Climate Change and Migration: Improving Methodologies to Estimate Flows

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Publisher: International Organization for Migration
17 route des Morillons
1211 Geneva 19
Switzerland
Tel: +41.22.717 91 11
Fax: +41.22.798 61 50
E-mail: hq@iom.int
Internet: http://www.iom.int

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Climate Change and Migration: Improving Methodologies to Estimate Flows

Prepared for IOM by

Dominic Kniveton
Kerstin Schmidt-Verkerk
Christopher Smith
and
Richard Black

Sussex University, Brighton, UK

IOM International Organization for Migration

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EXECUTIVE SUMMARY

The consequences of climate change, including changes in the frequency and violence of extreme weather events and changing precipitation patterns are expected to have large impacts on people's livelihoods, especially in poor and vulnerable rural societies. In many of these societies migration has already been a livelihood strategy for generations. Shocks and stresses evoked by the consequences of a changing climate that threaten people's livelihoods are therefore also likely to have impacts on their migratory behaviour. Migration might increase as people need to search for a living elsewhere. But it might as well decrease as fewer people can afford to move. It is also conceivable that migrants choose different destinations that they perceive as more appropriate for their changing needs.

Despite the growing awareness of the nexus between climate change and migration the subject has not been explored empirically in a way that generates conclusive results. In this, we outline the key elements of natural and human-induced climate change of potential relevance to migration; discuss the current state of the debate about the relationship between climate change and migration and describe approaches with which to further our understanding of climate change-related migration.

Climate change and variability can occur as a result of natural processes and due to human activity. Human induced climate change over the last century arises primarily from the alteration of atmospheric concentrations of greenhouse gases by the burning of fossil fuels and change of land use. Volcanic eruptions and variations in solar activity are the major processes causing natural climate change over the same timescales. The consensus view, as expressed by the Intergovernmental Panel on Climate Change (IPCC) is that an increase in greenhouse gases brought about by human activity is the main culprit for climate change since the mid 20th century.

Predicting future climate change is inherently uncertain due to a lack of information on known climate system processes, a lack of knowledge of all of the climate processes that affect the climate system and the chaotic nature of the atmosphere. The IPCC provide comprehensive assessments of the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The latest batch of IPCC reports, released in February 2007, predicts temperature increases throughout the globe, with these being greatest over land and high latitudes in the northern hemisphere in the winter. On the continents, warming is projected to increase from the coasts to the interiors and be typically larger in arid compared to moist regions.

Meanwhile, rainfall is predicted to very likely increase at high latitudes and likely to decrease in most sub-tropical land regions. Increased frequencies and durations of heatwaves and decreases in frost days are forecast almost everywhere in the mid-high latitudes, while sea level continues to rise and increased peak wind intensities and increased mean and peak rainfall intensities in tropical cyclones.

The impacts of these changes include an increase in the number of people living in severely stressed river basins; an increase the frequency and severity of floods and droughts; a reduction in freshwater availability in coastal areas as sea level rise with increases in the extent of areas of groundwater and estuaries that are subject to salinization, increased threats to ecosystems and human health; global food production is predicted to very likely decrease (with a 3°C temperature increase); reductions in yield in many semi-arid and arid countries by as much as 50 per cent by 2020, with small-scale farmers being the most affected; and coasts and low lying areas are expected to be exposed to increasing risks due to more intense coastal storms and sea level rise.

At present coastal communities most vulnerable to climate changes and sea level rise include deltas, especially Asian megadeltas such as the Ganges-Brahmaputra in Bangladesh and West Bengal; low lying coastal urban areas which are prone to human induced subsidence and tropical storm landfall such as New Orleans and Shanghai; and small islands, especially low lying atolls such as the Maldives. While small islands face the highest relative increase in risk, the largest number of people affected live in the megadeltas of Asia. Thus, vulnerability to climate change impacts is very likely to be highest in South, South-East and East Asia, urbanized coastal regions around Africa and small islands.

Considering the volume of recent academic and policy publications about the impacts that climate change might have on migration, the number of empirical studies of contemporary manifestations of the influence of climate on migration is surprisingly small. Of these, empirical results of the impact of drought on migration have found, that drought seems to cause an increase in the number of people who engage in short-term rural to rural types of migration, but does not affect, or even decrease international, long-distance moves. Studies into the effect of hurricanes on migration have yielded even fewer results than ones that investigated the impact of drought on migration. It has become evident, however, that the assumption that climate variability leads to migration in a linear way is not supported by empirical investigation. In short, these studies have found that many other factors play into the nexus between climatic factors and migration. Thus, conclusive evidence on how the shocks and stresses caused by climate change might influence migration is not yet available, so new knowledge will have to be generated.

A first step in this process is to try to understand how people cope with the different types of gradual stresses and sudden shocks brought about by climate change and variability. In doing so, the extent that migration appears to be a response to these different types of stresses/shocks needs to be ascertained. However, such an analysis needs to recognize that changing migratory behaviour might be just one strategy among a variety of other options available to individuals, households and communities in response to climatically induced stress and shocks. It should be also recognized that climate is just one of the factors influencing migration decisions so there is a need to understand to what extent climate is a relevant factor in the decision-making process and whether climate change and variability influence the choice of destination, the length of stay and the number of migrants sent.

Two possible approaches to understanding the causal linkages between climate stimuli and migration behaviour are: the Sustainable Livelihoods Approach which seeks to explain the responses of households to external vulnerabilities in terms of the natural, physical, financial, human, and social assets and different coping strategies available to households; and the New Economics of Labour Migration (NELM) which addresses more directly why individuals migrate, in the context of household decision-making.

A second step in the elucidation of new information on climate change and migration involves the quantitative methods of statistical regression and agent based modelling in order to integrate the multiple variables involved in migration and vary the values of these to obtain simulations of future migration patterns. The accuracy of a statistical regression is determined by the strength of relationship between the variables (e.g. migration and climate variable); the boundaries of climate change or variation for which the relationship was discovered compared to that which is being applied to; the nature of the relationship (e.g. linear or non-linear); and the ability to define the general characteristics or profile of a migrant producing household or migrant. Perhaps the most significant limitation of this approach, is the absence, for much of the world, of time-sensitive migration flow data such that change in climate and other factors at time t can be used to explain migration at time t+1.

An alternative solution to the predicting climate-migration linkages is to use agent-based models to simulate the behavioural responses of individuals and households to climate signals, as well as relevant interactions between these social actors. The basis of ABM relies on the understanding that the results of a series of individual interactions may be different to the sum of the parts. It is therefore an effective means of analysis for systems that are both composed of interacting agents and exhibit emergent properties (properties that arise from the interactions of the agents that cannot be deduced simply by aggregating the known properties). The influence of the unique cognitive responses and attitudes of individuals towards these manifestations is of considerable importance in identifying the livelihood impact perceived to occur by individuals and the importance of these in their current existence.

By including such aspects into the agent attributes of an ABM and developing rules for the interaction of such agents, agent-based modelling presents a means of simulation far more powerful than those of alternative statistical analysis. However the lack of longitudinal datasets providing the information necessary to derive both agent attributes and rules of interaction and behaviour has so far restricted the use of ABM simulations in studies migration and climate.

The paper concludes that the study of climate change impacts on migration requires the urgent interdisciplinary study of the relationship of climate with migration involving detailed data collection and conceptual and numerical model development.

GENERAL INTRODUCTION

This paper is concerned with the question of trying to further the understanding of how different types of shocks and stresses caused by climate change influence different types of migration. The relationship between climate change and migration is currently a topic of great interest as the ongoing "environmental refugee" debate demonstrates. Proponents of the concept of "environmental refugees" argue that climate change will increase the severity and the frequency of extreme weather events, which will in turn cause the displacement of the majority of the population of affected areas. As a consequence, hundreds of millions of "environmental refugees" from vulnerable regions all over the world are expected to seek refuge in wealthier countries.

This approach is potentially misleading for a number of reasons. First, the consequences of changes in climate patterns are diverse, ranging from slow-onset phenomena such as rising sea levels and melting glaciers, to increased extreme events that occur suddenly, and at variable intervals such as tropical cyclones and floods. It is likely that these heterogeneous manifestations of climate change will affect people's livelihoods in different ways. Second, people might make use of a variety of different coping strategies in response to these different shocks and stresses. It is not clear whether and under what conditions migration is one of them. Third, migration decisions are complex with respect to destination, length of stay, and the profile of migrants. In addition, migration itself is a multi-causal phenomenon, making it difficult to isolate climate change related factors from other factors that cause people to move.

In the first section of this paper, we introduce the concept of climate change and discuss the different causes of climate change before moving on to outline the key predictions of climate change in the future, when change is caused by human activities. We end this section with a description of the major impacts of climate change caused by human activities. The focus on human-induced climate change follows the United Nations Framework Convention on Climate Change definition of "climate change" as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 1992). However, it is recognized that climate change can be caused by both natural and human forcings. The second section of this paper then outlines existing ideas and studies that link climate change and climate variability with migration. This is followed by a section on the potential methodologies available to meet the challenge of furthering our understanding of the impact of climate change on migration. The last section of the paper concludes, reflecting on the limitations of such approaches, and their potential to provide better predictions of climate change related migration.

A. CLIMATE CHANGE

A.1 Introduction

Climate is an abstract concept, a statistical summary of the atmosphere over a prolonged period of time. Climate change takes the even more abstract form of the difference in statistical properties of the atmosphere from one long period of time to another. As a result, people and society are not and never will be directly affected by climate change; rather their lives and livelihoods are impacted by manifestations of the climate system, such as a lack of rain or a heat wave. Moreover, society's primary interactions with climate tend to occur via third parties, climate sensitive activities, such as tourism or climate sensitive commodities such as crop yields. The state of these activities and commodities not only reflect the state of atmospheric variables but any number of socio-economic, political and cultural factors which are often totally unrelated to atmospheric conditions. It is within this arena of abstractness and non-linearity that the concept of climate change induced migration sits.

A.2 Causes of Climate Change

The Earth's climate has been changing since the time it was first formed. Strictly speaking the climate system not only refers to the atmosphere, but also the cryopshere (the ice and snow bound parts), the lithosphere (the Earth's crust), the biosphere and the ocean. These spheres interact with each other over a variety of temporal and spatial scales. For instance, volcanoes (the lithosphere) inject millions of tons of microscopic particles into the atmosphere, which act both to trap outgoing longwave radiation from the earth and to reflect incoming shortwave radiation from the sun, while the extent of the Earth's ice sheets (cryopshere) alter the planetary albedo determining how much of the sun's radiation is absorbed by the Earth, which in turn affects the amount of heat in the atmosphere. Changes in the climate system in the different spheres occur both naturally and due to human activity.

A.2.1 Human-induced Climate Change

Human-induced climate change arises primarily from the alteration of atmospheric concentrations of greenhouse gases. The burning of fossil fuels and change in land use act to increase levels of gases such as carbon dioxide and methane. These naturally occurring atmospheric trace gases are responsible for trapping outgoing long wave radiation in the climate system. When artificially increased, the natural greenhouse effect of these gases is enhanced and the globe warms. The degree to which the earth's surface temperature would rise with a doubling of carbon dioxide was first calculated in 1896 by Swedish scientist Svante Arrhenius who estimated an increase by 5 to 6°C. Over a century later, the Intergovernmental Panel on Climate Change concluded that with a doubling of carbon dioxide the globe would warm by 1.9 to 4.4 °C (Solomon et al., 2007).

While on first viewing, it may seem as if there has not been much progress in one hundred years, the later statement is underpinned by thousands of peer reviewed publications and tens of thousands of studies. This body of work has at its core the aim of understanding how the whole climate system works so that accurate predictions may be made not just of one climate variable – temperature – but many others as well. That the climate system is so complex, and not replicable in the laboratory, requires the degree of research that the subject has attracted. Human activities act not only to warm the planet but also to cool it. The creation of microscopic particles through agricultural and industrial processes reduce the amount of incoming solar radiation reaching the Earth and this has had the effect in the last hundred years of negating some of the warming caused by increases in greenhouse gases.

A.2.2 Natural Causes

A 2.2.1 *Volcanic Eruptions*

Volcanic eruptions can cause climate change both locally and globally. Following the volcanic eruption of Mount Pinatubo in Philippines in July 1991, for example, global temperatures in 1992 were the coolest in 30 years. The volcanic plume from the eruption reached an altitude of 30 km, releasing particulate and gaseous sulphur dioxide (SO_2) into the stratosphere to form sulphurous aerosols. The estimated peak aerosol mass loading was $30*10^{12}$ g, which while large, was dwarfed by the eruptions of Tambora in 1815 and Krakatau in 1883, which produced atmospheric loadings in excess of $100*10^{12}$ g and around $50*10^{12}$ g, respectively. Following the eruption of Pinatubo, clouds of water, sulphurous gases and aerosols moved westwards and circled the globe in 22 days. The tropical location of the volcano meant that this cloud of aerosol had maximum effect in blocking the sun's incoming radiation. However, by the end of 1993 the global stratospheric aerosol loading had been reduced to $5*10^{12}$g and atmospheric cooling initiated by the eruption had diminished. Volcanic forcings are transient in nature, as the aerosols soon fall to the ground, but prolonged periods of volcanic eruptions can initiate global cooling with positive feedbacks reinforcing the signal.

