The science and economics of Climate Change

November 30, 2006

Topics

- The science of greenhouse gasses.
- Modeling climate change
- The economics of climate change

The gasses

- Major greenhouse gasses Methane, Nitrous Oxide, Carbon Dioxide.
- The global warming potential, per molecule, of Methane 2 is 25 times greater than a molecule of CO2, and global warming potential of a molecule Nitrous Oxide is 200 greater than a molecule of CO2.
- CO2 contributes more than half the increase in "relative forcing" over next 100 years, and it lasts much longer than the other gasses. It may be easier to regulate.
- Photosynthesis traps carbon, burning fuel releases it.
- Net primary production (the annual production of new plant tissue) captures 105 gigatons per year (54% on land and rest at sea)

The oceans

- The oceans absorb CO_2 by mixing surface water into the deep ocean.
- Thermohaline circuit (THC) is a major current system in the Atlantic Ocean.
- Gulf stream takes warm salty water from southern hemisphere northward, along the East coast of US and then northeast to Greenland, Iceland and Norway.
- The warm surface water is cooled by the cold air, increasing the density of the water and causing it to sink, creating a kind of vacuum which draws warm salty water from Gulf of Mexico, warming the air over the European continent.

Weakening of Thermohaline Circuit?

- Greater snowmelts due to global warming, increasing the flow of cold freshwater (which is lighter than salt water) could reduce the conveyor effect (because there is less "sinking" of water), leading to a smaller vacuum effect.
- Cooler sea temperature could cause ice to form, creating a kind of lid over ocean, reducing the amount of cooling of the water, reducing the vacuum effect. The reflectivity (albedo) of the ice leads to more cooling in Europe
- Although a possible weakening or shutdown of THC is widely discussed in science community, there is disagreement about the likelihood of this event.

The time-line of GHG (Greenhouse Gas) concentrations

- 70 million years ago, atmospheric CO_2 concentrations were several times current levels.
- Atmospheric CO_2 has ranged from 100 to 400 ppm over the past 20 million years. It has ranged from 180 - 290 ppm over the past 420,000 years, and between 270 - 290 ppm over last 2000 years, prior to industrial revolution.
- Current level about 380 ppm, an increase of about 30% from pre-industrial levels. About 75% of this increase due to fossil fuel burning, the remainder due to deforestation and industrial processes.
- 150% increase in methane concentration since pre-industrial, about half of which is anthropogenic. Nitrous oxide up about 17%.

Current emissions and projections

- IPCC projections show CO2 increases to 550 ppm in 2050 and greater than 700 ppm by 2100 under BAU.
- Current carbon emissions from burning fuel about 6.3 gigaton, projected to rise to 15 gigaton by 2050.
- We are currently removing carbon from earth's crust at a rate 100 times greater than the natural storage in marine sediments.
- There is mixed evidence whether forests are a net source or sink of carbon. Deforestation contributes about 1.6 gigaton per year, but there is substantial reforestation in northern latitudes.

Carbon fertilization and deforestation

- More carbon in the atmosphere increases the rate of photosynthesis. Some damage estimate models assume that carbon fertilization substantially increases plant productivity (a benefit of global warming).
- Carbon fertilization effect has been documented in short run experiments, but in the long run, as plants are able to adapt, it does not result in greater plant mass. Experiments found an initial 25% increase in plant growth of young pine trees, but after 4 years there was no statistically significant effect on growth.
- It would require reforestation of all land on earth (including agricultural and urban land) to store 6 gigatons of carbon a year.

Attempts to model climate change

- "Climate change" means a change in the distribution of weather.
- Small changes in the earth's orbit over 10s of millions of years have been linked to changes in the size of continental ice sheets on Greenland and Antarctica.
- Climate change models partition sphere into between 450 to 45,000 boxes (a grid of between 100 and 1000 kilometers in length). Portion atmosphere into 10 to 100 layers, resulting in 4,500 to 4.5 million cells.
- Similar, but finer partition of oceans. Even this level of detail is not fine enough to capture many important phenomena.

