

Introduction. Climate change and urban areas: research dialogue in a policy framework

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1. Background

In 2005, 50% of the world's population lived in cities consuming over 75% of the world's energy use; as human development (as measured by the UN index) energy use will increase faster than the increase in population. By 2030, it is predicted that over 60% of the world's population will live in cities with this percentage continuing to rise to the end of the century. Urban areas are particularly vulnerable to the effects of global warming, particularly extreme weather events such as floods, storm surges, drought and heat waves (Stern *et al.* 2006; IPCC 2007). For example, it is estimated that the 2003 heat wave in Europe killed as many as 35 000 people. With modern urban lifestyles cities are consuming ever more power, which is still largely generated by fossil fuel combustion; the main uses are heating or air conditioning homes and buildings and powering vehicles, with industry in cities now taking a relatively small proportion. In fact cities discharge an amount of heat comparable to that received from solar radiation. Inevitably they contribute to greenhouse gas emissions from fossil fuel combustion and also from waste disposal management practices. As rapidly growing cities are clearing forests and vegetated areas, they are reducing the surface absorption of greenhouse gases and thereby further increasing their concentration in the atmosphere.

Therefore, cities have special responsibilities both to their own citizens and to everyone else to mitigate future climate change, at the same time helping their communities to adapt to the growing seriousness of the consequences for people's health and welfare. Since the planning of such policies is complex as well as politically difficult, decision makers responsible for the future of cities require the best expert knowledge available. Hence, the importance and timeliness of the papers in this special issue, which are a selection from those presented at a conference held at University College London in April 2006.

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One contribution of 9 to a Theme Issue 'Climate change and urban areas'.

The remit of the London meeting was to take a broader look at research and policies on climate change and urban areas, following two conferences on a similar theme focusing on the USA, Germany and the UK held in spring of 2005 in Houston, Texas and London ([UCL Environment Institute 2005a,b](#)). Flooding was of particular importance in the previous meetings, which was particularly appropriate due to the events in Germany in 2002 and in New Orleans in August 2005.

The meeting brought together academics, policy advisers, business people, non-governmental organizations (NGOs), journalists and the public. Some participants and speakers also came from Canada, The Netherlands and Germany ([UCL Environment Institute 2006](#)).

A number of North American city and regional environmental officials attended the London conference and spoke about their experiences of dealing with the political aspects of climate change in a somewhat different political climate! Social scientists and representatives from NGOs presented new approaches about how to translate and apply scientific findings to action on the political level ([Hunt 2006](#); [Moser 2006, 2007](#)).

The international participants visited the GLA at the end of the conference, where they were briefed by the Deputy Mayor Nicky Gavron and by officials on the climate change policies and technological/planning methods being adopted in London, some of them in collaboration with other cities, notably Toronto. In the concluding discussions there was broad agreement about policy objectives, but differing views about the speed at which effective climate change policies can be introduced in the major cities of the world.

In this introductory article, we first review the key points of the papers in this issue, and comment on how they relate to other research and policy developments, especially to those discussed at the conference. Secondly, we draw some conclusions about future directions of research on climate change, especially in relation to urban areas. We review how these might be communicated and applied in practice, particularly by those involved at national and sub-national levels of government.

2. Key points of papers in this issue

(a) *A ministerial overview*

Elliot Morley MP (then Minister of Sustainable Development (UK)) summarized broadly the UK Government's policies on dealing with climate change. The Government accepts the scientific consensus about global warming ([Schellnhuber et al. 2006](#)). He pointed out that the warmest 10 years on record have occurred since 1990. The European heat wave in 2003 killed at least 35 000 people including 600 in London, where temperatures rose to above 38.5°C (100°F) for the first time ever recorded in the UK. Lessons can be learnt from the USA on how to deal with these urban heat waves. In 1800 only 3% of people lived in cities, but by 2030 it is predicted that at least 60% will be in urban areas. Hence, climate change impacts on urban areas are very important. Public acceptance of the climate change is required if significant changes are to be made. In London, the Climate Change Partnership was set up in 2002 to deal with London's considerable vulnerability to the effects of climate change. Temperatures in London can be as much as 8°C warmer than the surrounding areas. Although it is

one of the driest capitals in the world, it is at risk from inland and coastal flooding (e.g. [Hunt 2005](#)). The Mayor of London has thus developed a number of important strategies and has asked the Government's permission to raise a local tax on London to provide a fund to tackle climate change in the capital.