The climate system is characterized by both positive and negative feedbacks. Examples of positive climate feedbacks include decreases in snow cover causing a decrease in the amount of solar radiation reflected back to space and an increase in absorption by the Earth's surface of incoming radiation. This in turn gives rise to a warmer atmosphere which further increases the loss of snow cover and so on. Water vapour also forms an important feedback in current climate change. Increased warming of the Earth's surface will produce an increase in evaporation and water vapour in the atmosphere. Water vapour is a powerful greenhouse gas, which absorbs outgoing longwave radiation and so further increases both atmospheric and surface warming. However, there are also significant negative climate feedbacks. For example, increased water vapour in the atmosphere can in certain circumstances lead to increased cloud cover, which at low and middle altitudes tends to result in the reflection of more incoming solar radiation than absorption of outgoing longwave radiation. The net effect of increased cloud cover then is to cool the Earth and thus, decrease the evaporation of water to form water vapour in the atmosphere and so on. So while individual volcanic eruptions only cause short-lived changes in climate, a series of volcanic eruptions have the potential to initiate a more prolonged change by causing positive feedbacks in the climate system from an initial cooling. The warming of the globe up to to the 1940s coincided with a period in which there were few volcanic eruptions and this lack of natural forcing of climate change compared to the 1800s is recognized as causing some of the early century warming.

A.2.2.2 *Solar Variability*

One of the most contentious explanations of natural climate change is change in solar activity. The sun forms the primary source of energy that warms the planet in the form of shortwave radiation. A number of statistical studies have shown that measures of solar activity such as sunspots vary co-temporally with aspects of the climate. For example, the little ice age, which was a period of cooling in the middle of the second millennium, coincided with the Maunder minimum which was a period of about 50 years when the Sun appeared not to have any sunspots. Although sunspots are cooler areas of the sun's surface, their presence is considered an indication of increased solar activity and obviously their absence points to a weaker sun. In the last century, a wealth of studies has revealed statistical linkages between solar activity and variations of the terrestrial atmosphere. Unfortunately many of these linkages have broken down, with extended measurement over time and space. In addition, measurements of solar activity by satellites have revealed that changes of solar irradiance – the energy that the sun produces – over the timescales of study are too small to have induced the changes noted in the Earth's atmosphere.

The consensus view, as expressed by the Intergovernmental Panel on Climate Change (IPCC) is that there remains a low level of confidence of the role of solar variability on the climate (Solomon et al., 2007) and that an increase in greenhouse gases brought about by human activity is the main culprit for contemporary climate change.

A.2.2.3 *Slow Climate Change*

On longer time scales the processes of oregeny, epeirogeny and orbital variability can cause large changes in the climate. Oregeny relates to mountain building by plate tectonics. Mountains affect the general circulation of the atmosphere and over very long timescales influence the atmospheric content of the greenhouse gas carbon dioxide (CO_2) through the chemical weathering process involving bare carbonate rock and carbon dioxide dissolved in rain water. Epeirogeny refers to the distribution of land masses over the globe, also affected by plate tectonics. The relative distribution of land and sea affects the general atmospheric circulation via the different responses of land and water to radiation. The influence of orbital variability, the variations in the sun-earth geometry, is thought to be responsible for ice ages. All three of these processes are considered to have a negligible impact on climate change over the last 100 years.

A.2.2.4 *Climate Variability and Change*

In addition to long-term change, the state of the atmosphere varies hugely on a day-to-day basis. This is known as the weather and is an expression of the atmosphere's chaotic nature. This chaotic nature is why the state of the atmosphere at any particular location and time is virtually impossible to predict over a time period of more than two weeks, and often even for more than a few days ahead of time. While predicting the exact state of the atmosphere over a short and medium range lead time is difficult, the ability to project changes in climate (i.e. long-term average weather) due to changes in atmospheric composition or other factors is a much more manageable issue. For instance, we all know from first hand experience that any coming winter is highly likely to be cooler than the previous summer because of a fundamental change in the Earth's position relative to the sun. In a similar fashion we are able to determine that the climate will change in response to the amount of carbon dioxide it contains, as this affects the amount of heat that is trapped near the surface. So in terms of predicting the climate we have more confidence than predicting the weather.

Internal variability of the climate system manifests itself in a number of large scale atmospheric and oceanic patterns, two of which – El Nino Southern Oscillation and the North Atlantic Oscillation – are related to considerable variation in weather throughout the world.

A.2.2.4.1 *El Niño Southern Oscillation*

The atmosphere also varies at scales greater than days, such as from year to year or decade to decade and even century to century. This natural variability is widely recognized as taking certain fixed modes or patterns. The most influential pattern of variability is the El Niño Southern Oscillation (ENSO). Known for centuries by the fishermen of Ecuador and Peru, El Niño refers to the anomalous warming of the waters off the coast of these countries around Christmas time. Linked with the change in water temperature is a change in the atmospheric circulation known as the Southern Oscillation. In El Niño years, the increase in ocean surface temperature off the Peruvian coast results in enhanced cloudiness and rainfall in that region, especially during the boreal winter and spring seasons. At the same time, rainfall is reduced over the western side of the Pacific basin over Indonesia, Malaysia, and northern Australia. Under normal conditions in winter and spring the atmosphere is characterized as following a Walker Circulation in this part of the world. The features of this circulation are rising air, cloudiness, and rainfall over the region of Indonesia and the western Pacific, and sinking air over the equatorial eastern Pacific. During El Niño years, this circulation becomes weaker than normal, and for strong warm episodes it may actually reverse. The increased heating of the tropical atmosphere over the central and eastern Pacific during warm episodes affects not only the Pacific basin but spreads globally influencing the position and strength of jet streams in the subtropics and in the temperate latitudes of the winter hemisphere. These jet streams are related to the paths of extra-tropical storms and frontal systems, the changes of which result in persistent temperature and precipitation anomalies in many regions.

Studies of past El Niño events have revealed highly consistent precipitation and temperature anomaly patterns called "climate teleconnections" around the world. Examples of these teleconnections include:

- Drier than normal conditions over southeastern Africa and northern Brazil, during the northern winter season.
- Less than normal Indian monsoon rainfall, especially in northwest India where crops are adversely affected.
- Wetter than normal conditions along the west coast of tropical South America, and at subtropical latitudes of North America (Gulf Coast) and South America (southern Brazil to central Argentina).
- Mid-latitude low pressure systems tend to be more vigorous than normal in the region of the eastern North Pacific during winter. These systems pump abnormally warm air into western Canada, Alaska and the extreme northern portion of the contiguous United States.
- Storms also tend to be more vigorous in the Gulf of Mexico and along the southeast coast of the United States.
- The eastward shift of thunderstorm activity from Indonesia into the central Pacific during warm episodes results in abnormally dry conditions over northern Australia, Indonesia, and the Philippines in both seasons.

(Ropelewski and Halpert, 1987; Halpert and Ropelewski, 1992)

The opposite of El Niño is La Niña which is when the waters off Peru are unusually cold. Under these conditions a stronger Walker (east-west) circulation and weakened Hadley circulation are felt over the Pacific and a different set of climate teleconnections are experienced which are often the opposite of those of El Niño. Thus, it can be seen that the El Niño Southern Oscillation has a large impact on the weather experienced throughout the globe.

A.2.2.4.2 *North Atlantic Oscillation*

The North Atlantic Oscillation (NAO) is a pattern of pressure that strongly affects the weather of Europe and has climate teleconnections as far as the Indian Monsoon. It consists of a large scale alternation of atmospheric pressure between the North Atlantic region of sub-tropical high pressure and sub-polar low surface pressure. The state of NAO determines the strength and orientation of the poleward pressure gradient over the north Atlantic and thus the speed and direction of mid-latitude westerlies. When the NAO is "positive" (i.e. the pressure over the tropical region is higher than the sub-polar region), westerly winds are stronger or more persistent, northern Europe tends to be warmer and wetter than average and southern Europe colder and drier. When the NAO is "negative", westerly winds are weaker or less persistent, northern Europe is colder and drier and southern Europe warmer and wetter than average.

A.3 Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Its aim "is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation."

As an organization, the IPCC does not carry out research nor does it monitor climate related data or other relevant parameters, yet members of this body do engage in research within a wide range of institutions. Every five to six years it aims to produce a consensus assessment of the current understanding of climate change based mainly on peer reviewed and published scientific/technical literature. However, the process does not operate in a policy vacuum or without interaction with government and non-governmental bodies. As a formal intergovernmental body, governmental representatives meet to approve the options for assessment and workplans for the preparation of scientific reports. In addition, they review and accept the detailed scientific and technical reports and line by line approve the panels' summaries for policymakers. The scientific and technical reports themselves are compiled by scientists and technical experts alone but when considering the policymakers summaries it must be remembered that they are an interpretation of the scientific and social scientific analysis with the current political context contributing to the overall narrative.

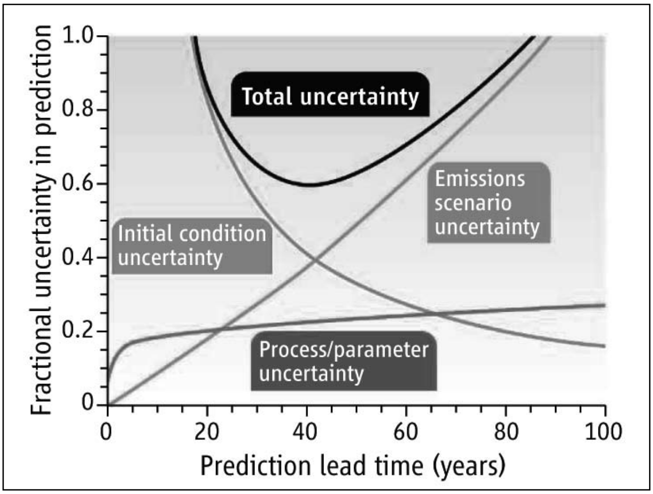
The idea of a consensus view of science is not one that sits very easily with the normal process of scientific discovery. Science is a process that advances our collective knowledge of the world by proposing and testing positive knowledge claims. Science depends on hypotheses or theories, what these imply for evidence and evidence to support or refute theory. It relies on public, collective and impersonal criticism, testing and replicating new scientific claims. Unfortunately, for those outside the scientific process, the way that science works can encourage the idea that there is overwhelming uncertainty – maybe more than actually exists – as science is based around criticism and argument. Additionally, because research papers have to be new and original, for those outside of science, consensus view or facts are often not immediately apparent. The IPCC tries to negate this uncertainty by providing consensus reports. That is not to say that the science and social science of climate change is without uncertainty, quite the reverse. Any process that attempts to predict the future will be inherently uncertain. Additionally, as was discussed above, the atmosphere is chaotic by nature. This places uncertainty on predictions of the future because of the impossibility of correctly and to the right degree of accuracy being able to specify initial climatic conditions. The other factor of uncertainty is due to the science community's vast lack of understanding of the climate system. For instance, much is unknown about the behaviour of clouds, yet they have a large impact on the magnitude of climate change expected from changes in greenhouse gas concentrations.

A.4 Predictions of Climate Change

The uncertainties in climate predictions vary both with the period used to average the state of the atmosphere to produce climate figures but also the lead time of the prediction (Cox and Stephenson, 2007). Additionally, the contribution of different types of uncertainties varies with time. For example, in forecasting global mean temperatures over less than ten years, the signal of anthropogenic climate change is small compared to uncertainty due to the inability to precisely define initial conditions (see Figure 1). On the other hand, when the prediction is for 100 years in advance, the initial condition uncertainty is insignificant and the uncertainty is determined primarily by the uncertainty in emission scenario e.g. how much greenhouse gases are being produced. The net effect of all of the uncertainties is that the fractional uncertainty of climate predictions is smallest when lead times are between 30 to 50 years.

FIGURE 1

MINIMIZING UNCERTAINTIES



Source: Cox and Stephenson, 2007

Contributions to uncertainty in the predicted decadal mean temperature vary with the lead time of the prediction. Here the fractional uncertainty is defined as the prediction error divided by its central estimate. Climate predictions focusing on lead times of ~30 to 50 years have the lowest fractional uncertainty. This schematic is based on simple modelling (taken from Cox and Stephenson, 2007).

