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Trapped Between the Falling Sky and the Rising Seas: The Imagined Terrors of the Impacts of Climate Change

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ABSTRACT

Some advocates of drastic greenhouse gas controls claim that the costs of global warming are underestimated and that a proper accounting of the full costs raises the specter of economic and political instability, conflict and mass migration as weak governments in developing countries with low adaptive capacity are buffeted by floods, droughts, famine, and rising seas driven by global warming. No country, least of all the US, will be immune from the spillover effects. Accordingly, they argue, the costs to the US of a unilateral pursuit of GHG reductions would be justified by the benefits to the US itself. This chapter shows that the central pillar for this argument, namely, countries', and specifically developing countries', adaptive capacity will be low, is flawed. Specifically, it shows that under the IPCC's warmest scenario, which projects a 1990–2085 warming of 4°C precisely because it assumes healthy economic growth worldwide, developing countries will in 2100 be twice as wealthy as the US is today, even after subtracting the costs of warming per the Stern Review's overblown estimates. Industrialized countries will be thrice as wealthy. Moreover future societies will have superior technologies at their disposal. Accordingly, their adaptive capacities should be much higher than it is today, the costs of warming have been overestimated, and fears of economic and societal breakdown are precisely that — fears. Moreover, empirical trends suggest that warming is currently proceeding slower than the IPCC's projections, nor is there any hint of any deterioration in climate-sensitive indicators of human well-being that might presage such breakdowns. Specifically, agricultural productivity has increased; hunger has declined; deaths from hunger, extreme weather events, malaria and other vector-borne disease have dropped; and people are living longer and healthier. Regarding environmental well-being, the Amazon and the Sahel are becoming greener, as is most of the world. Ironically, much of this improvement in human and environmental well-being has been enabled, directly or indirectly, by technologies dependent on fossil fuels or economic surpluses generated by the use of fossil fuels and other GHG-generating activities.

I. INTRODUCTION

Some advocates of drastic greenhouse gas (GHG) controls claim that the costs of global warming are underestimated and that a proper accounting of the full costs raises the specter of economic and political instability, conflict and mass migration as weak governments in developing countries with low adaptive capacity are buffeted by floods, droughts, famine, and rising seas driven by global warming.

As representatives of this school of thought, Freeman and Guzman (2009), henceforth FG, make the interesting, but ultimately unpersuasive, argument that conventional cost-benefit analyses of the impacts of global warming on the US underestimate the costs to the US, and that a proper consideration of the costs would show that they have been substantially underestimated. Accordingly, they claim, it would be in the US interest to make unilateral cuts in greenhouse gas (GHG) emissions and, if necessary, pay the full cost of mitigation.[1] They claim that a full accounting of losses to the United States indicates that it "stands to lose in a warmer world [, therefore] investing in mitigation, even at the risk of other nations' free riding, is the most rational course [for the US]. Though international cooperation should be pursued, the reluctance of others to fully engage the problem is not a sound reason for inaction by the United States. Whatever others do, the United States should move aggressively to reduce global GHG emissions" (FG: 170-171).

Central to their argument is the claim that the costs of global warming to the US are underestimated for a variety of reasons. First, they claim, assessments of the impacts of global warming are based on "optimism about projected temperature rise; failure to account for the possibility of catastrophic loss; omission of cross-sectoral impacts; exclusion of nonmarket costs; and optimism about projected economic growth (which assumes productivity will be unaffected by climate change)" [FG: 118]. Second, the assessments do not account adequately for the economic spillovers on the US from the effects of global warming on other nations (e.g., economic downturns for trading partners due to loss of productivity from reduced availability of food and water, severe weather events, major flooding, and large-scale refugee crises; FG: 138-140). Third, FG argue that the costs of global warming to the US do not account for a number of other spillover effects that would affect national security, increase migration

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[1] "A more complete accounting of the costs reveals that the United States would be better off paying the full cost of mitigating its impact by itself (if doing so were possible)" FG: 101.

pressures on the US, and increase the likelihood of the the spread of contagious disease. Specifically, they claim global warming is a threat multiplier for national security concerns because it “is likely to exacerbate political instability around the world as weak or poor governments struggle to cope with its impacts” (FG: 147) from increased hunger, water and energy shortages, and floods. FG also claim that global warming “threatens to interrupt the free flow of trade in critical resources such as oil, gas, and other essential commodities on which the United States depends” (FG: 147). In addition, FG argue that by increasing floods, droughts, and extreme weather, global warming would destroy crops and livelihoods in many places making life “impossible” in many places and leading to greater migration to the US’s shores (FG: 153). They also claim that global warming makes the spread of contagious disease more probable because there would be more disease in the world and countries are likely to have fewer resources to cope with disease (FG: 157).