The Government has placed climate change at the top of its policy agenda with its commitment to cut its 1990s carbon emission levels by 60% by 2050, with an interim voluntary target of 20% by 2010. At the moment, the UK is on course for a cut of between 15 and 18% by 2010, which exceeds the Kyoto Protocol target of 12.5% by 2012. The Government had undertaken an energy review for 2020 (subsequently published on 11 July 2006). In addition, they are setting up a 'carbon offsetting fund' for air travel undertaken by government officials. They will achieve this by buying credits from the Kyoto clean air scheme and in 3 years (to 2009) will offset 500 000 tons of carbon. This is not only sustainable but also provides an effective means of communicating the seriousness with which climate change is taken by the UK Government (e.g. [DEFRA 2006](#)).

While answering questions, the minister explained that the UK is determined to set an example with its climate change policies in order to influence policy in other countries, especially those with rapid rates of economic development. At the intergovernmental meeting in Gleneagles in 2005, where G8 and five other major countries were also present, negotiations on climate change were being made by the representatives of countries responsible for approximately 70% of the world's carbon emissions. The Government believes that the Kyoto Protocol is currently the most effective way to negotiate significant mitigation, and also ensures the efficient transfer of energy technology to enable developing countries to reduce their emissions. The minister also stressed that by reducing its carbon emissions, a country's economy should not be damaged. For example, the UK has had strong GNP growth over the last 20 years, at a similar rate to that of the USA, showing that the cuts in greenhouse gas emissions have not caused any economic damage. Indeed such policies lead directly to increased efficiency, innovation and energy security. For example in the housing and other facilities operated by the town of Woking in the UK, the energy efficiency has been increased over the last 15 years by 45% and carbon emissions have been cut by over 70%.

(b) *Recent climate change research results*

Progressively, modelling of the global climate and all the sub-processes involved has been improving through intensive scientific studies and the use of the huge increases in computer processing power which are still growing exponentially, according to 'Moore's law' ([NCAR 2005](#); [Killeen 2006](#)). As a result, more detailed simulations of critical processes in GCMs have become possible, such as ozone chemistry, aerosols and cloud interactions, biogeochemistry, ocean ecosystems, dynamic vegetation, changing land use and dynamic ice sheets. Complementary observational and investigative studies are also essential to verify these models as thoroughly as possible as they are introduced. Regional models can resolve climatic changes over distances of order 10 km on scales so that impacts of climate change on cities can be studied, even if only qualitatively at this time. A convincing method for testing the accuracy and robustness of GCMs in varying climatic conditions has been to develop palaeoclimate versions

of GCMs (Kiehl & Shields 2005). Other recent results confirmed the deductions of Mann *et al.* (1999) that the 'hockey stick' graph of global temperatures show little change over the last 1000 years in global temperatures before they rose markedly in the last 100 years (Ammann *et al.* 2007). Other models of intermediate complexity have simulated the pattern of ice ages over many thousands of years (e.g. Crucifix & Loutre 2002; Mysak *et al.* 2002).

The latest development in using GCMs for predicting the range of possible future climates is by computing multiple runs of the GCMs with varying starting parameters. Obtaining confidence limits in this way as well as modelling processes in greater detail will require 'petascale' computing facilities (i.e. a thousand times faster than at present). These may only become generally available through international collaboration, such as the projects currently underway at the Earth Simulator in Japan.