In this case, the fractional uncertainty is defined as the prediction error divided by its central estimate, thus it is proportional to the increase in temperature expected. Luckily this time period fits well with planning decisions.

In its reports, the IPCC pays much attention to the treatment of uncertainties. Firstly it recognizes that there are two types of uncertainty, "value" and "structural". Value uncertainties refer to the incomplete determination of particular values e.g. when the phenomenon of interest is not fully represented by the data or the data is inaccurate. Structural uncertainties refer to the incomplete understanding of processes, such that not all the relevant processes may be included. In particular, this second type of uncertainty requires a judgement and, in the case of the IPCC, a collective judgement, to be made of the confidence of the result which includes estimating the limits of knowledge. The latest IPCC report has made a distinction between levels of confidence in scientific understanding (Table 1) and likelihoods of specific results (Table 2).

TABLE 1

LEVELS OF CONFIDENCE

Confidence terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Source: Solomon et al. (2007)

TABLE 2

LEVELS OF LIKELIHOOD

Likelihood terminology	Likelihood of the occurrence/outcome
Virtually certain	> 99% probability
Extremely likely	> 95% probability
Very likely	> 90% probability
Likely	> 66% probability
More likely than not	> 50% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

Source: Solomon et al. (2007)

Recently doubts have been expressed about whether there is a limit to the consensus that can be formed about climate change (Oppenheimer et al., 2007). The criticism raised is that one potential pitfall of reaching for a consensus is that key structural uncertainties are set aside or their importance minimized (Oppenheimer et al., 2007). The example given by these authors refers to sea level rise and the contribution of ice sheets to sea level rise. In 2001, the IPCC said that global mean sea level was projected to rise by 0.09 to 0.88 metres between 1990 and 2100 for the full range of emission scenarios. In 2007, the IPCC anticipated a rise in sea level of between 0.18 to 0.59 meters by the year 2100, indicating a drop in uncertainty and a lower upper level of sea level rise. However this range of sea level rise did not take into account the increasing contributions from rapid dynamic processes in the Greenland and West Antarctica ice sheets.

In practice, these processes have already had a significant effect on sea level and include the large disintegration of the West Antarctica Ice Sheet in March 2002 that initiated the acceleration of glaciers discharging into the sea. Glacial acceleration has also been witnessed in recent years in Greenland, yet current ice sheet models incorporated in climate models do not include the processes thought responsible for this increased movement and discharge into the sea. Paleoclimatic studies point to past increases of several metres in less than 100 years and there remains the legitimate fear that current knowledge cannot rule out a return to such conditions (Overpeck et al., 2006). While the IPCC's latest report recognizes the possibility of a larger ice sheet contribution to sea level rise, its main quantitative results, described above, indicate the opposite. Oppenheimer et al. (2007) suggest that the omission in the latest report of a numerical estimate of a potential contribution to sea level rise from the west Antarctica ice sheet, although provided in a previous report, reflects a lack of consensus arising from the inadequacy of ice sheet models compared to recent observations. Thus, it can be seen that uncertainty is particularly problematic for estimating future climates both due to a lack of information on climate system processes and lack of knowledge of all of the climate processes that affect the climate system.

A.5 Simulations of Future Scenarios

Model simulations of the climate change in the last 100 years have led the IPCC to state that it is very likely that increases in anthropogenic greenhouse gases have caused most of the observed increase in global average temperature since the mid-20th century. They also note that without the cooling presence of atmospheric aerosols this rise would have been much greater. This is particularly worrying in light of recent attempts to reduce human-produced aerosols and their relatively short life spans in the atmosphere compared to greenhouse gases.

Simulation of possible future climates requires the development of emission scenarios of greenhouse gases and aerosols. The IPCC produced a Special Report on Emission Scenarios (SRES) in 2000. The SRES team defined four narrative storylines describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Different demographic, social, economic, technological, and environmental developments were represented in each of the storylines in an attempt to encompass much of potential changes in the future.

The four storylines, labelled A1, A2, B1, and B2, combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (Nakicenovic et al., 2000). Brief summaries of the scenarios from Nakicenovic et al. (2000) are as follows:

- **A1 storyline**: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.

- **A2 storyline**: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.

- **B1 storyline**: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

- **B2 storyline**: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

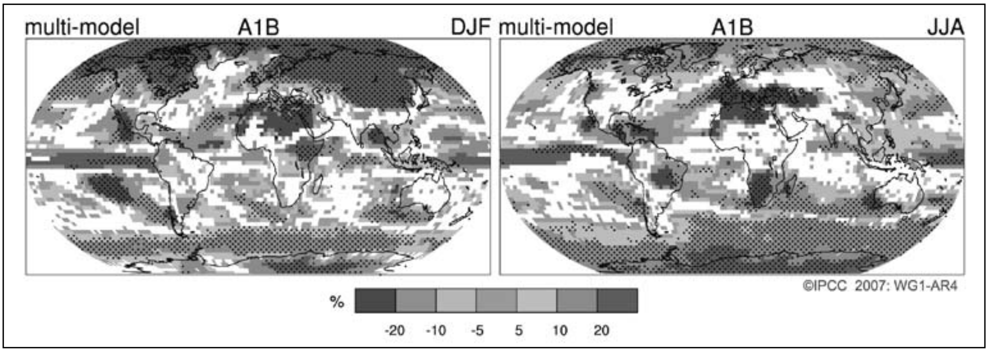
Families of projections based on each quantified storyline were then developed from quantitative projections of the major driving variables such as population and economic development taken from reputable international sources (e.g. United Nations, World Bank and IIASA). It should be noted that in simulations of the future the IPCC assumes each of the scenarios are equally valid, with no assigned probabilities of occurrence.

Not surprisingly, given the difference in storylines the projected changes in global average surface warming for the end of the 21^{st} century are dependent on which emission scenario is chosen. The temperature increases in 2090-2099 relative to 1980-1999 are lowest for the B1 storyline with a best estimate from a variety of climate models of 1.8°C. The highest temperature change of 4°C is predicted for the fossil fuel intensive version of the A1 storyline. The increase in temperature is positive throughout the globe, being greatest over land and high latitudes in the northern hemisphere in the winter. On the continents, warming increases from the coasts to the interiors and is typically larger in arid compared to moist regions.

Changes in rainfall are less robust than temperature with the signal change rising above natural variability more slowly than temperature. This is in part due to the high natural variability of rainfall and in part due to reduced knowledge of factors controlling rainfall variability. Over the globe, rainfall is predicted to very likely increase at high latitudes and likely to decrease in most sub-tropical land regions (Figure 2), although projections of rainfall change over the tropics are more uncertain than those at higher latitudes. However, some agreement is reached for an increase in the summer monsoon season of south and south-east Asia and east Africa. It is also worth noting the magnitude of the changes with some of the land regions in the subtropics experiencing 20 per cent decreases in rainfall. Other robust climate change predictions include increased frequencies and durations of heatwaves and decreases in frost days almost everywhere in the mid-high latitudes, therefore increasing growing season length. This potentially positive change for society however is offset by a tendency for summer drying of the mid-continental area indicating an increased risk of drought. As stated above, sea level is also predicted to keep rising, but not uniformly across the globe.

FIGURE 2

RELATIVE CHANGES IN PRECIPITATION (IN PERCENT)
FOR THE PERIOD 2090-2099, RELATIVE TO 1980–1999



Notes: Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66 per cent of the models agree in the sign of the change and stippled areas are where more than 90 per cent of the models agree in the sign of the change.

Source: Solomon et al. (2007).

In the last century, increases have occurred in the number of heavy rainfall events. This trend is set to continue in many regions including some regions that are predicted to experience decreased rainfall. In these cases the drop in rainfall results from a decrease in the frequency of rainfall rather than intensity. Models also indicate that a warmer future climate will be accompanied by increased peak wind intensities and increased mean and peak rainfall intensities in tropical cyclones. However, total numbers of tropical cyclones globally are predicted to drop. A summary of observed and predicted changes in extreme weather events affected by human activity is shown in Table 3.

TABLE 3

RECENT TRENDS, ASSESSMENT OF HUMAN INFLUENCE ON THE TREND AND PROJECTIONS FOR EXTREME WEATHER EVENTS FOR WHICH THERE IS AN OBSERVED LATE 20TH CENTURY TREND

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of human contribution to observed trend	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	Very likely	Likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Likely (nights)	Virtually certain
Warm spells/heat waves. Frequency increases over most land areas	Likely	More likely than not	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	More likely than not	Very likely
Areas affected by droughts increases	Likely in many regions since 1970s	More likely than not	Likely
Intense tropical cyclone activity increases	Likely in many regions since 1970s	More likely than not	Likely
Increased incidence of extreme high sea levels (excludes tsunamis)	Likely	More likely than not	Likely

Source: Solomon et al. (2007)

A.6 Abrupt Climate Change and Tipping Points

Information on climate change in the past, taken from studies of ice cores, tree rings and sequences of coral, reveal that the climate system can change abruptly over relatively short time periods. These changes occur when the climate system is forced to cross some threshold and it subsequently changes dramatically beyond that which would be caused by the initial forcing. In other words, the climate system can be forced to a point where it suddenly flips into another state. These points are collectively known as tipping points and include the shut down of the Gulf Stream in the Atlantic, the die back of the Amazon tropical rainforest, and the collapse of the ice sheets. These climate surprises would have dramatic consequences for society and the potential for massive demographic change. Furthermore, these points signify a loss of control of change of the climate system by humans and introduce the concept of irreversible climate change. This has important ramifications for efforts to reduce greenhouse gases as once these points are past, no matter how committed global society is to preventing climate change, large and widespread changes in the atmosphere are inevitable.

At present, the IPCC consider that currently understood tipping points in the climate system are unlikely to occur in the 21st century. However, it is also recognized that many of the climate feedbacks (see Section A.2.2) that are responsible for causing abrupt changes in the climate after the initial forcing, are poorly understood at present (Shindell, 2007). One of the most widely recognized tipping points is the shut down of the Gulf Stream. The Gulf Stream is one component of the Atlantic Meridional Overturning Circulation (MOC) which in turn is part of the thermohaline circulation (THC). The THC is a global system of surface and deep currents powered by differences in temperature and saltiness. In this circulation cold, salty water sinks at high latitudes, returning towards the equator at depth and is replaced by warm water moving towards the poles at the surface. Regionally, the Atlantic MOC is important because of its influence on the climate of the countries surrounding the north eastern Atlantic. Thus, the Atlantic MOC results in more hospitable climates in Europe than those experienced by countries at equivalent latitudes without this oceanic feature.

The main driver of the Atlantic MOC is deep water formation in the far north of the Atlantic caused by sinking salty water. In part this “excess” saltiness is caused by ice formation of the ice sheets. Should this saltiness be diluted by the melting of permafrost over Siberia or of the Greenland ice sheet, this deep water formation could be stopped and the Atlantic MOC turned off. This would stop the Gulf Stream causing cooling in Europe. Current climate model studies and comparisons with historical data indicate that changes in ocean circulation appear unlikely in this century although a reduction in MOC is possible.

The rapid melting of the Greenland and West Antarctic ice sheets has recently attracted widespread attention with the observation by satellite and in-situ data of accelerated ice flow (see Section A.2.5). While an ice-free Greenland is thought likely to take centuries to occur, this loss is seen as irreversible past a threshold temperature change of 1.9ºC to 4.6ºC. The timing of a potential collapse of the West Antarctic Ice Sheet (WAIS) is even less certain. The collapses of these ice sheets would have a big influence on sea level with a complete collapse of the WAIS predicted to cause a sea level rise of 5 m.

An irreversible loss of forest is predicted by many climate models in Amazonia starting in the 21st century due to a drop in rainfall in the region. Vegetation acts as a sink of carbon dioxide and its large scale loss is feared to be a strong feedback to continued warming. The loss of vegetation also increases the role of soil in providing carbon into the atmosphere further adding to warming. Estimates of the timescale of change from a sink to a source of atmospheric carbon indicate rapid change within two decades. Yet, there are still considerable uncertainties to when this may occur. Lastly, abrupt and irreversible changes in weather patterns have been observed in a number of palaeoclimatic reconstructions. These include stronger and prolonged ENSO events and a change in NAO to a stronger zonal circulation (positive NAO) although predictions of these changes in the future are uncertain. Thus it can be seen that while uncertainties are large there remains the possibility of irreversible abrupt changes in the climate system in the future. These changes would have major global consequences for society.

A.7 Impacts of Climate Change

The impacts of climate change are commonly assessed in one of three ways:

- **Sensitivity studies**: these can involve both empirical and modelling techniques to assess the outcome of perturbations to a system.

- **Analogues**: both historical and spatial analogues are used to explore the responses to future climate forcings.

