carbon dioxide (CO2), methane, nitrous oxide and chlorofluorocarbons. These gases trap infrared radiation and cause air temperatures to rise. Significantly elevated concentrations of these gases through fossil fuel consumption, deforestation and industrial processes contribute to changes in air temperature, precipitation patterns, ocean acidity, sea-levels and melting glaciers. The Inter-governmental Panel on Climate Change (IPCC) suggests that natural processes account for only 5 per cent of climate change (IPCC, 2007). Measured in parts per million (ppm), carbon emissions have risen from 280 ppm before the industrial revolution to 430 ppm by 2005 and are growing (IPCC, 2007). Climate change is expected to have a differentiated impact on countries as extreme weather events increase in frequency, produce climate change refugees and subject people in the poorest nations to increased risk of flooding when sea levels rise as weather gets wetter (colder in some places) or drought where it becomes warmer and drier (United Nations Development Programme [UNDP], 2007, 2008).

The science of climate change is contested with people lining up along a continuum while media discourses revolve around two opposing camps: the 'sceptics' and the

'greens' (Giddens, 2009). People experiencing disasters induced by climate change will require social work support to deal with the aftermath. Social work has a remit to work with the 'person in the environment' from a human rights and social justice perspective (www.iassw-aiets.org).Access to social justice by those affected by climate change is difficult, as the unproductive discussions in Copenhagen in 2009 revealed. Social workers, the professionals charged with enhancing human-well-being from a human rights and social justice framework (Ife, 2003), are well-placed to contribute to climate change policy discussions and interventions (Dominelli, 2009, 2010).

Although the profession has been relatively silent in these debates, I argue that social workers must engage effectively in these by learning about the science behind climate change; speaking about policies; developing resilience amongst individuals and communities; mitigating losses caused by climate change; helping to resolve conflicts over scarce resources; and responding to devastation caused by extreme weather events including floods and droughts. Social workers have to engage with the complex arguments and realities around climate change if they are to counsel effectively people suffering loss and grief in these circumstances and help build their resilience in preventing and/or adapting to its consequences. Within a future contextualised by climate change, the roles of social work educators and practitioners range from advocacy to community mobilisation. I draw upon two case studies, one from the Global South and the other from the Global North, to examine these because climate change affects everyone, everywhere.

12.1.United Nations initiatives

United Nations (UN) initiatives involve international negotiations among governments primarily through the Conference of the Parties (COP) with national governments ensuring that firms and individuals within their borders comply.

12.2.Kyoto and beyond

The Kyoto Protocol, signed by 184 countries in Kyoto, Japan in 1997, forms the basis of UN actions and came into force in 2005. It required 37 of the richest industrialised countries, known as Annex 1 countries, to reduce carbon emissions by 5 per cent below 1990 levels between 2008 and 2012. Kyoto was one of several international initiatives on climate that began in 1992 with the Earth Summit in Rio de Janeiro where the participating countries agreed on the UN Framework Convention on Climate Change (UNFCCC). The Rio Accord committed governments to prevent dangerous climate change which was defined as limiting rises in the earth's temperature to less than 20C. The COP met first in 1995 and annually subsequently to consider climate change. Copenhagen was the 15th such meeting, hence COP15. The next one in Mexico became COP16.

The West's acceptance of culpability in initiating climate change underpinned the

Kyoto agreement. In it, rich industrialised countries agreed to reduce greenhouse gas emissions and help industrialising countries financially and through technology transfers. Industrialising countries could participate in the Clean Development Mechanism (CDM) Projects to reduce emissions. These were to be funded through an Adaption Fund that levied a 2 per cent charge on CDM Projects. Casting industrialising countries as 'victims' meant that targets were not set whereby industrialising countries could industrialise and keep emissions low instead of rising substantially like those of China, India, Brazil, Mexico and South Korea.

Progress was hindered from the beginning. The American Senate refused ratification and George W Bush withdrew the USA from the Kyoto Protocol in 2001. Australia also failed to ratify that year. Other countries have not met their commitments. For example, Canada's emissions have risen by 25 per cent above 1990 levels despite committing itself to a 6 per cent reduction because in 2006 Prime Minister Harper decided to develop Alberta's oilsands.