The paper by Pope *et al.* (2007) from the Hadley Centre, Met Office (UK) reviews these three major directions of modelling improvement: increased resolution and complexity, and better characterization of uncertainties. The latest Hadley Centre model HadGEN1, which is a major improvement on the HadCM3 model, had been prominently used for climate simulations and predictions in the last IPCC 2001 report. The fundamental strength of HadCM3 and HadGEN1 is that they are based on weather forecasting and thus many (but not all) elements are tested every day. The improved physical processes in HadGEN1 include better cloud and sea ice characterization. The next generation of Hadley Centre models HadGEM2 with a fuller coupling of all the land, sea, atmosphere processes will be available from 2009. High-resolution regional models (TE2100) in combination with existing Hadley Centre global models have been used to predict possible future flooding events in London, especially beyond the year 2030 when floods may exceed the capacity of the current defences which include the Thames Barrier. These models have also provided key inputs into other detailed assessments of the future potential for coastal and river flooding. The three major causes of uncertainty in the predictions are natural variability, future emission scenarios and the assumptions in the models themselves. All these factors are being investigated and quantified through the extensive use of multiple model runs for each type of input and model variable.

A particularly important application of the global and regional models is to simulate and predict extreme events, which cause much of the damage associated with climate change.

The outputs of weather, climate and environmental models are now displayed simultaneously with many types of geographical data, such as agricultural, structural, social, economic, etc. on Geographical Information Systems (GIS) that are widely available on personal computers. This enables the relevance of climate data to be extensively applied in practice, for example in dealing with the effects of extreme weather patterns on vulnerable infrastructure such as gas pipes, rivers, roads, etc. (Wilhelmi & Betancourt 2005).

European heat waves (daily temperatures greater than 30°C) are likely to become more severe as a result of the human influence on global climate (Stott *et al.* 2004). The HadRM3 model predicts 9 days per year for Paris in the control run 1961–1990, increasing to more than 50 days in 2071–2100. Furthermore, the duration and intensity of the heat waves all tend to increase in these model predictions. In terms of future precipitation in winter, despite the admitted uncertainty of long-range precipitation forecasts, it is expected that northern

Europe will have more rain while southern Europe will have less. In summer both northern and southern Europe are predicted to become drier, although the number of extreme rainfall events in northern Europe is likely to rise. These changes are likely to be accompanied by a significant increase in average and extreme wind speeds leading to greater threat of storm surges along northern European coasts (Beniston *et al.* 2006). A broad explanation for both these trends is that the troposphere is becoming less stable and allowing deeper convection and more vertical transport of momentum (IPCC 2001).

There is a compelling argument (Kiehl *et al.* 2005) that, because aerosols can have a major impact on regional climate, better modelling is required. Aerosols can significantly affect regional climate by altering the fluxes of sunlight and moisture at the Earth surface. In some polluted areas such as East Asia, these affects can easily exceed the countervailing effects of global warming during certain seasons (Ramanathan *et al.* 2001). New synthesis of satellite data over Europe show that solar energy received on the ground was reduced by 6 Wm^2 leading to reduced temperatures of 0.7°C , a reduced boundary layer depth and lower rainfall (approx. 6%).

The paper by Ghosh *et al.* (2007) on this subject first stressed the lack of knowledge concerning aerosols themselves. This is because aerosols are by their very nature complex; they can vary in size from sub-micron up to $80 \mu\text{m}$, they can be hydrophobic and hydrophilic, they have a complex relationship with cloud formation and precipitation and they have a wide range of sources including sea salt, sulphates, nitrates and biomass burning. Ghosh describes models for combining the effects of different types of aerosols in the atmosphere to improve the parametrization of GCMs. The results of a parametrization with sulphate and sea salt aerosol within the Hadley Centre model have shown a significantly reduced effect of sulphate aerosol on cloud nucleation. Consequently, these sulphate particles may not be reducing solar radiation as much as has previously been assumed. This is an example of the strongly nonlinear relationship between increasing levels of aerosol in the atmosphere, and increased production of cloud droplets and global warming. These interactions need to be better understood in order to incorporate them correctly into global climate models (e.g. Diner *et al.* 2004).