- **Climate model data studies**: these "what if" studies are driven by future climate scenarios which are converted to potential impacts by passing through empirical and modelled representations of the system under consideration.

The majority of studies to date have been carried out in a linear fashion starting with climate data from general circulation models (GCM). In the following paragraphs a summary is given of the main projected impacts of climate change in which the IPCC has a high or very high confidence. The information presented comes from the technical summary of Working Group II of the Intergovernmental Panel on Climate change (Parry et al., 2007).

From a climate change perspective, freshwater systems and their management will predominantly be affected by increases in temperature, evaporation and sea level and precipitation variability. Currently, more than one-sixth of the world's population lives in glacier or snowmelt-fed river basins which are very likely to experience a decline in water volumes stored in glaciers and snow cover in the future due to warming of the climate. The resulting impact will be a reduction in summer and autumn flows. While runoff and water availability are very likely to increase at high latitudes and in some wet tropics, areas that are presently water-stressed in the mid-latitudes and dry tropics are predicted to experience drops in these variables. These changes will probably increase the frequency and severity of floods and droughts. The number of people living in severely stressed river basins is projected to increase from 1.4-1.6 billion in 1995 to 4.3-6.9 billion in 2050 for the A2 scenario (see Section A.5). Freshwater availability will also be reduced in coastal areas as sea level rise increases the extent of areas of groundwater and estuaries that are subject to salinization. Ecosystems, human health and water system reliability and costs are likely to be impacted by exacerbated water pollution resulting from higher water temperatures, increased precipitation intensity and longer periods of low flow.

In summary, overall the negative impacts of climate change on freshwater systems outweigh the benefits. The most severe hydrologic effects this century are likely to be reductions in subtropical precipitation. Water stress may become particularly acute in the South-West US and Mexico, and in the Mediterranean and Middle East, where rainfall decreases of 10 to 25 per cent (regionally) and up to 40 per cent (locally) are projected (Shindell, 2007).

Human societies rely on ecosystems not only for food and resources but free services such as water purification and defence against natural hazards (for example mangrove swamps are recognized as reducing vulnerability to tsunami damage). The natural ability of many ecosystems to adapt is likely to be exceeded by a combination of changes in climate variables such as increased flooding, drought conditions, wildfires and ocean acidification. On continents, the most vulnerable ecosystems to climate change impacts are those of the tundra, boreal forest, mountain, and Mediterranean ecosystems. At the coasts mangroves and salt marshes are particularly vulnerable to climate change impacts, while in the oceans, coral reefs are virtually certain to be severely negatively impacted. Initially, increased concentrations of carbon dioxide will increase net primary productivity as plants are able to photosynthesize more and use water more efficiently. For temperature increases of up to 2°C, plant growth is expected to increase at high latitudes, whereas at low latitude, net primary production is likely to decrease. Ocean acidification brought about by increased atmospheric carbon dioxide concentrations will impair the formation of shells and exoskeletons of ocean dwelling organisms requiring calcium carbonate. Species likely to be affected include corals, crabs, squids, marine snails, clams, and oysters.

In terms of food, fibre and forest products, the carbon fertilization effect will initially increase plant production in locations where water and nutrients are not limited. However, for temperature increases above 3°C, global food production is very likely to decrease. Coasts and low lying areas will be exposed to increasing risks due to more intense coastal storms and sea level rise. At present, coastal communities most vulnerable to climate changes and sea level rise include deltas, especially Asian mega deltas such as the Ganges-Brahmaputra in Bangladesh and West Bengal; low lying coastal urban areas which are prone to human-induced subsidence and tropical storm landfall such as New Orleans and Shanghai; and small islands, especially low lying atolls such as the Maldives. While small islands face the highest relative increase in risk, the largest number of people affected live in the mega deltas of Asia. Thus vulnerability to climate change impacts is very likely to be highest in South, South-East and East Asia, urbanized coastal regions around Africa and small islands.

Thus, we can see climate change is likely to influence people's livelihoods by both slow and rapid onset phenomena. In terms of slow onset climate change impacts, agricultural production and food security are likely to be heavily affected by both decreases and increases in crop and pasture yield and quality, the carbon fertilization effect, changes in forestry, and increased soil erosion. According to the latest IPCC report (Boko et al., 2007) in Africa alone projected reductions in yield in some countries could be as much as 50 per cent by 2020, with small-scale farmers being the most affected. Linked with decreasing crop yields there are likely to be increases in water stress and water pollution. Again according to the latest IPCC report (Boko et al., 2007) in Africa alone the population at risk of increased water stress is projected to be between 75-250 million and 350-600 million people by the 2020s and 2050s, respectively. Drought can be classified as both having a slow and rapid onset. Increases in water stress and change in areas of arid and semi-arid land are likely to increase the risk of drought. In Africa it is estimated that, by the 2080s, the proportion of arid and semi-arid lands is likely to increase by 5 to 8 per cent. While this may not be beneficial to crop productivity, livestock farming may benefit. For example, Seo and Mendelsohn (2006) estimate that in Africa, a warming of 2.5°C could increase the income of small livestock farms by 26 per cent (+ US$ 1.4 billion). This increase is projected to come from stock expansion. However they also noted that further increases in temperature would then lead to a gradual fall in net revenue per animal.

Fisheries are expected to be impacted by slow onset climate change impacts with reductions in production off the coast of north west Africa and the east African lakes. Related to impacts on fisheries sea level rise is predicted to continue with increased flooding, particularly affecting mega deltas and low lying islands. Sea level rise will probably increase the high socio-economic and physical vulnerability of coastal cities. Lastly, amongst the slow onset impacts on livelihoods, climate change is likely to cause increasing deaths, disease and injury due to heatwaves, floods, storms, fires and droughts; an increased burden of diarrhoeal disease; mixed effects on the range (increases and decreases) and transmission potential of malaria in Africa; an increase in the frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone related to climate change; and alterations in the spatial distribution of some infectious-disease vectors (Boko et al., 2007). Intuitively, all of the slow onset climate impacts are likely to influence migration decisions of all types of flow including international, rural to rural, rural to urban, forced and non forced migration.

Faster or rapid onset climate change impacts are likely caused by inundation from sea level rise and tropical cyclones; flooding from extreme rainfall events; and destruction due to storms of transport, economic and building infrastructure. While intuitively affecting all types of migration, rapid onset climate phenomena are likely to be related more readily to distress migration than slower onset causes.

B. CLIMATE CHANGE AND MIGRATION

B.1 Introduction

Current discussions of climate change-related migration build on earlier discussions of "environmental refugees". Before exploring the theoretical and empirical evidence for climate change-related migration we discuss the idea of an "environmental refugee".

B.2 The "Environmental Refugee" Debate

The term "environmental refugee," was first coined by Lester Brown of the Worldwatch Institute in the 1970s (Saunders, 2000), but became more widely known by the work of El-Hinnawi (1985) of the United Nations Environment Programme (UNEP) a decade later. Most estimates of the numbers of "environmental refugees" are based on those made by Myers and Kent (1995). Other texts by Myers (1993, 1997, 2002, and 2005) are also quoted in this context. Myers estimates the number of people that will be forced to migrate internationally because of environmental reasons by calculating the number of inhabitants of a region that might become affected by some form of environmental degradation. He assumes that all these people will become "environmental refugees". Other scholars have also made the claim that the numbers of "environmental refugees" will be immense. Jacobsen (1988) concludes that, "environmental refugees have become the single largest class of displaced persons in the world", whilst Cairns even suggests that all human beings might become "environmental refugees" one day:

> *"When countries capable of absorbing environmental refugees are at or beyond their carrying capacity, every individual on the planet becomes a potential environmental refugee with no place to go" (Cairns, 2002: 34).*

Crucially, such migration is often constructed as a major public policy challenge for industrialized nations, as this is where "environmental refugees" are expected to seek "asylum".

However, the term "environmental refugee" has been challenged by a number of scholars (McGregor, 1993; Suhrke, 1994; Kibreab, 1997; Black, 1998, 2001) for a variety of reasons. First, predictions of the number likely to be displaced are based on population estimates, as reliable population statistics do not exist in many affected areas. Second, it is unlikely that a whole population would leave as a result of most forms of climate change, whilst even those who might are relatively unlikely to cross an international border, let alone travel across continents to reach an economically more developed western country. Moreover, there is broad theoretical consensus that it is generally not the poorest people who migrate overseas because international migration is an expensive endeavour that demands resources for the journey and for the crossing of borders (Castles, 2000; de Haan, 2000; Skeldon, 2002). This reasoning has been supported by empirical evidence (Hampshire and Randall, 1999; Hampshire, 2002). It is thus difficult to imagine that people whose livelihoods are undermined by climate change will manage to embark on a journey to Europe or to North America.

In addition, the reasoning behind the term "environmental refugee" is that it is environmental change that is primarily responsible for forcing people to leave their homes. Yet, there is a consensus in the migration studies literature that migration is a complex phenomenon that can only rarely be explained by one single reason alone (Kritz et al., 1992; Castles and Miller, 1993; Boyle et al., 1998; Wood, 2001).

The term "environmental refugee" is also currently legally meaningless, as the Geneva Convention clearly defines "refugees" as people who are outside the country of their nationality "owing to a well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion" (UNHCR, 2006: 16). For this reason, Hugo (1996) suggests using the concept of "environmental migrant" instead, although he acknowledges that environmental change is a factor that drives involuntary migration and should be recognized academically and politically as such. One might argue that changes to the legal framework for refugee recognition have become necessary because of the growing significance of climate change-related migration, a claim supported amongst others by the United Nations University Institute for Environment and Human Security (Renaud et al., 2007), Christian Aid (2006, 2007), the New Economics Foundation (Conisbee and Simms, 2003), the Dutch-based organization LiSER (Living Space for Environmental Refugees)[1] and Greenpeace (Jakobeit and Methmann, 2007). However, there remains little agreement on who should qualify as an "environmental refugee", whilst, the problem remains as to how environmental reasons can be theoretically or practically separated from other motives for migration (Lonergan and Swain, 1998; Flintan, 2001), particularly in the context of such a distinction leading to significant claims by affected people to stay in, and receive protection from another state.

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[1] www.liser.org

B.3 Migration and Climate Change: A Definition

Despite these caveats, a working definition of climate change-related migration is required for discussion to continue. Here, we follow the IOM definition of environmental migrants as:

> *"persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad".*[2]

Migration related to the impacts of climate change may be considered a sub-set of environmental migrants, with a revised definition reading that "climate change migrants" are:

> *"persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment as a result of climate change that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad".*

Like the discussion note on migration and the environment (IOM, 2007) in this document we steer clear of the term climate change refugee due to the lack of legal grounding in international refugee law as outlined in the previous paragraph.

B.4 Linking Climate Change and Migration

The nexus between weather phenomena that are attributed to climate change and migration has been addressed theoretically and empirically since the 1990s. However, the subject has gained growing attention after the release of the Summary for Policymakers of the Working Group II document on Impacts, Adaptation, and Vulnerability, which is part of the Fourth Assessment Report of the IPCC. This report mentioned the "potential for population migration" due to increases in the number of areas affected by droughts and an increase in intense tropical cyclone activities (Parry et al., 2007: 16).

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[2] IOM (2007)

Most recent estimates of the numbers of expected "climate change refugees" or "climate change migrants" draw on figures put forward by Myers and Kent (1995) in the context of the "environmental refugee" debate. Thus a recent report written for Greenpeace Germany suggests there will be 150 to 200 million "climate change refugees" in the coming 30 years (Jakobeit and Methmann, 2007), whilst the Stern Review on the economics of climate change (2006: 77) reports the same figures as "conservative assumptions." Based on Stern's observation that "climate change will lead to hundreds of millions more people without sufficient water or food to survive or threatened by dangerous floods and increased disease" (Stern, 2006: 77), a report for Christian Aid (2007) goes further by suggesting that there will be one billion climate change refugees by 2050. However, the report admits that "there are no recent, authoritative, global figures on the number of people who could be displaced from their homes by climate change" (Christian Aid, 2007: 22).

One reason that likely affected numbers are unclear is the lack of agreement over the way that factors such as poverty, scarcity of natural resources, and political conflicts influence the nexus between environmental stressors and migration. The fact that the consequences of climate change will particularly affect the poorer regions of the world has been generally accepted (Yamin et al., 2005). Christian Aid claims in two reports (2006, 2007) that climate change might limit the effectiveness of development assistance as water and other resources will become even scarcer. Furthermore, climate change might lead to violent conflicts over the ownership of resources, which in turn could cause the displacement of a large number of people (Christian Aid, 2007). For the same reasons the United Nations Environment Programme identifies environmental factors as "one of three major causes of displacement in Sudan" (UNEP, 2007: 104). Meanwhile, a report published by the International Peace Academy points out that the relationship between climate change and conflict on its own is weak, but that mass migration can be seen as the linking element (Gleditsch et al., 2007). Two different scenarios are presented: 1) environmental stress in sending areas leads to migration and then conflict in receiving areas; and 2) environmental stress leads to conflict in sending areas, migration and further conflict in receiving areas (Gleditsch et al., 2007). However, despite wide coverage of these reports in newspapers, magazines and other media, there remains a lack of empirical evidence to support these claims (Salehyan, 2005: 2). Some of the limited available evidence is briefly reviewed in the next section.