A recent report by McKinsey Consultants criticised the UN for poor administration of the CDM and not monitoring adherence to the Kyoto Protocol. Its implementation was tardy.Agreement on the methodology for monitoring Kyoto was not reached until 2001 in Marrakech. Two years later, the Bali Climate Conference established the timetable for agreeing a successor to the Kyoto Protocol that expires in 2012. The Poznan Climate Conference of 2008 proceeded slowly as politicians waited for American President Obama to support decisions that tackled climate change and agree on a new Protocol at the Copenhagen Summit on Climate Change in December 2009. While no binding targets materialized in Copenhagen, Obama succeeded in getting China to agree to reduce its emissions (Averchenkova, 2010). Under the 'Copenhagen Accord', each country would set its own limits and politicians discussed these at the COP16 meeting in Mexico in 2010 (Cryderman, 2009) without reaching a legally binding agreement. Compliance mechanisms proved problematic. Carbon 'credits', intended to incentivise private firms to reduce emissions, were developed in the USA to reduce industry's price-tag for becoming less polluting. Carbon trading schemes (CTSs) set up a market whereby polluting industries and firms could purchase 'carbon credits' held by non-polluting ones.

Entrepreneurs favour CTSs because millions of dollars can be earned by selling carbon 'credits'. CTSs are ineffective because they reward polluters, enable certain groups to profit from selling carbon credits without reducing overall emissions, ignore those who pay if nothing is done and allow fraudsters to profit from their operation. For example, the scheme established by the EU rewarded heavy polluters in Eastern Europe when they sold carbon credits to Western companies that then lacked incentives to lower emissions. Fraudsters have targeted the European Emissions Trading Scheme (ETS) worth around 90 billion Euros per year by claiming and reclaiming VAT.

In Canada, the provincial government in BC paid CDN$14 million in 'seed' money to

the Pacific Carbon Trust (PCT) and a further CDN$869,000 to offset the 34,370 tons of carbon emissions it was expected to produce. The scheme subsidises firms using clean, green technologies by paying an undisclosed amount per tonne of carbon reduced. The scheme is funded by charging public sector agencies, especially schools and hospitals, $25 per tonne of carbon emitted. The money collected goes to private firms and earns them profits (Bader, 2009). To save tax dollars, Bader suggested that public firms use the Chicago Climate Exchange Scheme which charges only $0.14 per tonne to off-set carbon emissions, as this is cheaper than the government's scheme! Most private firms would not deem 14 cents an incentive to reduce emissions, but if calculated over substantial tonnage, it becomes a considerable amount. Despite these limitations, during COP 15, the then UN Executive Secretary Yvo de Boer (still in office at time of publication – he was replaced by Christiana Figueres at COP 16, but I think my reformulation is OK now?), assumed that the market is more efficient than the state and supported market-based mechanisms rather than taxes and regulation for reducing emissions. This view is shared by large polluting private companies like Exxon Mobil and was the prevailing view at COP16 (Khor, 2010).

Another important and contested hurdle is agreeing on the costs of cutting emissions globally and who would pay them. The Stern Report of 2006 informed rich countries that tackling climate change now would cost less than 1 per cent of Gross Domestic Product [GDP], but would rise to 20 per cent of GDP if significant responses were not forthcoming. Lamumba Stanislaus Di-Aping, Sudanese chief negotiator for the G77 (group composed of poor industrialising countries and rising superpower China) and covering 132 of the 192 countries attending COP15, argued that the IMF and World Bank should not run the proposed 'climate fund' and that lack of a deal at COP15 in Copenhagen meant 'certain death' for Africa. He derided Gordon Brown's budget of $10 billion yearly to fund climate change djustments in industrialising countries as even insufficient to buy 'poor nations the coffins' they would need if climate change was not halted (Gray, 2009).

To advance action in curbing carbon emissions, the EU proposed that contributions to the 100 billion Euros needed annually until 2020 were paid annually as follows: $30 billion by Europe; $25 billion by the USA; and the rest of the industrialised world the remainder. The EU considered this allocation, comprising less than 0.3 per cent of the annual overall income of rich countries, affordable. The EU's calculations were based on the size of GDP connected to the level of carbon emissions (Hayden, 2009: 28). Extensive dissent over this proposal caused Danish Prime Minister, Lars Løkke, presiding at the time of COP15, to suggest 'one agreement, two steps'. Under this, COP15 negotiators would agree on the outline of a Treaty in Copenhagen and finalise details at COP16 in Mexico. This strategy nearly won the day after two weeks of heated deliberations. It fell apart when the USA, China, India, Brazil and South Africa brokered the deal known as the Copenhagen Accord. Some small, island nations in danger of being submerged by sea level rises refused to sign it, for example Tuvalu.