The background to Holland & Webster's (2007) paper is that since the 1980s predictions about the potential impacts of climate change on tropical cyclones have varied considerably. The first WMO conferences of experts on this subject generally discounted alarmist statements being made that tropical cyclones would, essentially, double in frequency and intensity. In the 1990s, our improving knowledge of the manner in which tropical cyclones interact with their environment, plus improved climate projections, led some researchers to conclude that a modest increase of intensity was probable in the future due to climate change. At that time not much could be said about changes in the statistics of tropical cyclones, such as frequency and location. This paper reviews two recent independent statistical studies by Emanuel (2005) and Webster *et al.* (2005), both of which concluded that the proportion of intense cyclones had increased over the past 30 years. These new data coincide with our greater understanding concerning the impacts of tropical modes (such as easterly waves) on tropical cyclone development and intensification. Owing to the limited period over which such data are available, these conclusions have been controversial. (For example, the WMO's Commission for Atmospheric Sciences did not agree with

the new results (WMO/CAS 2006).) Holland & Webster (2007) described a novel analysis using a mesoscale numerical model to compute detailed climate statistics of tropical cyclone development and intensification. They showed how both aspects are affected by interactions with large-scale modes in the tropical atmosphere, especially easterly waves and the monsoon circulations. Rising sea surface temperatures also affect the development of cyclones. They present a detailed analysis of the 2005 Atlantic hurricane season which provides support for the Webster *et al.* study. For example, the 1991–1993 combined seasons had a total of 22 storms, 12 of which were hurricanes, and of those two were category 4–5. Compared with just the 2005 season which had 27 storms, 12 of which were hurricanes, and of those five made it to category 4–5. They conclude that the most relevant hurricane characteristics, namely location and intensity, are likely to change for the worse with greenhouse warming.

To predict the future climate change, it is also essential to understand how climate has varied in the past. Shindell's (2007) paper argues that the modern-day climatic variations associated with rapid warming of oceans, ice sheets, methane hydrates and the impact of human societies can be studied through case studies of dramatic events of recent climate history. He uses palaeoclimate modelling and the evidence of marine sediments to analyse the cessation at the end of the ice age of the North Atlantic Ocean thermohaline deep ocean circulation. During the Younger Dryas warming period, starting about 10 kyr ago, the global climate briefly returned to glacial conditions when in the year 8200 BC, a huge freshwater lake on North America flooded into the North Atlantic Ocean. Equally important are vegetation–climate dynamics, which for example determined the end of the African Humid Period. In the middle of our current interglacial (warm period) *ca* 5.5 kyr ago, the Sahara suddenly dried out and became the extensive desert we have today. The fact that vegetation changes can happen at the time scale of decades is illustrated by modern data from Lake Chad. In 1963, it was the sixth largest lake in the world; by 2001 reduced rainfall had shrunk it to the tenth largest in the world.

Ice sheets are also not as stable as once was thought which is significant for the future of the Greenland and West Antarctic ice sheets. With continued climate change causing melting of these sheets would lead to such enormous volumes of water being discharged into the ocean that there could be a 4–6 m of rise in sea level around the world. Another dangerous consequence could result from the release of large quantities of methane hydrates from beneath the ocean. Geologists have deduced that such an event occurred in the past, *ca* 55 Myr (ago), in response to sustained global warming and at that time added another 5°C to global temperatures. However, at the moment it is uncertain how much methane hydrate is stored beneath the oceans and by how much ocean temperatures would need to rise in order to cause climatically significant releases of methane gas into the atmosphere. Methane will also be released into the atmosphere as permafrost melts; some estimates of the resulting global warming are as high as 2°C (see Stern *et al.* 2006). Clearly there are great similarities between the key mechanisms likely to influence and control future global climate change and those that occurred in the past.

A related danger raised at the conference is the possibility of the deep ocean circulation changing in the future. Currently, none of the global circulation models (GCMs) used to predict future climate change show a shut down of the

North Atlantic deep ocean circulation (Wood 2006). Thus, although this event has a low probability, if it did occur it would have a very large impact. Furthermore even by artificially adding freshwater into a GCM, it is very difficult to make the deep ocean circulation to vary, which could be partly due to the inherent conservative nature of GCM simulations. One reason is because westerly winds will continue to force the Gulf Stream and maintain the ocean circulation (Wunsch 2004). Nevertheless, data from the North Atlantic Ocean do indicate a slowing down of the ocean circulation compared with the 1950s (Bryden *et al.* 2005). It is not yet possible to tell whether this is a start of a longer-term trend or cyclic variability.

(c) *Urban climate change; science and policy*

A deliberate feature of the design of cities is that their climates should differ from those of their surroundings in order to be more comfortable, whether by sheltering their inhabitants from cold winds in high latitudes or, at lower latitudes, by protecting them from desert heat with shade and irrigated gardens; after all Babylon's hanging gardens were one of the seven wonders of the ancient world.