B.5 Empirical Evidence on Climate Change–Migration Linkages

Considering the volume of recent academic and policy publications about the impacts that environmental/climate change might have on migration, the number of empirical studies of contemporary manifestations of the influence of climate on migration is surprisingly small. A number of studies have documented historical evidence for a link between climate and migration (e.g. Gupta et al., 2006) although contemporary examples are fewer. Most recently work by Reuveny (2007) has explored the role of the environment in the cases of migration related to Hurricane Katrina, the US Dust Bowl in the 1930s and Banglasdesh in the 1950s. Most other studies are concerned with the effects of drought on migratory behaviour and many are set in the Sahel. Some studies also investigate the link between tropical cyclones and migration, floods and migration and sea level rise and migration.

B.5.1 Drought and Migration

One of the first studies that examined the relationship between drought and migration was Findley's (1994) research into migration from rural Mali during the 1983 to 1985 drought. She found that long-distance migration – notably of male household members to France – decreased during drought periods, and suggested that this could be explained by the fact that food scarcity leads to increased prices, forcing people to spend more money on their basic needs rather than long-distance migration. However, short-distance migration to larger agglomerations increased during drought years as women and children left in search of work to contribute to household incomes. In addition, this strategy reduced the number of persons in a household and thus the amount of food needed.

Haug (2002) has suggested the classification of pastoralists in Northern Sudan, – whose livelihoods became affected by the mid-1980s drought – as "environmental refugees", because many of them would have starved if they had not migrated. Nevertheless, she acknowledges that:

> *At the same time, mobility and different kinds of migration have always been part of the Hawaweer's livelihood strategy. In addition, not all the Hawaweer perceived the situation as forced. Some people chose to stay behind. Among these, some were in a situation where migration was impossible because they did not have access to the necessary number of animals needed for migration. For them, the reason for staying was not because they chose to but because they were forced to (Haug, 2002: 76).*

Haug thus stresses that the consequences drought has upon livelihood decisions, including migration, largely depend on the socio-economic situation of the people concerned. Similarly, Meze-Hausken (2004) points out that vulnerability to drought alone does not cause migration. In her study in Northern Ethiopia, in which she surveyed more than 100 peasants, she found that "people in marginal regions have developed a great variety of adaptation mechanisms, which strengthen their ability to cope with both, slow climatic changes and extreme climatic events" (Meze-Hausken, 2004).

Henry et al., (2004) investigated the effect of changing rainfall patterns on migration in Burkina Faso using event history analysis. They found no relationship between changing rainfall patterns and migration in general when they did not distinguish between different types of migration by destination and duration. Individual characteristics of people, such as level of education, type of activity involved in, and belonging to a particular ethnic group seemed to be the deciding factors for migration. However, when migration was divided into different types, the study revealed that people living in areas with scarce rainfall are much more likely to engage in short distance moves than people living in other regions. Yet the number of migrants was not found to increase after periods of minimum rainfall in the dryer regions. The fundamental conclusion that the authors draw from their findings is that: "long-term migrations seem to be less related to environmental conditions than short-term moves..." (Henry et al., 2004: 455).

The empirical results discussed above reveal that the nexus between drought and migration is not straightforward. The findings of the studies produced two general results. First, drought seems to cause an increase in the number of people who engage in short-term rural to rural types of migration. On the other hand, it does not affect, or even decreases international, long-distance moves. Second, the conceptualization of drought-affected people as helpless victims who are left with no choice but to flee seems to be false. Depending on their socio-economic position, they might have the choice between a variety of coping strategies, including migration. On the other hand, they might be too poor to migrate at all.

B.5.2 Tropical Cyclones and Migration

Empirical research into the effects of tropical cyclones on migratory behaviour is even scarcer than that concerned with the linkage between drought and migration. Paul (2005) investigated the effects of a tornado on migratory behaviour in two village communities in north-central Bangladesh. He used an approach that combined secondary data on household statistics with the results of a survey he conducted himself and some interviews with local officials and NGOs. The major finding of his study is that the 2004 tornado in the region did not cause higher rates of out-migration in the affected villages. He concluded that there was no link between the tornado and migratory behaviour at all.

An earlier study by Smith and McCarty (1996) looked into the demographic consequences of Hurricane Andrew that hit parts of Florida in 1994. They surveyed inhabitants of South and North Dade County and asked people first about their own, but then also about their neighbours' reactions to the hurricane. They found that people who lived in the wealthier southern part of the county migrated in much larger numbers than people who lived in the poorer northern part. The question of whether this was caused by the fact that the South was more severely affected or by the distribution of wealth in the population is left unanswered in the study. In general, Smith and McCarty conclude that: "many of the moves caused by Hurricane Andrew were short-lived, others lasted for many months, and some were permanent" (Smith and McCarty, 1996: 274).

Some studies have also investigated the consequences of Hurricane Katrina that hit parts of the US states of Alabama, Mississippi, and Louisiana, and destroyed the city of New Orleans in 2005. They are mostly concerned with demographic changes after the hurricane and the nature of return migration (Elliott and Pais, 2006; Falk, Hunt, and Hunt, 2006; Landry et al., 2007). However, Reuveny (2007) does reveal that 1.36 million people were displaced by Katrina and that, as of August 2006, 60 per cent of New Orleans residents had not returned.

Studies into the effect of hurricanes on migration have yielded even fewer results than ones that investigated the impact of drought on migration. It has become evident, however, that the assumption that climate variability leads to migration in a linear way is not supported by empirical investigation. Many other factors play into the nexus between environmental factors and migration. Furthermore, a distinction has to be made between different types of movements, along both geographical and time scales.

Interestingly, the work of Reuveny (2007) in a study related ultimately to violent conflict via environment induced migration highlights two features of environmentally induced migration that the events of Hurricane Katrina, the Dust Bowl in the 1930s and Bangladesh in the 1950s share. These are a dependence of the affected societies on the environment for livelihood; and that human action exacerbated the environmental aspect of the disaster. For instance, the societies of the Great Plains in the US in the 1930s and Bangladesh in the 1950s were largely agricultural whilst in the case of Hurricane Katrina, coastal Louisiana and Mississippi depended on fuel extractions and refinement, agriculture, tourism and the Mississipi waterway. When conditions deteriorated in these areas, many people lost their livelihoods and left. Meanwhile, in the case of Bangladesh, the expansion of agriculture and deforestation, as well as the construction of the Indian Farakka Barrage on the Ganges exaggerated the impact of environmental degradation. In the case of the dust bowl, inappropriate tillage practices had a similarly negative impact on drought whilst in the case of Hurricane Katrina a defunct levy system and elimination of natural processes contributed to the impact of the hurricane. Thus, as highlighted above, the study of the link between climate change and migration needs to consider a plethora of factors not only the climate. In the following section we discuss possible methodologies that take into account the multiple factors involved in migration.

C. METHODOLOGIES

C.1 Introduction

The overall objective of climate change impact studies is to present scenarios of how changes in, and future types of climate are likely to affect the current workings of bio-physical systems so that policy options can be put in place to facilitate and/or deter these impacts depending on whether they are viewed as beneficial or detrimental, or to assist societies in adapting to these impacts. In this section of the paper, we are interested in exploring the methodological options for quantifying the additional numbers of migrants that may be expected in response to changes in the climate, caused by human activities. While climate change trends in the last 100 years have been relatively small compared to the climate variability experienced, in the future the climate change signal from human activity is expected to outgrow levels of variability seen today, while variability of future climates is expected to grow. Conclusive evidence on how the shocks and stresses caused by climate change might influence migration is not yet available, so new knowledge will have to be generated.

C.2 Understanding Migration Behaviour in Response to the Impacts of Climate Change

The first step in this process of quantification is to try to understand how people cope with the different types of gradual stresses and sudden shocks brought about by climate change and variability. In doing so, the extent that migration appears to be a response to these different types of stresses/shocks needs to be ascertained. However, such an analysis needs to recognize that changing migratory behaviour might be just one strategy among a variety of other options available to individuals, households and communities in response to climatically induced stress and shocks. For instance, certain types of migration may not be considered feasible as scarcer resources might force people to concentrate on other activities. It should be also recognized that climate is just one of the factors influencing migration decisions so there is a need to understand to what extent climate is a relevant factor in the decision-making process and whether climate change and variability influence the choice of destination, the length of stay and the number of migrants sent.

In this section, we examine two different approaches to understanding the causal linkages between climate stimuli and migration behaviour. One – the Sustainable Livelihoods Approach (SLA) – seeks to explain the responses of households to external vulnerabilities in terms of a variety of strategies. For our purposes, climate change and variability can be considered as a factor that changes households' levels of vulnerability, whilst migration is one possible strategy in response. The other approach – the New Economics of Labour Migration (NELM) – addresses more directly why individuals migrate, although again in the context of household decision-making.

C.2.1 The Sustainable Livelihoods Approach

SLA comes in various forms (Brocklesby and Fisher, 2003), but essentially builds on the assumption that people act to maintain a socially and environmentally sustainable livelihood (DFID, 2000). According to Chambers and Conway (1992), "a livelihood is environmentally sustainable when it maintains or enhances the local and global assets on which livelihoods depend, and has net beneficial effects on other livelihoods." A socially sustainable environment can "cope with and recover from stresses and shocks, and provide for future generations". (Chambers and Conway, 1992: iii).

The initial aim of SLA was to understand people's livelihoods so that development assistance could be tailored according to their individual needs. The underlying idea is that families possess a variety of natural, physical, financial, human and social assets, which are all used to maintain a family's livelihood. If one of the assets suffers a loss, it can be compensated for by falling back on the other available assets in the so-called asset-pentagon. External influences in the form of policies and institutions are also taken into account (DFID, 2000). Yet SLA is also concerned with the question of how vulnerable livelihoods are to shocks, trends, and seasonal developments and what kinds of coping strategies are used by people in the case of one of these events (Carney, 1998). This aspect is of particular interest in understanding how shocks and stresses caused by climate change and variability are likely to influence people's livelihoods in an important way. Thus, Ziervogel and Calder (2003) used SLA to assess the impact of climate variability on adaptive capacity in Lesotho. In their case, therefore, adaptive capacity was the coping strategy of interest.

One of the main strengths of the approach is its holistic view of the various strategies people adopt to maintain their livelihoods. An understanding of how people cope with shocks and stresses can then lead to an understanding of the importance of migration in this context. However, despite the fact that SLA offers a useful framework of analysis for the study of the effects of shocks and stresses on people's lives, some of its shortcomings have to be acknowledged. One major disadvantage is that investigating people's livelihoods is a very time-consuming endeavour. It requires an in-depth understanding of people and their habits. SLA also arguably neglects inequalities of power at the community level and within families and is based on the assumption that households are conflict-free, with decisions based on consensus between its members. Yet inter-generational and gendered conflicts and inequalities of power are common within many households (Waddington, 2003).

In this context, it has been suggested that the analysis of the influence of institutions should be broadened to include community and family structures (Toner, 2002). This change would shift the meaning of a household from a homogenous unit to a structured and complex entity.

C.2.2 The New Economics of Labour Migration

Turning to the more direct question of what causes people to migrate, a key approach in migration studies is that of the New Economics of Labour Migration (NELM), developed by economists Oded Stark and David Bloom (1985). The key relevant insight for our purposes here is the observation that "migration decisions are often made jointly by the migrant and by some group of non-migrants" (Stark and Bloom, 1985: 175) – usually within families and who expect remittances in return for investment in the initial migration of a household member. Migration is thus not a strategy used to maximize individual income, but a means to diversify sources of household income and reduce risk (Arango, 2000). Massey et al., (1993) compare the function of these risk-minimizing strategies in developing countries to systems of insurance or social welfare in the developed world. If local markets fail for some reasons, some family members can compensate these losses by providing money they earned in systems that are not linked to the local market.

C.2.3 SLA and NELM-based Research Design

Taken together, the SLA and NELM approaches provide a way of understanding how households respond to climate shocks, and the extent to which migration is part of their response. However, they require intensive knowledge of the community(s) under study to gain an understanding of migration from the perspective of the people concerned. Information is required from the family members of migrants, families who have not sent migrants, and from the migrants themselves. Information on the community's social structure and interaction with institutions is also required. Figures 3 and 4 show the focus of questions in the gathering information stage using the two approaches of SLA and NELM.