Despite being a party in reaching the Copenhagen Accord, South Africa's opposition dubbed it the 'Hopelesshagen Flop'. The Copenhagen discussions disappointed the 'greens', as the ambitions of Kyoto were not realised. Carbon emissions globally are now 25 per cent higher than in 1990 with 37 countries covered by Annex 1 of the Kyoto Protocol producing 25 per cent of global emissions. This figure overestimates progress because it excludes the USA which withdrew from the list.

These responses indicate that bringing together reductions in greenhouse gas emissions with sharing technological developments requires a political will that seems absent. Social workers, with their skills in seeing the whole picture and mediating between conflicting groups, can facilitate implementation discussions at international policy and community levels. The International Association of Schools of Social Work (IASSW), the International Council of Social Welfare (ICSW) and the International Federation of Social Workers (IFSW) hold consultative status at the UN and can use their positions to suggest alternative policies. They can use mediating skills and interventions to move people beyond the impasse epitomised by negotiators' failure to reach a legally binding agreement at COP15 (Averchenkova, 2010) and COP16 (Khor, 2010).

All is not gloom and doom. Copenhagen 2009 has demonstrated that politicians and environmentalists agree on the nature of the problem and the physical limits to ongoing pollution that the world can sustain, while disagreeing strongly about how to contain it. Many politicians favour market-based solutions rather than state regulatory ones. These are usually associated with carbon trading schemes (CTS). But markets seem unreliable instruments that cannot be trusted with the delicate and crucial problem of reducing carbon emissions to limit temperature rises to no more than 20C between now and 2050.

In December 2009, the Environmental Protection Agency in the USA ruled that carbon dioxide is a health hazard. Consequently, the US Senate, which vetoed the Kyoto Protocol, no longer has to approve any carbon trading scheme that President Obama signs (Mason, 2009). Lack of national government action has prompted local responses. British residents formed the 10–10 campaign to reduce emissions by 10 per cent during 2010. Individuals, companies and local authorities sharing this aim can join. Over 100 local authorities have done so. Social workers can help people understand wider global concerns from their local context and mount consciousness-raising campaigns to engage them in local actions such as the 10-10 initiative.

People can seek equitable solutions, using and sharing green technologies and limiting the amount of greenhouse gases that enter the air, water and soils of the planet. Clean technologies make good business sense. They create jobs, can alleviate poverty and help people realise their human rights and claims for social justice. Bolivia, at the climate change discussion in Bonn in the summer of 2010, argued for such an approach and included social workers in advocating for them (TWN, 2010).

Concern about these failures in reducing greenhouse gas emissions led me to develop the Equitable Carbon Sharing Scheme (ECSS) as a way of transcending the binary divide that pits one group of interests against another. Originally presented at the seminar organised by the IASSW, ICSW and IFSW during COP15 in Copenhagen on 10 December 2009, it was adopted unanimously. I discuss it below.

13.Social workers' roles in climate change endeavours at individual and collective levels

Dealing with climate change requires personal and collective action at the local, national and international levels. The political and contested nature of climate change debates and potential solutions raise questions about social work's contributions. What can social work educators and practitioners do about climate change, other than support people who are flooded out of their homes or seek humanitarian aid as they escape droughts? Is their role simply about adapting existing skills to address a new social problem?

Social workers as community development workers can mobilise people around initiatives that do not destroy the environment nor produce ill health among people. Below, it is demonstrated that social workers can and do play additional roles through community social work, advocacy and community mobilization around green technologies to enhance the quality of life in disadvantaged localities and reduce carbon emissions. They can promote clean, renewable energy to enable people's living standards to rise without increasing greenhouse emissions at the unsustainable rates set by carbon-based technologies. Industrialization based on carbon neutral or green technologies can benefit people and the planet, as exemplified by the following case studies. One is from the Global South, the other from the Global North.

Case Study: Indigenous approaches to climate change in Misa Rumi, Argentina

Indigenous peoples are amongst the poorest of the world's inhabitants, live in fragile ecosystems and have low carbon footprints because their lifestyles are communal and respectful of their surroundings through a holistic approach to the world and their place within it. They also seek to safeguard the future for their children, are adversely affected by climate change and have many examples of mitigating risk and building resilience in their communities, as illustrated here.