An equally essential feature of urban planning from earliest times is that cities should be safer places than isolated communities in the countryside subject to floods, or wind storms or the depredations of enemies and wild animals. However, these advantages of a better climate and a safer environment are under threat as the climate changes, and also as technology, the infrastructure and urban society undergo unprecedented transformations (e.g. Schellnhuber 2006; CABE/CIC 2007). The concern expressed by city governments everywhere has promoted many research organizations to establish research programmes into connections between climate change and the urban environment (NCAR 2006).

Currently, the worst climatic events to affect cities result from the combination of high-temperature events on a regional scale, exacerbated by the trends of global warming, and the heat island effect in city centres caused by the high energy use and the designs of modern buildings. The maximum daily excess temperatures (averaged over a 24 h period) are increasing in city centres faster than in the outlying areas (e.g. in London the excess temperature has increased from 1 to 6–7°C in 50 years, while the average UK temperature has increased only by approx. 0.6°C). Although this extra rise is not caused by the greenhouse effect, it is also a consequence of high energy use; and could well increase, even if all the energy in the city was produced carbon free. The heat-related deaths in European cities in 2003 were much greater than in recent comparable events in US cities, such as Chicago in 1995 (Klinenberg 2002; Kovats & Kristie 2006; Morley 2007). This is probably due to the larger regional temperature excess during the European episode and also differences in building design and cooling systems between Europe and USA. In future, the regional high-temperature events are likely to become more frequent (Pope *et al.* 2007) and may worsen people's health (as in Athens in 1987) when they are associated simultaneously with high levels of locally induced air pollution (Stern *et al.* 2006; IPCC 2007). At the conference, it was emphasized that reducing the heat island and ensuring comfort within buildings requires new types of low energy design (where energy savings of more than 50% are quite practical). Such buildings can maintain liveable temperatures (that have been redefined in Japan to be as high

as 27°C in the summer in part due to a change from western style office clothing), and can avoid excessive energy dissipation from air conditioning systems (Hacker et al. 2005). The heat island can also be reduced through the use of new materials for buildings (e.g. with tiles that reflect UV rays but are not aesthetically objectionable because they do not reflect light in the visible range), roads and infrastructure, and much greater use of parks, green roofs, etc. (Bennetts 2006). Cities can become more self supporting in energy with less risk from outside disruption by using solar power and local electrical grids. These are some of the ways that pioneering cities around the world are effectively combining the mitigation of greenhouse gas emissions with measures for adapting the environment of cities; in other words, an integrated approach to reducing the adverse effects of climate change and ensuring that the benefits are shared as equitably as possible. This combined task is a huge organizational and political undertaking even for the rich cities of the world with their great availability of financial and social capital; but it is even more demanding in the burgeoning cities of developing countries where interest on loans is often prohibitive and the social and political structures are only now beginning to become involved in such large and comprehensive projects (Kammen 2006). Nevertheless, some cities in these countries have maintained or improved the environment through local initiatives with wide public support, such as clean fuels in Brazil and India. Also many of these countries have preserved, against great odds, open green spaces which help reduce the heat island effects and the rising concentrations of aerosol.

The surface monitoring of the climate of urban areas is still as inadequate as when Howard (1833) first made this comment. However, with the increasing availability of environmental instrumentation aboard orbiting satellites the urban heat islands of many cities are beginning to be well documented (e.g. ASU 2003)—an essential tool for planning the changing urban climate. But it is now being argued that even the climate at rural sites is uncertain owing to the contribution of the heat island from growing urban areas. It has been proposed (Vose 2006) to establish a new surface network in the USA with upgraded precision instruments, with of course a careful recalibration against the form.