FIGURE 3

FOCUS OF SLA BASED ENQUIRY

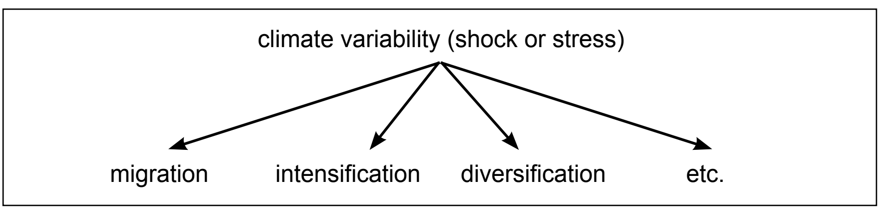
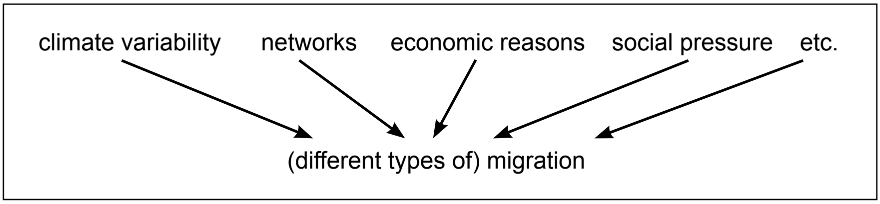


FIGURE 4

FOCUS OF NELM BASED ENQUIRY



Essentially, if information can be obtained on how people perceive the impact of shocks and stresses, what they do to maintain their livelihoods, what assets they possess, what they think about the future, and what has changed from the past, estimates can in principle be made both of the significance of climate change and variability as shocks and stresses, and the significance of migration as a response. An understanding is also needed of who takes migration decisions and whether and how a consensus is achieved; what family members usually migrate and why; why certain destinations are preferred over others; what determines the length of stay; what has changed from the past; and what the future is likely to be.

Yet even if such information is known from carefully-worded surveys, it remains difficult to find out if climate variability is one of the factors that influence migration. This question cannot be asked directly as people are likely to have difficulty separating climate variability as a reason from other motives. Respondents can be asked to list the reasons why they or their family members migrate, with these reasons subsequently being tested for climate-sensitivity. Ezra and Kiros (2001) used this strategy in exploring the effects of the 1980s drought in Ethiopia.

Furthermore, migration is generated not only from the decisions of households, but also from the economic and social pull of destination regions – and it is conceivable that climate variability also influences such pull factors for migration. For instance, in Mexico many migrants seasonally work on farms in California and Texas. Longer periods with high temperatures and little or no rainfall may affect the viability of irrigation systems, and overall agricultural productivity, lowering the need for workers and hence Mexican migration in agricultural and agriculture-related sectors. Conversely, in some temperate regions of the world, agricultural growing seasons may lengthen as a result of climate change, increasing the demand for workers, and in turn, for south-north migration. An estimate of such processes could theoretically be obtained from surveys in origin areas, but would be likely to give only a partial account.

A significant advance on the SLA-NELM inspired approach could be made if information was available about change in both stress/shock factors, and migration and other livelihood responses over time, and yet such time-series data is extremely scarce. One possible solution is to use life history data, as attempted by Sabatés (2005) in his study of the evolution of the labour market in the Mexican city of Léon.

C.3 Quantifying Migration Responses to the Impacts of Climate Change

While the above approaches provide a means of possibly disentangling the multiple factors influencing migration at the household or individual level they do not allow predictions to be made of expected numbers of migrants in the future or under different conditions from those under which communities are studied. The quantitative methods of statistical regression and agent based modelling however do provide a method of taking the multiple variables involved in migration and varying the values of these to obtain simulations of future migration patterns.

C.3.1 Statistical Methods

As noted in Section B.2 past studies of how climate change might impact on migration have commonly calculated the numbers of potential migrants by projecting physical climate changes, such as sea level rise, on an exposed population. Alternatively migration responses can be considered the result of much more complex contextual based behavioural decisions not captured by such analyses. At the individual or household level factors such as knowledge, attitudes, goals, power and personality are known to influence a person's disposition to certain behaviour. However, how these factors combine under different conditions and contexts is unclear. At a social system level, complexity arises from large populations of heterogeneous people interacting through a variety of networks. Thus, predicting the resulting group processes from these different level interactions remains an uncertain procedure.

One solution to this complexity is to use correlation analysis in order to assess whether various climate variables such as start of wet season date are significantly correlated with the migration behaviour of a particular type of potential migrant or migration producing household. Regression analysis allows any statistically significant relationships to be converted into a numerical expression that allows the prediction of migrant numbers. The accuracy of the prediction is determined by the strength of relationship between the variables (e.g. migration and climate variable); the boundaries of climate change or variation for which the relationship was discovered compared to that which is being applied to; the nature of the relationship (e.g. linear or non-linear); and the ability to define the general characteristics or profile of a migrant producing household or migrant.

The Sustainable Livelihoods Approach allows households to be characterized in terms of cultural, social, physical, economic and natural capitals or assets, and potential livelihood pathways. These profiles can then be used to define different sample populations from which to derive relationships between migration and climate parameters. Alternatively assets and capitals can be used as variables in addition to climate parameters in a multiple regression to determine migration. Different types of asset lend themselves to different levels of quantification with some types such as cultural assets generally considered to be unquantifiable. This obviously places restrictions in their use as variables in multiple regression analysis.

Perhaps the most significant limitation of this approach, however, is the absence, for much of the world, of time-sensitive migration flow data such that change in climate and other factors at time t can be used to explain migration at time t+1. Indeed, given the seasonal form of both climate and migration variables, time series data are clearly required at monthly or quarterly level, rather than at an annual basis. The availability of such data is clearly one of the strengths of the work of Henry et al., (2004) cited above, although here data was limited to one country – Burkina Faso – and therefore excludes significant external migration flows.

In addition, all statistical based relationships are limited in their extrapolation to conditions outside those used to define the initial relationship. The relationship between migration and climate is no exception to this rule. This means that, for example, while a particular statistical relationship might exist between sea level rise of 0 to 30cm and resettlement in a nearby location (e.g. a rural to rural migration) this relationship may not hold for a 2 m sea level rise. This also raises the question of the nature of the relationship between migration and climate parameters. Some relationships are linear, others non-linear and others dependent on thresholds to be crossed.

Despite these limitations regressional analysis combined with Geographical Information Systems (GIS) and climate model data do allow for spatial patterns of migration to be determined. Moreover GIS allows the combination of spatial and non spatial data from a variety of sources including both social science and scientific data and provide the platform to analyse and display the migration impacts of climate change.

C.3.1.1 *Mexican Migration: Case Study*

Mexico has a long history of international migration and is the second largest migrant sending country in the world (OECD, 2007). In 2005 alone, 164 million migrants left the country. It is also a country subject to extreme climate variability in the form of droughts in the north and centre, while the coast of the Gulf of Mexico is frequently hit by hurricanes. In Zacatecas for instance, about 85 per cent of the crops were destroyed by droughts in 2005 and 2006 according to the Mexican media. While in Veracruz, hurricane Stan destroyed large parts of the coffee crops in October 2005, and in August 2007 the state was hit by hurricane Dean that again caused extensive damage, mostly by inundations. In terms of future climate change water stress is predicted to become particularly acute in the South-West US and Mexico with rainfall decreases of up to 40 per cent locally (Shindell, 2007). Additionally, while the incidence of tropical cyclones is predicted to decrease, their strength is likely to increase with higher peak wind intensities and increased mean and peak rainfall intensities.

In this case study, we take a brief look at the empirical evidence for a relationship between climate variability and international migration in the drought prone states of Zacatecas and Durango (see Figure 5 for location). Information on international migration is derived from the Mexican Migration Project (MMP). The data available covers the migration and labour histories of male household heads that went to the US to work. These longitudinal data open up the possibility to test the effects of different types of climate change impact over time. In Figure 6, the volume of first-time migration is plotted against time of the two neighbouring states, Zacatecas and Durango. From Figure 6, it can be seen that both states exhibit high levels of interannual variability of migration. A minority of this variability is shared; in fact from 1951 to 1990 nearly 16 per cent of the variance of the numbers of migrants from Durango can be explained by the variance in numbers of migrants to the US from Zacatecas and vice versa. This statistically significant (at the 5% probability level) result may indicate that in both districts migration behaviours are subject to the same annually varying forcing be it climate or non climate related. In terms of climate variability the spatial variation of significant correlations of the numbers of first time migrants from Durango with the rainfall record for the whole of Mexico and Southern USA are shown in Figure 7 for the 40 year period from 1951 to 1991. Statistically significant (at the 5% probability level) negative and positive correlations are shown in purple and orange respectively. The rainfall data comes from the University of Delaware dataset and is based on raingauge measurements. It can be seen from this figure that there is a positive relationship for Durango between rainfall and migration to the US, suggesting that as more rainfall occurs more migration occurs. This finding is in agreement with the findings of the study by Findley (1994) in Mali who, as discussed above, found that drought tended to decrease international, long-distance moves. However, this finding is in opposition to the findings of Munshi (2003) who found a negative correlation between rainfall and migration to the USA in the South-Western States of Mexico.

FIGURE 5

STATES OF MEXICO

Source: Google Images

FIGURE 6

INTERANNUAL VARIATION IN NUMBERS OF MIGRANTS
LEAVING THE STATES OF DURANGO AND ZACATECAS FOR THE US

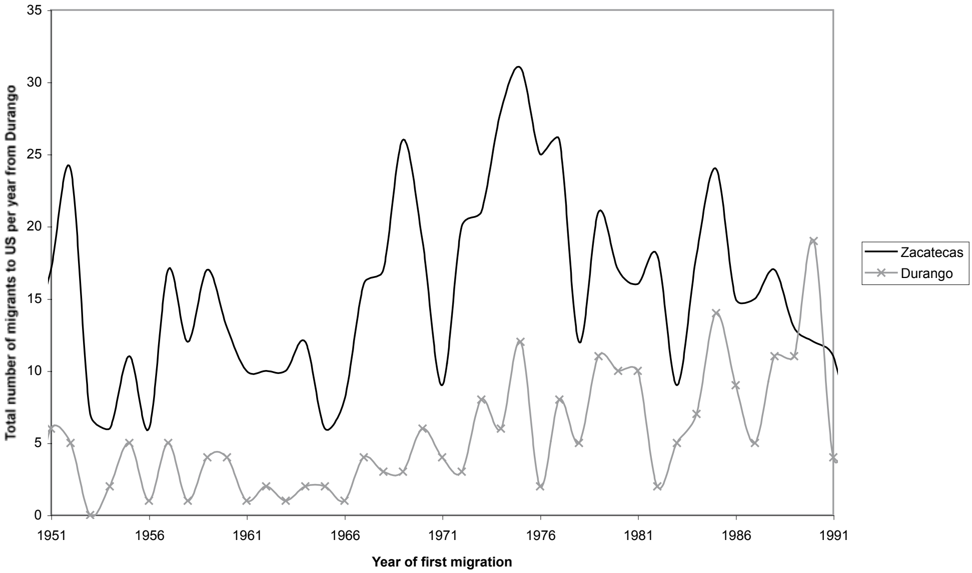
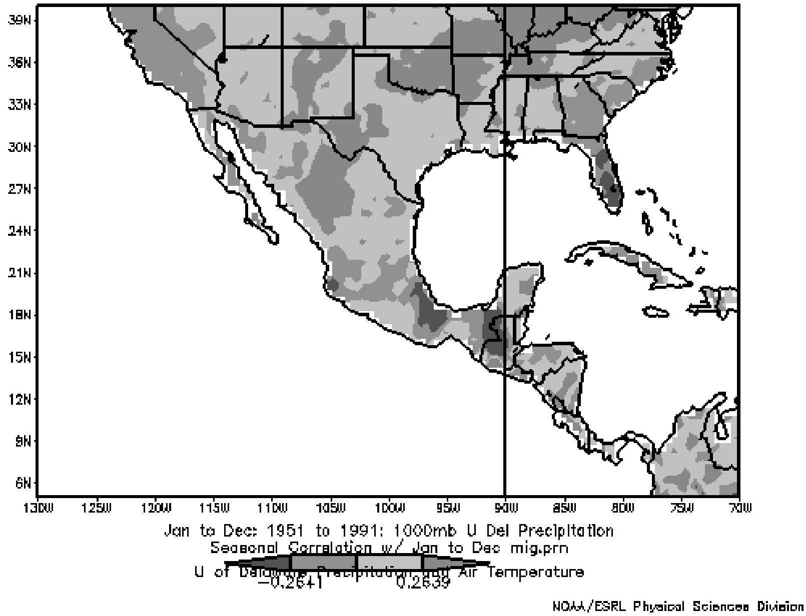