In Misa Rumi, Argentina, an indigenous community that herds llamas sought renewable energy sources for cooking, heating their homes and cutting back on firewood consumption. Over-demand had caused deforestation and soil erosion and was jeopardizing livelihoods. The villagers teamed up with a local NGO, the EcoAndina Foundation, which had community workers working with them since 1989. Through this partnership, they acquired solar-power to run their stoves, including one used by the communal bakery; heat water for showers; heat the school; and operate water pumps to irrigate vegetable plots.

Now producing energy, the community does not require carbon-offset trading schemes, collect firewood or purchase expensive natural gas. Their solar energy strategy reduced pressure on a scarce commodity – firewood derived from the yareta tree that took hundreds of years to grow. This benefited their reforestation initiatives.

The EcoAndina Foundation believes that villagers can earn carbon credits for reducing carbon emissions because each solar-powered stove saves 2 tons of carbon dioxide a year. As the scheme covers 40,000 people in the region (Stott, 2009), the considerable amount involved can generate income for other activities. Sustainable lives and environments lie at the heart of this project which honours indigenous ways of thinking; doing and living. This example involved community social workers linking villagers with EcoAndina to promote dialogue around the wisdom of embracing a technology that could readily accommodate their aspirations without undermining their social and cultural traditions. It also demonstrated the importance of local people owning the change process and of outsiders being culturally sensitive and locality specific.

Case Study: A white working-class initiative on climate change in Gilesgate, England
Gilesgate, located in northern Durham, has around 6,000 residents. A small part of it, the Sherburn Road Estate, covers a disadvantaged community of people either in low paid work or on benefits. Juggling money to pay energy bills is a normal routine. Fuel inequalities are exacerbated by pre-payment meters whereby the costs per unit of energy are double those charged to middle class consumers paying by direct debit (Bachelor, 2009).

Community social workers from Durham University have a long-standing relationship with these residents. Several problems to be addressed were identified in public and individual meetings. All were responded to, but two resonated with climate change discussions – unemployment and fuel poverty. Traditional endeavours rooted in reducing energy consumption and ensuring all benefits were claimed had been unsuccessful. New thinking was required.

Seeking innovative solutions, a community social worker initiated discussions on renewable energy sources, their sustainability and importation into the community at minimal cost to the environment and residents. Various stakeholders were brought together to address fuel poverty and develop a self-sustainable energy community. Social scientists from the School of Applied Social Sciences at Durham University, physical scientists developing renewable energy technologies associated with the Institute of Hazard, Risk and Resilience Research and Durham Energy Institute contributed scientific expertise on climate change and renewable energy sources. Other players included local representatives from housing associations, civil society organizations, policymakers and businesses interested in renewable energy production and creating jobs in the locality. Private enterprise saw the opportunity of using government subsidies to provide renewable energy technologies without charge to a

community that could not otherwise engage in climate change initiatives, despite being aware of the issues.

The stakeholder group provided energy audits for private homes, advice to housing developers on reducing energy consumption in new-build homes and retrofitting existing ones in less energy-hungry ways; distributed free low energy light bulbs to residents; and equipped several public buildings with low energy consuming equipment to reduce energy bills and carbon emissions. The manufacture of renewable energy sources, particularly inflectors, was to create jobs and counter high levels of unemployment. These renewable materials have the potential to develop long-term prospects for the area through the export of goods to other communities as part of the strategy of becoming self-sustainable in energy.

The Gilesgate Project faced the challenge of addressing fuel inequalities (fuel poverty) without adding to carbon emissions. It used community social work to include a marginalised and normally excluded white working-class community in a major issue – tackling climate change whilst resolving their own pressing social problems, including creating sustainable jobs, building community and individual resiliences and addressing fuel inequalities. The Project demonstrates the value of involving community social workers in climate change initiatives for both the short and long haul. Community social work (Hadley and Hatch, 1980) is not new in England. It was advocated as a holistic response to community issues by the arclay Report of 1982.

The initiatives considered above reflect in microcosm global problems faced in climate change debates. They involved poor people who have lower carbon footprints than their richer counterparts, but would not normally access renewable energy products to cut energy consumption, meet their needs and care for the environment. Social workers were crucial in making that possible. The Gilesgate Project reveals that private industry can provide services for poor people in the short-term and make profits in the long-term by bringing renewable energy technologies to local communities. Large companies like Siemens argue that investing in renewable energy technologies is the future for business (Löscher, 2009).