Despite generally being areas where people have more amenities and experience less risk than in isolated communities (in both developed and developing countries), disastrous events can also strike city populations. Floods, infectious diseases and enhanced air pollution are the hazards most likely to be caused by climate change or greatly exacerbated by its wider consequences. The scientific understanding of severe flood events is developing rapidly with better computer models and warning systems that are now available for hurricanes, tropical cyclones, dam failures, storm surges, rainstorms and tsunamis. But as recent events have shown, there can still be great failures in forecasting the events and the damage caused, in providing effective warnings to populations and in assisting recovery afterwards. Progressively, it is realized that static structures such as permanent flood barriers and dykes are not sufficient to deal with all types of flood in urban areas; dynamic structures can also be used, such as moveable flood barriers, e.g. steel walls in Prague, the Thames Barrier and floating houses in The Netherlands (Stelling 2006).

Crichton's (2007) paper focuses on the policy framework for dealing with flooding, especially in urban areas. He notes that owing to its huge financial liabilities, the global insurance industry, which is three times larger than the

global oil industry, has had to establish reliable measures of risk. Crichton (2007) himself has designed the Risk Triangle, a framework for adaptation and modelling, which takes into consideration the relative importance in any given type of naturally caused risk of the natural hazard, the vulnerability of people and property and their exposure to risk in their actual situation. For example, 93% of homeowners in the UK have private insurance cover including flood. The UK insurers realize that they not only need to map flood exposure but also to manage it. In fact, insurers have better flood maps and flood data than the government. Crichton pointed out that the UK government has regulated neither planning nor building design to allow for the effects of climate change (though new regulations are planned in the UK; DEFRA 2006; CABE/CIC 2007). Governments have failed to ensure resilience of communication systems. During Hurricane Katrina, three million phones were disabled (although in India cell phone warnings of cyclones are provided to millions of people and in 14 languages). In Carlisle, England during the 2005 floods (10 000 homeless) all communications were disabled except coastguard radios. However, in Scotland all cell phone transmitters must be in safe locations to ensure continued operation during a flood. Sewage and drainage networks are also at risk with flooding. Crichton stated that UK hazards are growing due to global warming with increases in severe rainfall events, rising sea levels, higher storm surges, more droughts and subsidence and changing storm tracks. For example, Met Office data suggest that since 1930 there has been a doubling of the frequency of extreme events when rainfall occurs over a 3 day period. Crichton argues that new approaches will be needed. First—mitigation: we must reduce the carbon emissions which cause climate change by avoiding use of fossil fuels. Second—adaptation: we must make our buildings and cities more resilient. But above all, policies must stop ‘Maladaptation’, especially through collaboration between insurers, loss adjusters, builders, architects, planners and those setting building regulations.

Pielke’s (2007) paper argues that coastal hazards associated with climate change will have the biggest societal impact. In developed countries, the major effect will be economic loss within and beyond these regions while in developing countries there also tends to be a large loss of life. There are two major reasons for the vulnerability of these regions: first is the increase in storm and flood risk; and second is the massive increase in the coastal population. For example, Hurricane Katrina was not the worst storm that has hit the USA. A storm that hit Miami in 1926 was 150% larger but did little damage as Miami Beach was not yet developed. In the USA, coastal population has doubled in the last 10–15 years. Pielke’s calculation of future economic loss suggests that societal changes far out weigh the climate changes. In terms of climate change, therefore, mitigation policies will have little immediate effect on the coasts, while adaptation of coastal regions will be essential. Adaptation should therefore be the immediate objective of any policy response to coastal development. The effectiveness depends on the cumulative effects of many decisions which have to be related to the whole social and economic structure of the affected societies. Experience shows how different approaches are needed for dealing with the vulnerability of coastal communities in developing and developed countries.

Reaching policy decisions about climate change and environmental problems requires three-way communication and dialogue is necessary between the communities affected, the responsible politicians or administrators, and the

technical experts and scientists. Open dialogue is particularly essential in weighing up the technical advice, which is often uncertain, before decisions are made. Social science, including its recently established sub-discipline of the study of science-based decisions, is contributing new understanding of these relations; the theme of the last paper in this issue by Corfee-Morlot *et al.* (2007), which also provides a useful history of how climate change issues have entered the public policy arena.