FIGURE 7

CORRELATION BETWEEN HOUSEHOLDS FROM ZACATECAS MIGRATING TO THE US AND RAINFALL DATA

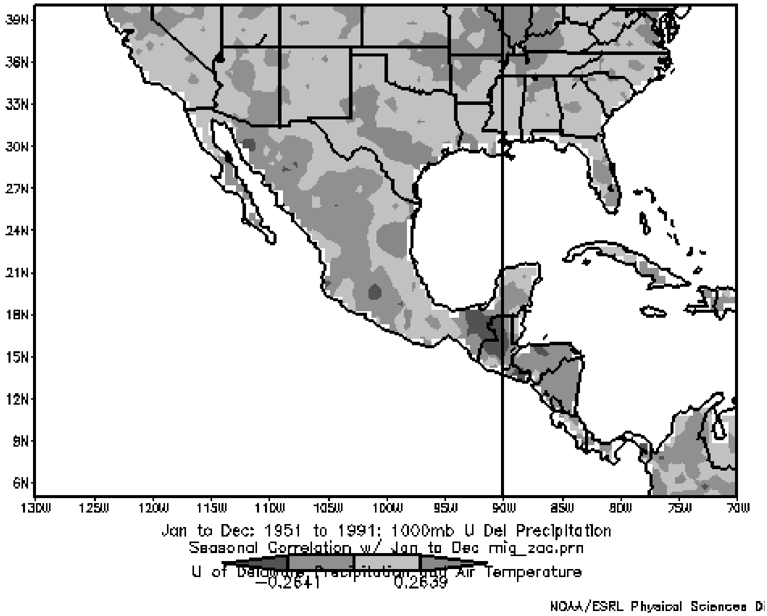


Statistically significant (at 5% probability level) correlations between annual numbers of male household heads from Durango migrating to the US for the first time and rainfall data at 0.5° latitude/longitude spatial resolution. University of Delaware rainfall data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/

A number of caveats however should be added before exploring this statistical relationship further. Firstly, numbers of migrants are low so the variability in numbers may be little more than noise. Secondly, statistically significant positive (negative) correlations are also found between migrant numbers from Durango and rainfall in the southern US (in parts of southern Mexico and Florida). As with the correlations with the rainfall over Durango these results may be due to random chance. Alternatively they may indicate climate relationships between rainfall systems in these regions. Interestingly, when one looks at the same form of figure for migrants from Zacatecas and rainfall no statistically significant correlations (and negative signed correlations) are found over the migrant source region (Figure 8). Of course statistical relationships do not prove causation but the valid question remains why there may be a positive relationship between migration to the US and rainfall over the country in Durango; is this indicative of a climate variability-migration link. However, the variation in even the sign of the correlations between rainfall and migration of the two neighbouring states indicates the presence of other factors and complexity in determining migration behaviour.

FIGURE 8

CORRELATION BETWEEN HOUSEHOLDS FROM DURANGO MIGRATING TO THE US AND RAINFALL DATA"



Statistically significant (at 5% probability level) correlations between annual numbers of male household heads from Zacatecas migrating to the US for the first time and rainfall data at 0.5° latitude/longitude spatial resolution. University of Delaware rainfall data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/

A number of refinements can be made to exploring statistical relationships between climate and migration including looking at climate parameters that are more related to livelihood pathways or separating different types of household according to their socio-economic context (or capital/asset basis). For example, a better relationship might be found by restricting the rain period to the rainy season rather than an annual total, or even by using the start date of the wet season. Studies of agricultural users have revealed that the information of most interest to the user is not rainfall total but the start and end dates of the wet season (Ingram et al., 2003; Ziervogel and Calder, 2003). In particular, the start date of the wet season is of crucial importance as it determines sowing times, with planting too early possibly leading to crop failure and planting too late leading to a reduced growing season and crop yield (Dodd and Jolliffe, 2001). Creating different profiles of migrant households and separating out migrant flows from these different profiles requires relatively large sample sizes of migrants but recognizes the role of non-climatic factors contributing to the decision and ability to migrate.

Where non continuous data are the only source of information on migration composite analysis allows comparisons of climate features on years of high migration flows with low ones that can then be tested for local and field significance using simple t-tests and randomized Monte Carlo simulations, respectively.

C.3.2 Agent-based Modelling

A solution to the complexity of climate-migration linkages is to use agent-based models to simulate the behavioural responses of individuals and households to climate signals, as well as relevant interactions between these social actors. The concept of agent-based modelling (ABM) evolved from simple cellular-automata (discrete model consisting of a regular grid of cells) type models as early as the 1940s but, due to the computation-intensive procedures involved, was not widely available until the mid-1990s. Intended as a means to model a simplified representation of reality, agent-based models have been specifically developed within a social sciences perspective to model both individual behaviour and how the interaction of the actions of those individuals results in large-scale outcomes. As such, at its most simplistic level, within the specific context of this paper, ABMs may be used to infer macro-scale population responses to climate change as a result of micro-level migration data collected, for example, through community surveys and censuses.

The basis of ABM relies on the understanding that the results of a series of individual interactions may be different to the sum of the parts. It is therefore an effective means of analysis for systems that are both composed of interacting agents and exhibit emergent properties (properties that arise from the interactions of the agents that cannot be deduced simply by aggregating the known properties). Mathematical analysis of social science situations where past experience and subsequent adaptation plays a considerable part in the interaction of agents has in the past been limited in its ability to derive dynamic consequences. However, in this scenario, ABM presents a practical means of analysis.

C.3.2.1 *Agents*

In an ABM a system is modelled as a collection of autonomous decision-making entities known as agents. Although there is no universal agreement on the precise definition of the term agent, some authors insist that a component's behaviour must be adaptive in order for it to be considered an agent. In this sense an agent can learn from their environment and past experience and change their behaviour accordingly. From a practical modelling perspective, Wooldridge and Jennings (1995) describe the key features common to most agents as autonomy, heterogeneity and activity (including reaction, perception, interaction, communication, mobility, adaptive capacity/learning and bounded rationality). In the context of an ABM implemented to simulate the migratory response of communities to climate change, a single agent may be used to represent an individual, family unit or small group. The response of the agent to particular climate stressors is both simulated on a micro scale by the ABM and permitted to interact with the responses of other agents within the proximity.

Multiple interacting agents situated within a model or simulation environment therefore comprise the basis of an ABM. By assigning a set of rules to the agents within a system the relationships between the agents are specified and bonds formed linking agents to agents and/or other entities within the system. The agent behaviours resulting from these relationships may be specified to be reactive (triggered by an external stimulus) or goal-directed and to occur synchronously (at a discrete step in time) or asynchronously (scheduled by the actions of other agents). According to the rules created for a specific simulation, each agent individually assesses its situation and makes decisions which result in the execution of various behaviours appropriate to the system they represent. Bonabeau (2002) reports that even a simple agent-based model can exhibit complex behavioural patterns as a result of the interactions specified. As a result, such a model can provide valuable information about the dynamics of the real world system that it emulates. Agents are even capable of evolving, permitting unanticipated behaviours to occur as a result of the ability of an ABM to capture emergent phenomena – the essential property that is central to both the definitive concept and greatest benefit of agent-based modelling techniques. The responses of individual agents to climatic stimuli may therefore be influenced by the actions of other agents so that, from micro-scale individual motives, macro-scale group processes will emerge.

C.3.2.2 *Complexity and Rules*

Classed as "expert" or "knowledge-based" systems structured around a series of user-defined rules, ABMs incorporate a high degree of complexity within their simulations in order to present an accurate model from which emergent properties may be inferred. This concept of an ABM capturing phenomena emerging from the lower micro level to the macro level stands out as the significant advantage of such modelling but also inherently forms the basis for the high level of complexity required in the simulation. In the past, mankind has learned to implement techniques involving simplification and analysis in order to understand reality. However, including the capacity for artificial intelligence within an ABM significantly increases the complexity of the analytical process used in simulating and understanding real-life events. Such artificial intelligence permits the simultaneous operations and interactions of multiple agents acting in what they perceive to be their own best interests.

In construction of the rule base for an ABM the precise formation of the rules upon which the behaviour of the individual agents will be based plays a central role in the success of the simulation. Bonabeau (2002) reports that simple rules applied to individual agents can lead to the emergence of coherent group behaviour while small changes in those rules can have a dramatic impact upon the precise nature of the behavioural outcome of that group. Rather than involving inviolate laws, agent-based systems rely upon the formation of more flexible rules that can adapt and change in a reflexive relationship which allows the system to accommodate new information. By incorporating more complex individual behaviour, such as learning and adaptation, the emergent phenomenon produced by the simulation increases in complexity and, through the bounded rationality agents can be capable of applying to a situation, they may be capable of deductively solving complex mathematical optimization problems in order to maximize their well-being.

C.3.2.3 *Applications*

Agent-based modelling is capable of bringing significant benefits when applied to the complex interactions evident in human systems. Where other models fail to accurately simulate the richness of detail present in a social system an ABM is capable of modelling phenomena as dynamical systems of interacting agents. A number of situations exist where Bonabeau (2002) describes that it is particularly advantageous to use an ABM as a result of the inherent capabilities of the modelling structure. These include:

- When the interactions between agents mean that the behaviour of one agent can be altered dramatically by other agents as a result of the complex, nonlinear interactions between agents.
- When space is crucial to these interactions and the agent's positions within that space are not fixed.
- When the population of agents is heterogeneous.
- When the topology of the interactions between agents is heterogeneous and complex so that the interaction identified between particular agents is (potentially) unique to those agents.
- When the agents exhibit complex behaviour such as learning and adaptation.

On the basis of the above framework for identifying situations for which ABMs are particularly advantageous, the process of modelling the link between the shocks and stresses of climate change and migration is particularly well suited. Within both climate and migration analyses, the concept of space, and the dynamic nature of an agent's position within that space is of paramount importance. In addition, the consideration of influential interactions between individuals within a community affected by climate stressors is necessary to perform a complete assessment of the potential large-scale migratory response to climate. Furthermore, individuals migrating as a result of climate change will be both inherently heterogeneous in nature, interact in a heterogeneous manner with other individuals and be capable of adapting and learning from their/other's past experience of climatic shocks and stressors. As a result of the relevance of the complex capabilities of an ABM to a hypothetical climate change and migration analysis, agent-based modelling presents a well-suited simulation platform from which to model emergent macro-scale migratory movements on the basis of the interacting micro-motives of numerous agents.

Now a relatively mainstream simulation technique, ABMs have previously been used in a number of environmental contexts including water resource management (Croke et al., 2007), palaeo-environmental research (Dearing et al., 2006), climate forecasting and food security (Bharwani et al., 2005; Ziervogel, 2005), climate policy formulation (Downing et al., 2001) and emergency planning (Chen and Decker, 2005; Molina and Blasko, 2003). Despite these various environmental applications, little attention has been focused upon the use of ABMs in migration studies and, in particular, the migratory response to environmental and climatic change. This may in part be due to the lack of longitudinal data relating to migratory patterns of populations within the specific contexts under study. In the few instances where migration has been modelled using agent-based methods, these have taken the form of hypothetical simulations based around differences of earnings between rural and urban sectors (Silveira et al., 2006; Espíndola et al., 2006) and urban-to-urban migration (Benenson, 1999).

C.3.2.4 *ABMs, Climate, and CMigration*

A variety of techniques are available for agent-based modelling. These derive from artificial life, autonomous systems and related intelligent systems techniques. They enable a range of sophistication in agent modelling from simple analytic techniques to decision-theoretic and BDI (Belief, Desire, Intention) models. The complex group behaviour resulting from the interaction of numerous individuals within a climate-migration analysis may frequently be an emergent property of very simple mechanisms dependent upon the environmental context. It is therefore important to establish whether beliefs and aspirations play a role in determining the behaviour from which macro phenomena are to emerge (cf. Doran and Palmer, 1995; Downing et al., 2001).

As a means of understanding how people cope with the different types of gradual stresses and sudden shocks brought about by climate change and variability, neither the "Sustainable Livelihoods Approach" (SLA) nor the "New Economics of Labour Migration" (NELM) explicitly attempt to model an individual or household's attitude in adopting migration as an adaptation strategy. SLA considers the possession of natural, physical, financial, human and social assets into the understanding of migration while NELM considers the opportunities migration provides to spread the risk of a household's income loss. Although these methods of analysis (particularly SLA) present some explanation for the motives behind an individual's decision to undertake a migratory response to stress and shock factors, they assume simple adoption behaviour by individuals with no deeper understanding of the unique behavioural circumstances of each decision-maker or collection of decision makers. While numerous assets and economic opportunities will no doubt affect an individual's wish to undertake migration as an adaptive response to climate stresses and shocks, the decision will also be influenced by deeper cognitive stimuli required to account for human bounded rationality (Kant and Thiriot, 2006).