Modeling feedback effects

- Increase in water vapor in atmosphere leads to further warming, which might magnify an exogenous increase in temperature by as much as a factor of 2.
- Melting of ice sheets diminishes reflectivity, increasing absorption of heat; this effect could amplify an exogenous temperature increase by a few tens of percent. (Spring snowmelt in Artic tundra has increased about 2.5 days per decade since the 1960s.)

Feedbacks, continued

- The sign of the feedback effect of clouds is uncertain, but often thought to be positive. There is not a unique way of incorporating these feedback effects into models; they occur at the subgrid level, so different models can give different results.
- Higher temperatures would cause more rapid decomposition in soils, leading to faster carbon production. The cold and waterlogged conditions in in boreal and tundra soils causes the accumulation of organic matter. A slight warming could lead to the faster decomposition of this material, and greater release of carbon.

Measures of recent changes

- Data from thermometers show that the earth's global average surface temperature has increased by about 0.6 degrees Celsius over the past 100 years, and sea-level has increased by 0.1 to 0.2 meters.
- Frequency of Atlantic hurricanes has not changed, but the number of category 4 and 5 level storms has doubled in the past 35 years.

Climate model assumptions

- IPCC report develops over 40 different scenarios of emissions. (About 75% of emissions remain in atmosphere.) The different scenarios show concentration levels in 2100 from about 500 ppm to 1000 ppm.
- A rough estimate is that over the next century concentrations could double from current levels (reaching 760 ppm).
- Climate modelers use these emissions scenarios as inputs into their models to predict changes in temperature and sea level.

Climate model results

- Using emissions scenarios and two models of climate change, the average temperature change over the next century is expected to rise between 1.8 and 6 degrees Celsius.
- The sea level is expected to increase from between 0.1 and 0.9 meters, with estimates concentrated around 0.4 meter.
- Recent model runs have concluded that temperature and sea-level increases might be substantially higher.

Model results change as we learn more

- Models in early 90s predicted more global warming.
- Mid 90s models reduced these estimates because they took into account the cooling effect of sulfites (caused by SO_2 emissions).
- Late 90s models increased estimates because it was predicted that poorer countries would begin to reduce their SO_2 emissions as they became richer.

Estimates of market damage from climate change

- There is much more uncertainty about damages than about abatement costs.
- The link between changes in GHG concentration and climate change is uncertain, as is the link between the change in climate and the associated ecosystem change and the effect on the quality of life and economic activity.
- Types of evidence of economic costs of temperature change: (i) experimental, e.g. grow plants in experimental plots, changing carbon and temperature and (ii) cross-sectional statistical (hedonic) models. These estimate the relation between agricultural productivity and climate.
- These estimates ignore “catastrophic” changes. They find that global warming has small economic effects.

Several (older) damage estimates for US

- Nordhaus, Cine, Fankhauser and Tol estimate cost to "current" (e.g. early to mid 90's) US economy of doubling GHG concentrations. Many of these studies were based on evidence from a 1989 EPA report.
- These estimates are for the cost to the US 1990 economy of doubling GHG concentrations. (There is no reason to assume that the cost to the economy in 2050 would be comparable to cost today -- although it might be.)
- The estimates range from 0.1-- 0.9 % of annual GNP. Most of the damages in Agriculture, Water, and Coastal regions.

Forward-looking estimates for US

- Meldesohn and Neuman (1999) attempted to estimate the cost on the future economy that will exist when GHG concentrations are doubled (2060).
- This creates even more uncertainty, since we don't know what the economy will look like 100 years from now, but it addresses a more relevant question.
- This study attempts to include the effect of adaptation, which will reduce the damages. It also includes the effect of carbon fertilization which converts annual agricultural damages of $11 billion into benefits of $10 billion.

US damage estimates, continued

- The study also attempts to include other benefits, e.g. fruits and vegetables do better in warmer climates; some timber species will be grown in new areas.
- Study finds that the benefits to agriculture swamp the costs, at moderate (2.5 degree Celsius) increases in temperature (and 7% increase in precipitation): net US benefits are $19.8 billion 1998 dollars.
- If temperature increases to 5 degrees Celsius, estimated annual damages are $10 billion 1998 dollars. (Compare estimates of federal costs from Katarina in excess of $200 billion).

Global damage estimates from 2.5 – 5 degree Celsius increase.