In this chapter, I will examine FG’s arguments that the impacts of global warming on the US are underestimated. Part II will examine the claim that models of the impacts of global warming suffer from a “systematic downward bias” (FG: 106). It will show that, in fact, these models are more likely to have overestimated the negative impacts — and underestimated the positive impacts — of global warming. Part III will address issues related to impacts from potential catastrophes that may be caused by global warming over the next century. Part IV will address claims that “things [related to global warming] are worse than expected.” Part V will examine issues that FG claims are frequently overlooked, e.g., cross-sectoral impacts, reduced access to resources, and myriad other impacts of global warming that, acting in combination, could lead to economic instabilities resulting in international spillovers affecting the United States. Part VI will deal with claims regarding migration, conflicts and national security. Part VII summarises this chapter.

A note on terminology: In most public discourse the term “climate change” is synonymous with “global warming.” For the sake of accuracy, this paper uses “global warming” rather than climate change when the change under discussion is warming.

II. DO IMPACT MODELS HAVE "A SYSTEMATIC DOWNWARD BIAS"?

RG (p. 118) claim that "methodological limitations of … models almost certainly cause them to understate the impact and cost of climate change." They attribute this to the following "five problems": "optimism about projected temperature rise; failure to account for the possibility of catastrophic loss; omission of cross-sectoral impacts; exclusion of nonmarket costs; and … [the assumption] that productivity will be unaffected by global warming" (RG: 118). This section will address whether the impacts estimates are likely to have been understated.

1. Optimism about Projected Temperature Rise

Estimates of the impacts of global warming are based on a chain of linked models with the uncertain output of each model serving as the input for the next model. The first link in this chain are emission models which use socioeconomic assumptions extending 100 or more years into the future to generate emission scenarios, which strains credulity. As Lorenzini and Adger (2006: 74) noted in a paper commissioned for the Stern Review, socioeconomic scenarios "cannot be projected semi-realistically for more than 5–10 years at a time." Nevertheless, in the following I will eschew skepticism regarding the ability of mere mortals to accurately forecast socioeconomic variables more than a few years hence.

The results of these emissions models are fed into coupled atmosphere-ocean general circulation models (AOGCMs) to estimate spatial and temporal changes in climatic variables (such as temperature and precipitation) which are, then, used as inputs to simplified and often incomplete biophysical models that project location-specific changes in biophysical factors (e.g., available habitat, or crop or timber yields). Notably, the uncertainty of estimates of climatic changes increases as the scale at which they have to be specified becomes finer. This is particularly true for precipitation, which is a — if not **the** — critical determinant of natural resources (e.g., water and vegetation) that human beings and all other living species depend on either directly or indirectly. Next, depending on the human or natural system under consideration, the outputs of these biophysical models may have to be fed into additional models to calculate the social, economic, and environmental impacts on those systems. Ideally, the outputs from this set of models should be fed back into the emissions models, thereby closing an iterative loop of models. But models have, so far, not yet incorporated this feature.

Another shortcoming is that since the outputs from AOGCMs drive the impact models, any problems and uncertainties associated with the former will necessarily be transmitted to the latter. Remarkably, end-to-end uncertainty estimates of the results from the series of models are never provided, which gives many readers a false sense of confidence in the results.

A major problem with AOGCMs is that they are developed and calibrated using the surface temperature record. But there are strong indications that the surface temperature record has been compromised, as discussed below. Therefore, quantitative estimates made using that record are also suspect.

Figure 1 shows a thermal satellite image of New York City at 10:30 am on a summer morning. It shows that at that instant the surface temperature within the city varied from at least 89°C to more than 121°C. The variation in temperature within the city is due to differences in its surface characteristics. Figure 2 indicates that surface temperatures can vary by tens of degrees Celsius within a few meters, depending on the type and color of surface cover, and the presence of vegetation, water bodies, or heat sources or sinks.