Social workers can and do facilitate activities by individuals, communities and nation-states to reduce carbon emissions. The case studies portray how collective actions can solve individual problems and contribute to addressing global social problems like climate change.

14.Personal action

Each individual can cut their personal carbon footprint by consuming less energy, for example using energy saving light-bulbs, insulating homes, lowering heating temperatures by 10C, having renewable energy sources like solar panels and heat pumps in the home, not having electrical gadgets on ‘standby’ and using public transport. Social workers can raise awareness about these issues, linking solutions to

personal problems like reducing fuel bills to climate change initiatives and bringing people and resources together, as the case studies exemplify.

Personal action alone is insufficient. Collective solutions, achieved by consensus at all levels in all societies can solve global problems. The Equitable Carbon Sharing Scheme (ECSS), which transcends the binary whereby rich nations and poor nations blame each other and fail to reach a legally binding treaty as occurred in Copenhagen, could be one such initiative.A collective response: the ECSS
The Third World Network's (TWN's) daily summaries of discussions at Copenhagen 15 and since reveal that the 'rich' country (polluter)–'poor' country (victim) binary cannot achieve consensus because none dare taking action before another. The ECSS reduces this risk by:
building consensus around the assumption that there is only one world that every person on earth is responsible for; using the scientific insight that a finite amount of carbon emissions can be absorbed by the planet if temperatures are not to rise by more than 20C, that is, 1,400 billion tonnes by 2050 (Stern, 2006); linking an equitable sharing of the earth's resources with technical know-how; and bringing into the equation the world's future inhabitants.

The earth's population is expected to surpass 9 billion by 2050 (UNDP, 2009), so finite emissions have to be shared equitably amongst current and future inhabitants. An equitable distribution requires that pollution associated with each individual's carbon emissions covers all their needs including manufacturing processes, transportation, housing, heating, lighting, growing food, and the provision of services like health, education and defence. The earth's limited capacity to absorb carbon emission necessitates the curbing of polluting approaches to industrialisation, whether perpetrated by industrialised or industrialising countries, and rapid deployment of shared renewable technologies. Ultimately, each individual will have the same
allocation of greenhouse gas emissions regardless of status or residence. Mathematical models can forecast consumption for each individual. Social workers can liaise with mathematicians to get data into public domains and translate these into information that people can understand and use.

15. Implementation of ECSS
The implementation of ECSS on an equitable basis would result in rich people and high fossil fuel energy consumers in the Global North reducing their carbon emissions considerably over present levels. Poor people in the Global South whose current consumption is low would be able to increase it and rise out of poverty through sustainable development. This approach has the advantage of taking account of the historical privileging of the West while including consumption by the emerging economies and enabling the living standards of the world's poorest people to grow.

The money currently being spent on polluting the earth could be used to promote clean

technologies while running down polluting ones, including declaring a moratorium on the construction of environmentally damaging forms of energy production and consumption. The implementation of ECSS includes the free transfer of clean or green technologies so that everyone in the world can meet their energy needs in less environmentally destructive ways. Companies could still make profits even if they initially make these technologies available free and charge for the end product rather than research and development costs as these have often been subsidised by the public purse. The need for developing new approaches to this intractable problem is great: ECSS offers a new way forward. Social workers can advocate for this as they are doing when engaging in mitigating natural and human-made disasters the world over (Desai, 2007). An Economic and Social Sciences Research Council (ESRC) funded project based on the 2004 Indian Ocean Tsunami (Internationalising Institutional and Professional Practices) that I head at Durham University has also exposed the dangers of short-term thinking when responding to those surviving disasters and highlighted the importance of long-term solutions and capacity building in disaster interventions like those of climate change. Social workers from around the world can emphasize this message along with the importance of working in egalitarian partnerships with disaster survivors.

16.Climate Change as a Public Health Issue

"Climate change is understood to be a public health issue because it affects the quality of our water, air, food supplies, and living spaces in a multitude of key ways," according to Terri Klemm, MSW, LCSW, an associate professor of social work and director of the Bachelor of Social Work program at Centenary University in New Jersey.