- Estimates depend on the regional change of climate. Most models assume that precipitation increases in most places; temperatures increase everywhere, but most strongly in higher latitudes.
- Most damage estimates from the mid 1990s are in the range of 1 -- 2 % of GDP, although for some countries there are much higher estimates (9 - 21% for India).
- Damage estimates from late 90s and early 2000's are much smaller -- a fraction of 1% of world GDP. Some regions continue to gain from warming, but gain is again small, a fraction of 1% of GDP.

More on damage estimates

- Agriculture, energy and water are the important sectors for damages.
- Recent studies show smaller costs to coasts regions (compared to earlier studies) because they assume that responses (e.g. better sea walls) are spread out over a century.
- Distribution of costs and benefits are unequal. Define rich country as those with per capita income greater than $10,000 (1998 dollars).

Annual costs and benefits (1998 dollars) for rich and poor

	2.5 degrees warmer	5 degrees warmer
Rich	$18 - $45 billion benefit	$10 - $26 billion benefit
Poor	$60 -$80 billion benefit	$20 - $80 billion damages

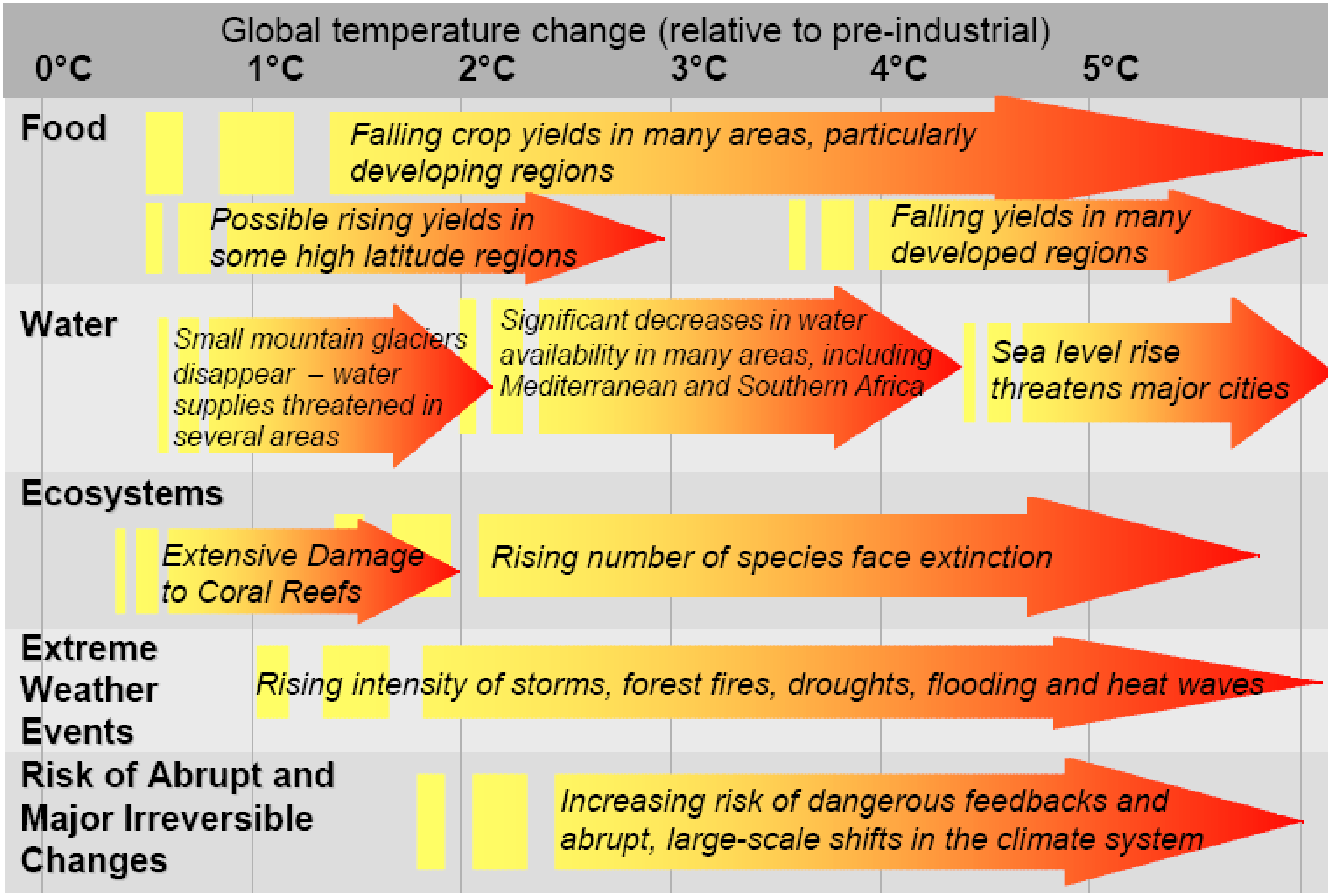
What is behind these small damage estimates?