It is generally accepted that the SLA fails to consider the broader influence of community and family structures that may produce inequalities of power and influence within a group. However, deeper cognitive inputs such as an individual's attitude towards their current location, their proposed/intended destination, their ability to migrate and the concept of actual migration, may be incorporated in an agent-based simulation. As illustrated by Kant and Thiriot (2006) the rules upon which the decision model is based may be developed according to the application of cognitive psychological theories. Therefore, the complexity and variation of factors that may be included in an ABM through the consideration of numerous detailed influences enables agent attitudes, behaviour and power to be included in the formation of macro-scale emergent phenomena. For this reason, the emergent phenomena generated by an ABM with such complex interacting influences may potentially represent behavioural outcomes unanticipated by alternative analytical techniques.

As a statistical summary of the atmosphere over a prolonged period of time, climate, and therefore climate change, is an abstract concept. In simulating the migratory response of a community to the manifestations of the climate system, one is therefore modelling people's perceptions of an abstract phenomenon. The influence of the unique cognitive responses and attitudes of individuals towards these manifestations is therefore of considerable importance in identifying the livelihood impact perceived to occur by individuals and the importance of these in their current existence. By including such aspects into the agent attributes of an ABM and developing rules for the interaction of such agents, agent-based modelling presents a means of simulation far more powerful than those of alternative statistical analysis.

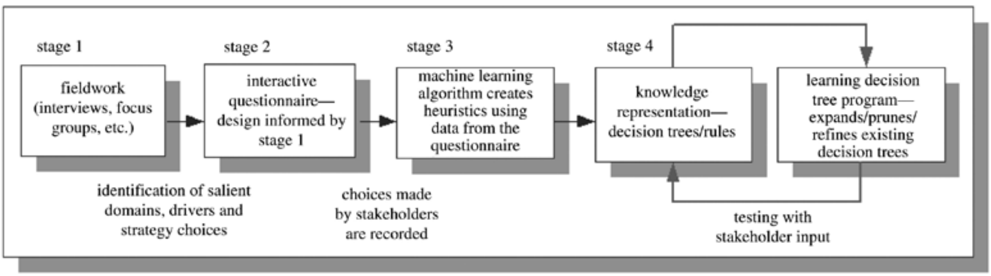
C.3.2.5 *Knowledge Elicitation*

Although agent-based modelling techniques can be applied to hypothetical simulations (Silveira et al., 2006), the value of the modelled output is far more reliable and applicable when the simulation is based upon an existing community and specific scenario. However, in order to perform such a simulation, longitudinal data is required relating to the community in question. The lack of longitudinal datasets providing the information necessary to derive both agent attributes and rules of interaction and behaviour, is likely to have resulted in the significant lack of ABM simulations of migration and climate.

However, the availability of an appropriate ethnographic dataset represents only the beginning of the formulation of an ABM. In order to derive the agent attributes and rules of interaction necessary to complete an accurate simulation, a process of knowledge elicitation must be performed. A key skill in the process of anthropological enquiry is the interview and the ability of the analyst to access tacit knowledge and make inferences on what is voiced and observed without the influence of his/her own cultural assumptions. When analysing interview outputs it is imperative to understand ethnographic data in a formal manner in order to deal with the complexity introduced by the multiple responses of humans to their environment. Wood and Ford (1993) have developed a four-stage model (see Figure 9) based on ethnographic methods to enable accurate elicitation of an informant's knowledge regardless of the knowledge engineers' depth of understanding.

FIGURE 9

STAGES WITHIN THE KNOWLEDGE ELICITATION PROCESS



Source: Wood and Ford, 1993, sourced from Bharwani, 2006

Although the process of elicitation and formalization may be undertaken manually on the basis of the four stages identified in Figure 9, Bharwani (2006) describes the availability of participatory computer-based Ethnographic Knowledge Elicitation Tools (KnETs). KnETs typically involve such steps as interviews (stage 1 of Figure 9), simulated-scenario problem solving tasks using interactive questionnaires to identify dominant drivers (stage 2), rule-induced algorithms to produce decision trees (stage 3) and validation with domain experts (stage 4). Using stages such as these, such computational tools may be implemented to ease the formalization of qualitative ethnographic data for producing quantitative inputs for ABMs. The capabilities of KnETs enhance our understanding of data to reveal new avenues of enquiry. On this basis, a simulation consisting of the combination of a social model of formalized ethnographic data with a model representing physical environmental processes is likely to result in a better analysis of the interaction of social and physical models and a greater understanding of the processes involved.

Due to the capabilities of ABMs in simulating multifaceted systems where the interactions of agents result in the emergence of complex phenomena, they present a practical and potentially highly effective tool for modelling climate change impacts on migration. Permitting the agent attributes and rules of interactions to be derived from actual data using methods of knowledge elicitation, the climate shock and stress factors that impact upon human communities may be analysed to determine how, as a result of the attitudes and interactions of individual agents, macro-behaviour may be formed. Through the appropriate development of this technique, agent-based modelling may therefore provide a means by which the community-level response of populations to climatic stimuli may be accurately predicted according to specific future climate scenarios.

D. DISCUSSION AND CONCLUSION

The climate system is a collection of complex and non-linear operating spheres including the atmosphere, ocean, cryosphere, lithosphere, and biosphere. Due to strong linkages between these spheres, changes and variability in parameters and processes of these individual spheres can cause change and variability throughout the climate system. Climate change can be caused by human activities and natural events including volcanic eruptions and orbital variability. The international scientific community is highly confident that climate change will occur throughout the 21st century, caused by human activities including greenhouse gas production and land use changes. The impacts of this climate change include rising sea levels, deforestation and dry land degradation, as well as increased natural disasters. It is recognized that these changes will pose severe challenges on development and livelihoods, settlement options, food production, and disease. In turn, these environmental events and processes are feared to likely lead to large-scale displacements of people, both internally and internationally.

The variation of the migratory response to climate events has been shown by a number of events recently. At one extreme, the experience of the US Gulf coast with Hurricane Katrina in 2005 showed the ability of a single event to induce considerable displacement of the human population. By contrast, studies of migration of agricultural populations in the Sahel have shown that rather than encouraging migration, decreases in the climate variable, rainfall (and the subsequent bad harvests) tend to limit peoples abilities to invest in long-distance movement. It has thus been argued that there is considerable uncertainty in the prediction of climate change related migration. This results both from uncertainties in the extent and magnitude of the climate signals responsible for pushing and pulling migrants, and from variation in the contexts and thus the behaviour of the people upon whom they act.

Predictions of future climate changes are inherently uncertain as they pertain to variable potential future society activities and their influence on climate change causing greenhouse gases. However, there is also uncertainty in predictions of future climate change due to the complexity of the climate system, which remains not fully understood, and the chaotic nature of the atmosphere. Despite these uncertainties a number of changes can be predicted with high degrees of confidence. The best estimates for global temperature change by the end of the century range between 1.8 and 4°C, with larger changes locally and regionally. The warming will be greatest over land, in continental interiors, and at high northern latitudes. Increases in rainfall are predicted in high latitudes while decreases are likely in most sub-tropical land regions. It is very likely that hot extremes, heat waves and heavy rainfall events will become more frequent and tropical cyclones more intense with heavier rainfall and stronger peak wind speeds. Global sea level is predicted to rise by 0.18 to 0.59m by the end of the century (Solomon et al., 2007).

The impact of these changes depends on the sensitivity of the variety of biological and physical systems that exist in the climate system. On one extreme drought affected areas are predicted to increase in extent, while on the other increases in heavy rainfall events are considered very likely to augment flood risk. For one-sixth of the world's population living in regions where water supplies are stored in glaciers and snow, water availability is expected to be reduced. The resilience of many ecosystems is likely to be exceeded by a combination of flooding, drought wildfire, insects and ocean acidification combined with land-use change and over exploitation. Twenty to thirty per cent of plant and animal species are likely to face increased risk of extinction. While initially, crop production is projected to increase slightly in mid to high latitudes, at lower latitudes, especially for seasonally dry and tropical regions, crop productivity is predicted to decrease increasing the risk of hunger. Initially, global food production is projected to increase with small increases in temperature and carbon dioxide but it decreases afterwards. Local food production, especially subsistence farming at low latitudes, is predicted to be affected by increases in frequencies of droughts and floods. Coastal ecosystems and populations will have to deal with rising sea levels as well as changes in climate events such as storm surges. The largest number of people vulnerable to these impacts will be in the mega-deltas of Asia and Africa while those most vulnerable will be those inhabiting small islands (Parry et al., 2007).

Studies of past migratory responses to climate variability have revealed that the concepts of hazard, risk and vulnerability alone are inadequate in explaining the response of human society to the manifestations of climate change. For example, the most vulnerable to a flood or drought are not necessarily the most likely to migrate as migration needs a variety of assets including economic capital and access to social networks to facilitate the migration. The motivation to migrate can be conceptualized as based around: economic reasons (e.g. the New Economic Labour Migration approach); a broader defined asset base including social and cultural capital (e.g. the Sustainable Livelihoods Approach); and including a more psychologically based behavioural approach combined with sociological concepts of interaction to reveal emergent behaviour (e.g. agent based modelling). These conceptualizations require detailed and where possible historical data sets detailing the socio-economic, political, physical and cultural environments that communities exist in, if they are to be used to understand potential future flows of migration. Statistical and agent based modelling techniques potentially provide the means to convert the detailed understanding of migration responses to the impacts of climate change, in predictions of future larger scale patterns of population movement.

In terms of the climate events that are likely to impact on migration a wide variety of phenomena need to be considered, from creeping environmental degradation caused by gradual changes in the mean climatic conditions, to catastrophic events such as sudden loss of land caused by the climate extremes such as storm surges. The impact of climate on livelihoods is also manifested in a number of direct and indirect ways including loss of natural resources, and changes in the viability of economic processes due to changes in global markets.

The answering of the question of how climate change impacts migration depends on understanding: the socio-cultural-political-economic environment that communities exist in; the cognitive processes of the people experiencing the impact of climate change; the individual, household and community attitudes to migration and migration outcomes; and the type of climate stimulus that migration may be responding to. These different factors act and are measured over a variety of time and space scales. For instance, regional climate models provide downscaled information on potential climate changes at spatial resolutions of up to 625 km^2. However, while they are able to provide detail (e.g. numbers) of extreme occurrence due to the enhanced space and time resolutions compared to global climate models, there are large enhanced uncertainties (e.g. the distribution of these events) associated with models operating at this scale. By contrast information on capitals varies on scales of tens of metres.

The study of climate change impacts on migration therefore needs to involve contributions from a number of disciplines including sociology, development studies, economics, geography, informatics and climate science, while encompassing processes acting on a range of scales from local to global. Only through the interdisciplinary study of the relationship of climate with migration involving detailed data collection and conceptual and numerical model development can a picture be developed of the potential changes to migration in the future due to the impact of climate change.

Finally, and regardless of likely numbers, in terms of possible policy responses to migration caused by the impacts of climate change, a key option at the earliest stages is to strengthen the adaptative capacity of communities at risk from climate change impacts. In this respect a co-evolutionary approach is required that highlights the role of individual and social (including institutional) learning for adaptative management. As suggested by the IOM discussion paper on Environment and Migration (IOM, 2007), principles for effective management of migration caused by climate-change impacts should include proactive policy and early action; comprehensive 60 and coherent polices that have sufficient budgetary support for long-term planning; bilateral and regional cooperation; and multi-stakeholder partnerships involving public and private service actors, non-governmental and inter-governmental organizations, trade unions, individual migrants and Diaspora associations. Effective management of migration caused by climate change should not assume that climate-change induced migration is part of the problem; it may indeed be part of the solution.

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Despite the growing awareness of the nexus between climate change and migration, the subject has not yet been explored empirically in a way that generates conclusive results. Climate change might increase migration as people need to search for a living elsewhere, but migration might as well decrease as fewer people can afford to move. Recent empirical studies have found that climate variability and migration are characterized by a non-linear relationship, identifying many other factors influencing the linkage between climate change and migration. Climate change represents only one of the factors influencing migration decisions, while changing migratory behaviour might be just one strategy among a variety of options available to respond to climatically induced stress and shocks.

This study explores the climate change impacts on migratory processes: (a) by outlining the key elements of natural and human-induced climate change of potential relevance to migration; (b) by discussing the current state of debate about the relationship between climate change and migration; and finally (c) by describing possible approaches and methodologies with which to further our understanding of climate change-related migration, such as the New Economics of Labour Migration (NELM), Sustainable Livelihoods Approach (SLA), and the Agent-based Modelling (ABM).

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