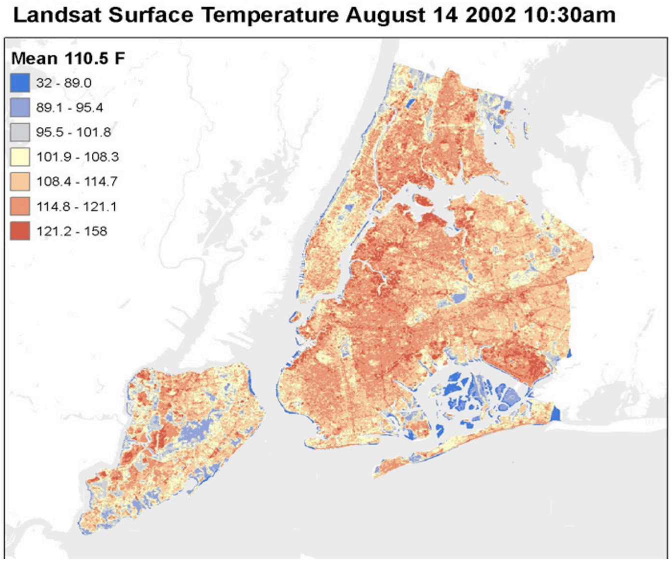

Figure 1: Thermal Satellite Image, New York City (NASA 2006).

That urban areas are generally warmer than their surroundings because the former have more paved surfaces and heat sources within them is well known. This phenomenon is called the urban heat island effect (UHIE). It is also known that the magnitude of the UHIE has generally increased over time.[2] Consequently, efforts are made to correct surface temperature data for the UHIE before developing long term temporal trends for temperature. According to the IPCC WGI's Fourth Assessment Report (henceforth, AR4WG1), "Urban heat island effects are real but local, and have not biased the large-scale trends. A number of recent studies indicate that effects of urbanisation and land use change on the land-based temperature record are negligible (0.006°C per decade) as far as hemispheric- and continental-scale averages are concerned because the very real but local effects are avoided or accounted for in the data sets used" (AR4WG1: 237).

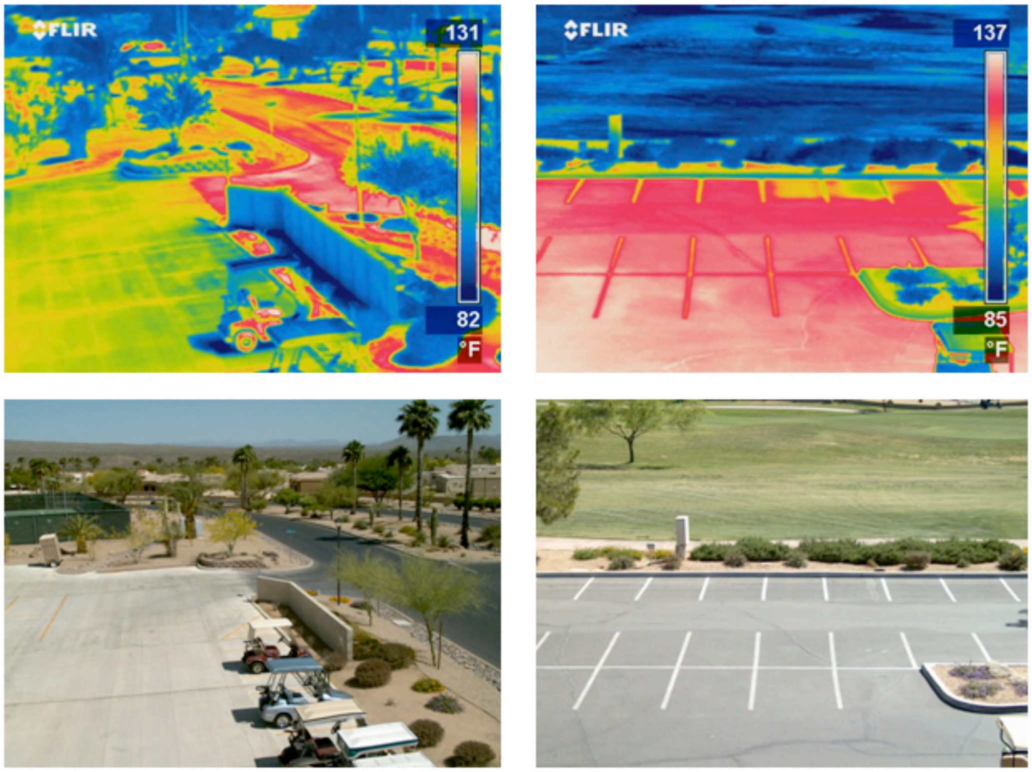

Figure 2: Normal and Infrared Photographs of Two Parking Lots and Their Environs (Pavements4Life 2008).