- Mendelsohn claims that the evidence suggests a global warming presents steadily increasing risk, not a threshold phenomenon.
- Most models assume that change is gradual, and that damages can be mitigated by adaptation.
- These models (typically) recommend that only modest near-term efforts should be made to reduce GHG emissions.

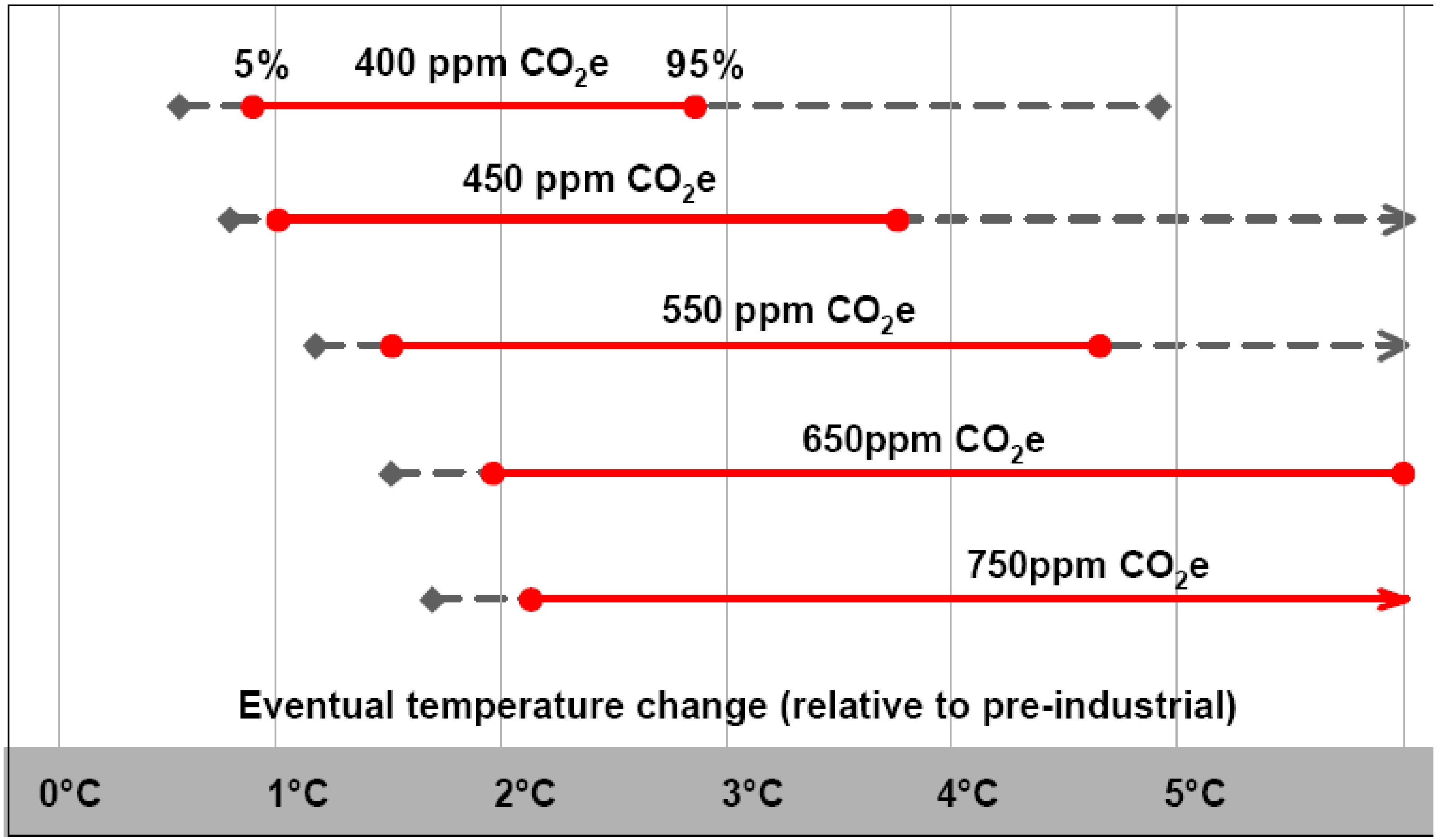
Overview of Stern Report

- Stern report estimates much higher damages, and accordingly calls for greater effort to reduce GHG emissions.
- Climate change represents the greatest market failure ever seen.
- Current actions will have small effects over next couple of decades, but can have large effects over next century and more.
- The benefits of strong, early action outweigh the costs.