"Since the year 2000, we've experienced 16 of the hottest 17 years ever recorded. In fact, in every year for the last several years, we've exceeded the previous record for the hottest year in recorded history. It's past the point where we can talk about climate change only as an issue that will impact future generations because we're beginning to feel some of the severe effects of the climate crisis now."

"Extreme events like heat waves, heavy rainfall, and winter extremes are more likely with a changing climate," says Lisa Reyes Mason, PhD, MSW, an assistant professor at the University of Tennessee College of Social Work.

"The increasing number of these extreme weather events—hurricanes that are unprecedented in size and strength, for example—are very much in line with what climate scientists have been warning we should expect as a result of global warming," Klemm says.

These extremes, Mason says, also lead to increased flooding, prolonged draught, and greater risk of wildfires, which in turn result in "greater incidence of infectious disease, illness, death, and emotional or mental stress. During heat waves, for example, people with preexisting health conditions such as asthma may be even more likely to suffer health problems."

17. Effect of socio economics on environment and its consequence on climate change and vice-versa

In many countries the people earn through production of industrial goods, food and agricultural products, fertilizer/agrochemicals, medicines, energy and implements utilizing natural resources with conventional technology resulting in flux of pollutants being poured into environment as explained by various authors described above. The nonconventional energy efficient technology implements and continuous growth of natural resources like greeneries and minerals, land and implements may safe guard the environment and simultaneous action on social consciousness to the citizen of the country to contribute least emission of green house gases on the one hand and conservation of environment on the other to give continuous impetus to the climate improvement. Some countries, like Republic of China, started shifting hutments of villages to multistoried apartments for vertical accommodation families instead of horizontal spread of residences/commercial complexes increasing the greeneries instead of reducing the natural greeneries as is being the trend among developing and developed countries.

Conclusion

There is consensus among GCMs that 21st-century climate change will increase the frequency of stagnation episodes over northern mid-latitudes continents. This increase in stagnation reflects the weakening of the general circulation and a northward shift of the mid-latitude cyclone tracks, decreasing the frequency of cold fronts that are the principal ventilation mechanism for eastern North America, Europe, and East Asia. General degradation of air quality is therefore expected if anthropogenic emissions remain constant.

All models find significant ozone increases in the north eastern U.S. and in south-central Europe. Other regions, such as the southeastern U.S., show large differences between models. This partly reflects differences in regional climate projections, but also the choice of isoprene chemistry mechanism including the uncertain yield and fate of isoprene nitrates.

Background ozone in air ventilating polluted regions responds to climate change very differently from regional ozone pollution. The beneficial effect of climate change on the ozone background may partly offset the expected global increase in the ozone background due to rising methane and Asian NOx emissions over the coming decades. The offset is likely to be more important in summer than in other seasons.

The response of PM and VOCs to climate change is more complicated than that for ozone because of the diversity of PM and VOCs components, compensating effects, and general uncertainty in GCM projections of the future hydrological cycle. Precipitation frequency, which largely determines PM loss, is expected to increase

globally but to decrease in southern North America and southern Europe. PM is highly sensitive to mixing depths but there is no consensus among models on how these will respond to climate change.

The effect on PMHC air quality could also be significant but is far more uncertain. Wildfire management for PM abatement will likely become an increasing consideration. The climate penalty for ozone air quality implies the need for more stringent emission controls to attain a given air quality objective. It does not affect in a major way the type of emission control strategies needed, although attention is needed to possible local shifts between NOx-limited and NMVOC limited conditions for ozone production. Decreasing ozone background in the future climate due to higher water vapor will partly mitigate the climate penalty and increase the return from NOx emission controls.

Climate change is a global problem and is not confined to the particular source country. On reviewing the various research works described above towards climate change and precautionary measures to be taken to control climate change, it is concluded that with the improvement of socio- economic status of majority of population irrespective of religion, caste and creed; the need of earning to meet the day-to-day expenditure at the cost of environment must be reduced. If proper socio-economic programs are initiated with continuous inspiration on population control as well as removal of economic barriers and economic discrepancies among people at the interest of the nation, there is sign of improvement of climate change through raising environment /climate consciousness through social workers among the general mass of the globe.

Acknowledgments

The author(*) is grateful to Prof.(Dr.) R.Debnath, chairman ,URSCHARD, NGO, Uluberia Distt.-Howrah, West Bengal, India for his continuous encouragement on the work presented. The author thanks to colleagues of the Institute for their cooperation on undertaking the work.

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