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[2] Sometimes corrections may be made to the data assuming that UHIE is related to changes in population. However, this would not capture the full trend that is introduced in virtually every inhabited area in the world because even in non-urban areas there has been a broad trend toward greater paving of surfaces, introduction of heating and air conditioning systems (sometimes adjacent to the sensors), and construction of other structures in their vicinity. At the same time as areas are depopulated (e.g., some rust belt areas, and parts of Russia), paved areas are rarely taken out.

However, the UHIE is only one of the issues that must be confronted while developing long term temperature trends from surface temperature data. Consider surface data from the US Historical Climatology Network (USHCN), which is the US's network of record.

One would think that US would have one of the more reliable surface temperature networks in the world, yet a survey of USHCN sites indicates that the instrumental record may be compromised because of inhomogeneities,[3] and siting and maintenance issues. Many monitors are in close proximity to asphalt roadways, parking lots, trees, other kinds of land cover, a variety of heat sources or sinks (e.g., buildings, sewage treatment facilities, and heating and air conditioning units, and so forth. Few, if any, of these features existed at any site from the beginning of that site's temperature record, nor were they introduced in one fell swoop. They mostly accreted over time. Other sources of inhomogeneities in the data include changes in station location (in all three dimensions); instrumentation; land use, land cover and other factors affecting temperature readings at the micro- to higher-scales; seemingly minor changes in the height of thermometers; and operational and maintenance procedures and practices, including the time at which temperatures are recorded, erratic or non-uniform maintenance of sites (such as monitor enclosures, their conditions, including the condition of the paint job, and their immediate environments) (Hale et al. 2006; Pielke et al. 2007a, 2007b). Figures 3 and 4 illustrate two among many poorly sited monitoring stations.

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[3] Inhomogeneities are discontinuities in data quality or comparability due to equipment changes, missing data, poor quality control, etc.

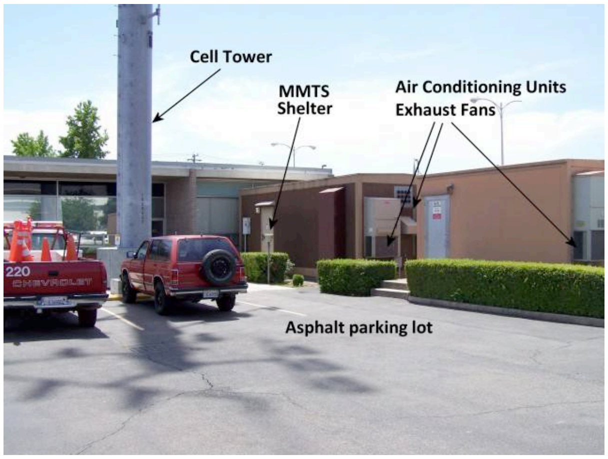

Figure 3: Marysville, California (Watts 2008)

Figure 4: University of Arizona, Tucson (Watts 2008)

Results from a citizen survey of 78% of the 1,221 USHCN sites indicate that, based on siting guidelines adapted from U.S. National Climatic Data Center, over two-thirds (69%) of the sites are prone to errors of ±2°C or more (see Figure 5; Watts 2009a). These errors are much greater than the IPCC's estimate of global temperature change from 1906 to 2005 (which is 0.74°C ±0.18°C; AR4WG1: 237).

Arguably, the USHCN is among the highest quality surface networks in the world. If the problems seen for the USHCN are typical of other national networks, then little confidence can be placed either in quantitative estimates of historical trends in temperature, or in the development and validation of models that used data from these networks.