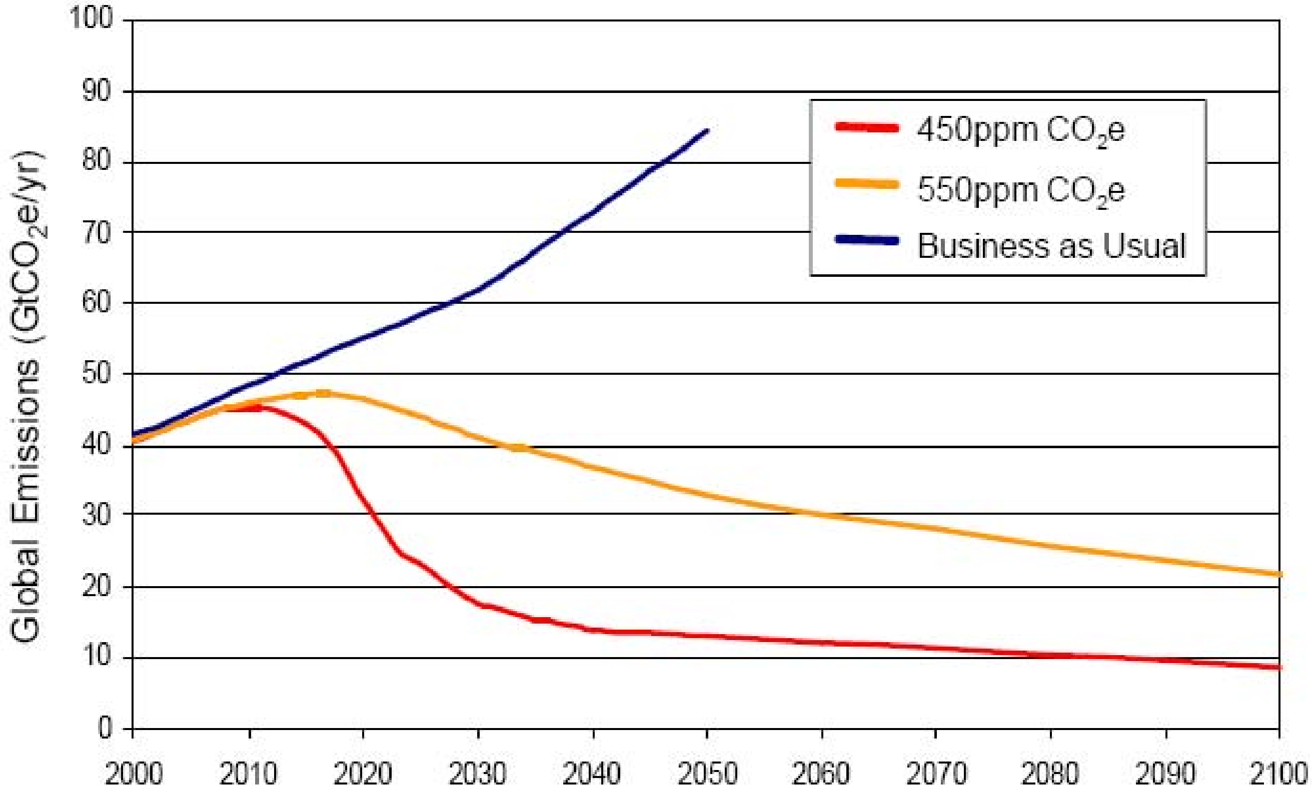
Projected Impacts of Climate Change



Stabilisation and Commitment to Warming



Emissions Paths to Stabilisation



On current trends, average global temperatures will rise by 2 - 3°C within the next fifty years or so.[5] The Earth will be committed to several degrees more warming if emissions continue to grow.

Warming will have many severe impacts, often mediated through water:

- Melting glaciers will initially increase flood risk and then strongly reduce water supplies, eventually threatening one-sixth of the world's population, predominantly in the Indian sub-continent, parts of China, and the Andes in South America.

- Declining crop yields, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food. At mid to high latitudes, crop yields may increase for moderate temperature rises (2 - 3°C), but then decline with greater amounts of warming. At 4°C and above, global food production is likely to be seriously affected.

- In higher latitudes, cold-related deaths will decrease. But climate change will increase worldwide deaths from malnutrition and heat stress. Vector-borne diseases such as malaria and dengue fever could become more widespread if effective control measures are not in place.

- Rising sea levels will result in tens to hundreds of millions more people flooded each year with warming of 3 or 4°C. There will be serious risks and increasing pressures for coastal protection in South East Asia (Bangladesh and Vietnam), small islands in the Caribbean and the Pacific, and large coastal cities, such as Tokyo, New York, Cairo and London. According to one estimate, by the middle of the century, 200 million people may become permanently displaced due to rising sea levels, heavier floods, and more intense droughts.

- Ecosystems will be particularly vulnerable to climate change, with around 15 - 40% of species potentially facing extinction after only 2°C of warming. And ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems, with possible adverse consequences on fish stocks.

The damages from climate change will accelerate as the world gets warmer.

Higher temperatures will increase the chance of triggering abrupt and large-scale changes.