3. Conclusions

As the ministerial paper clearly states, it is generally accepted (Schellnhuber 2006; IPCC 2007) by governments and societies based on the largely unanimous scientific advice that human activities are responsible for recent changes in the global climate, and that these changes will become more marked over the next 30–50 years. This is both the time scale for making an impact on the rising trend of climate change and the time scale on which it is possible to change both the level of greenhouse gas emissions and the efficiencies of energy use by industry, cities and the infrastructure of communities everywhere. The natural and even social effects of climatic change are already evident, with the widespread melting of glaciers, increased river flow into the Arctic, earlier spring activity of plants and animals, loss of Arctic sea ice and melting permafrost and rising sea levels. The extreme summer heat wave of 2003 and the extent of droughts and intensity of rainfall increasing since 1970s have led to loss of life and significant economic losses. Although the jury is still out on hurricanes, recent events and studies should ring alarm bells. What will be the impacts of increasing greenhouse gas concentrations, especially temperatures rising above 2°C?

There are still difficult research questions that need to be answered in order to guide international policies and economic investment (Stern *et al.* 2006). In particular what options are there for achieving stabilization of greenhouse gases at different stabilization concentrations in the atmosphere, taking into account costs and uncertainties? For different levels of climate change what are the key impacts, for different regions and sectors and for the world as a whole?

To help deal with these overarching problems many specific issues have to be dealt with, some of which are addressed in this issue and were discussed at the conference.

(a) Regional modelling

The recent improvements of regional (mesoscale) computer modelling were shown to provide a vital complement to global climate models which predict long-term trends. These methods are demonstrating the importance of predicting and understanding the extremes in climate change phenomena such as very hot/dry summer spells, or trends of increasing intensity of hurricanes, whose tracks may also be altering in a way as to cause greater damage to shoreline communities and cities as we saw in 2005. Predictions of future climate change impacts on the city scale are essential for guiding local and regional policies on both adaptation and mitigation policies.

(b) Atmospheric processes understanding

As more comprehensive monitoring and modelling of ozone, aerosols and clouds is developing, it is clear from sensitivity analyses (e.g. Davey & Hunt 2007) that uncertainty about these particular physical processes significantly affects the uncertainty of global climate predictions. They control to a large extent the radiation balance in the atmosphere and the modelling of precipitation whose patterns are changing substantially but so far it seems quite erratically. More research is required to understand and model these natural processes, and also the direct effects of dust and aerosols from industry, transportation, forest burning and land use (Ramanathan *et al.* 2001).

(c) Petascale and multicentre computing

Despite the steady year-on-year increase in speed and capacity of computer processing power, more is still required. First, there is the need to provide finer resolution for regional modelling; second, general climate models (GCMs) should include more detailed simulations of ozone, aerosols, clouds, biogeochemistry, ocean ecosystems, dynamic vegetation, changing land use and dynamic ice sheets; and third, multiple GCM runs with varying starting parameters are required to produce confidence limits to future predictions. This will require petascale (i.e. 10^{15} operation per second) computing and thus significant investment both at the national and international scale. Complementary to these enormous stand-alone systems is the growing involvement of thousands of personal computer users to provide additional information about an even wider range of possible climate change scenarios. The Climate.net innovation that began in the UK (supported by the Natural Environment Research Council (NERC)) now has many online participants all over the world (Stainforth *et al.* 2005).

(d) Investment in renewable energy R&D

To increase the proportion of energy supply up to the 20% level attained in some countries, e.g. Denmark, there needs to be a substantial increase in both private and government research and investment in development projects. Since the technology needs to change to increase reliability and reduce costs, this investment needs to increase more rapidly than is now being proposed even to compare to the peak levels in the 1970s. Some US evidence shows that solar (photovoltaic) and wind energy are already cost effective, although this is not the official view of the DTI or the Energy Research Centre of the UK. The enthusiastic US university view is that the reason for the success of the renewable energy campaign in Japan has been that with an increasing demand for photovoltaics, the unit prices have dropped significantly. In the last 8 years the installation price has halved. In the USA and UK, high-profile buildings such as the Moscone Conference Centre in San Francisco and City Hall in London are leading the way by illustrating the use of solar technology.

(e) Redesigning cities

Cities are both the largest source of carbon emissions and at the same time are particularly vulnerable to the impacts of climate change. Therefore, cities of the future will have to be redesigned first to reduce carbon emissions as

much as possible and second to adapt to climate change in order to protect their populations from its worst effects. A number of key points were raised about how to redesign cities: (i) strong legislation is required in all cities to ensure adaptation and mitigation policies are followed; particularly important are building regulations, waste and water management and overall city planning, (ii) planning infrastructure changes needs to start now since these can take up to 30 years to implement, (iii) the latest building technology needs to be widely introduced and incentivized as it can reduce buildings' energy requirements between a half and two-thirds, (iv) alternative/renewable energy options must also be encouraged as solar and wind can be built into new building design and retrofitted to existing buildings, (v) local 'in-city' power generation should be developed to reduce the loss of energy via transportation (which can be as high as 60%), (vi) help new cities in developing countries to build sustainable cities which do not blindly follow the western temperate climate model which may not be appropriate for that region, and (vii) consider downsizing and even abandoning unsustainable or highly vulnerable cities.

(f) *Policy framework and targets*

Despite the seriousness of climate change, economic models are required to demonstrate to policy makers that climate change mitigation and adaptation are cost effective. Some measures, such as improved coastal defences or large power stations with low carbon emission are certainly very expensive; but on the other hand many conservation and technological measures save money in the short term. Examples of what is possible need to be publicized and replicated, such as the town of Woking (mentioned earlier). Policy makers both at national and international levels require mitigation targets, which should include the time scale on which these measures need to be introduced (Stern *et al.* 2006). This will inevitably be controversial due to the varying economic impacts on different countries and because of a fundamental objection which has been raised by some economists (e.g. Dasgupta 2006). They argue that investment in mitigation measures would be better spent on raising the general level of prosperity, because this would ensure that everyone would then have the money to adapt to climate change! The counter argument is that greater GNP will not restore permanent loss of species and ecological habitats (with their associated economic losses especially for the poorest and most disconnected communities). Nor would it compensate for loss of life and amenities caused by increasing severity and frequency of natural disasters (Holland & Webster 2007). Taking the latter view, policy makers and governments are generally focusing on how to move the world towards lower levels of carbon emissions that will ensure a sustainable climate over the long term (at least a few centuries). For cities the target may be as low as zero net production, while for national carbon emissions there need to be reductions of more than 60% below 1990 levels in the major developed countries, including the UK and USA (Stern *et al.* 2006; IPCC 2007). Through the UN-Framework Convention on Climate Change, the Kyoto framework currently provides the only international regulatory, market-based and economically redistributive arrangement for reducing global carbon emissions. Many sub-national governments, notably cities and states, are managing their own mitigation strategies within this framework, even where

their national governments have not ratified the protocol. As for the future, governments, researchers as well as non-governmental groups are all engaged in exploring what kind of international framework will operate after 2012 when the current agreement ends.

(g) *Better science communication is required*

Scientists, economists and social scientists are steadily becoming more interested in communicating issues of their specialisms to diverse audiences. Those involved in climate change studies are taking this responsibility seriously. The notable contribution of US professional societies in training specialists in public outreach is now being copied in Europe and elsewhere. In India scientists have written some excellent popular texts with guidance about daily life and vivid illustrations. A number of practical suggestions were made at the London conference: communication must be integrated into the development of policy and not just as an afterthought; and audiences with different interests should be identified and the communication strategy tailored accordingly ([Agenda for Climate Action 2007](#)). As in the USA, Canada is making innovative use of its science museums to communicate climate change to a wide audience. Communication should be a dialogue, avoiding scare tactics. It needs to move beyond the science and focus on solutions and capacity building, and bring together valid visions of the future that everyone can support (e.g. [Walker & Simmons 2005](#)). This approach might be more understandable and successful than those based on the hesitancy of the precautionary principle and the uncertain definitions of sustainable development. Improvement in communicating climate change requires providing the public with clear statements about the well-established results of scientific research, and also about the uncertainties of scientific prediction (e.g. [Gore 2007](#)). Education and debate are beginning to inform the public about the changing views of governments during the critical stages of the international negotiations leading to the framework that should succeed the Kyoto Protocol. (Opinion polls show great ignorance of what is happening.) Equally important is the involvement of the public as investors, consumers and as citizens in the measures being taken at every level to mitigate and adapt to climate change. (Here opinion polls show that where practical steps are being taken and publicized they are supported by local communities.)

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