- Warming may induce sudden shifts in regional weather patterns such as the monsoon rains in South Asia or the El Niño phenomenon - changes that would have severe consequences for water availability and flooding in tropical regions and threaten the livelihoods of millions of people.

- A number of studies suggest that the Amazon rainforest could be vulnerable to climate change, with models projecting significant drying in this region. One model, for example, finds that the Amazon rainforest could be significantly, and possibly irrevocably, damaged by a warming of 2 - 3°C.

- The melting or collapse of ice sheets would eventually threaten land which today is home to 1 in every 20 people.

While there is much to learn about these risks, the temperatures that may result from unabated climate change will take the world outside the range of human experience. This points to the possibility of very damaging consequences.

Vulnerability of poor regions

- Poor regions already tend to be warmer and suffer from higher variability of rainfall. Further warming will bring few benefits to these regions
- Heavy dependence on agriculture.
- Poverty makes it difficult for these regions to invest in adaptation/mitigation.
- Rising sea levels and other climate-related events could spur mass migration.

Stern's estimates of damages of temperature change

- Earlier models used scenario of 2-3 degree Celsius warming, predicted losses equal to 0-3% of annual gross world product (GWP).
- Recent evidence suggests greater climate change, possible 5-6 degrees. Existing IAMs show a loss (including only market losses) of over 5% of GWP at these levels.
- Including non-market losses (direct impacts on health and environment) increases estimate to 15% of GWP.
- Costs fall disproportionately on poor. Weighting these costs more heavily increases estimate to 20% of GWP.

Cost estimates of stabilization

- Stabilization at or below 550ppm requires emissions to peak within the next 10-20 years and then fall at an annual rate of 1-3%.
- Global emissions by 2050 would have to be 25% below current levels
- Since world economy may be 3-4 times current size by 2050, emissions per $ output in 2050 would have to be ¼ of current levels.
- They estimate that this would cost about 1% of GWP.
- They conclude that a stabilization target of 550 ppm is reasonable; a more ambitious target might be too costly.