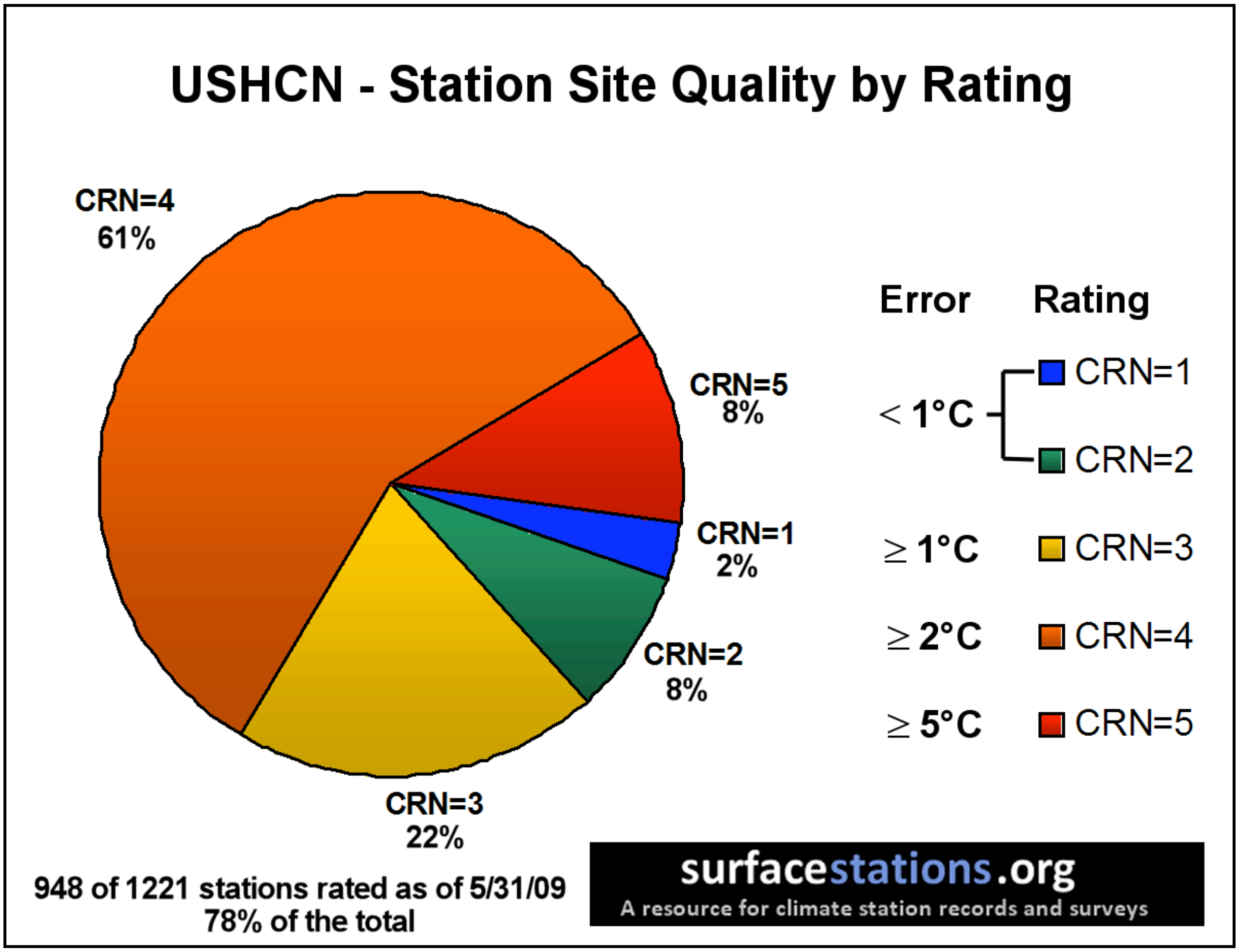

Figure 5: Summary of Quality Rating of USHCN Stations. Station quality ratings adopted from NCDC Climate Reference Network Handbook, 2002, specifications for siting (section 2.2.1: 6) (available at <www1.ncdc.noaa.gov/pub/data/uscrn/documentation/program/X030FullDocumentD0.pdf>). Source: Watts (2009a).

The researchers who compiled the data for the U.S. Historical Climatology Network (Williams et al. 2005) recommend “that users make full use of the information contained in the station histories when performing analyses with these data. The data have not been adjusted for station relocations, heat island effects, instrument changes, or time of observation biases. The nature of inhomogeneities arising from such factors depends on a station's climatic regime.”

However, this has generally not been done on a site-by-site basis, although generalized algorithms have been used to make some corrections. The implicit or explicit assumption is that all other errors are random. Clearly some will be, but how do we know that all errors are random? [This was probably why Williams et al. recommended using station histories.]

In fact, McKitrick and Michaels (2007) have shown that global temperature trends in climate data seems to be correlated to some extent with socioeconomic variables (population, real average income, real national gross domestic product and coal consumption), and the density of economic activity (GDP per square km). This indicates that the errors in the surface temperature data are not random but may be contaminated by socioeconomic factors. They conclude that data contamination may lead to an overstatement of actual trends over land, correcting for which reduces the estimated 1980–2002 global average temperature trend over land by about half.

Reinforcing McKitrick and Michaels' conclusion is the fact that temperature trends from 1979–2008 from satellite data do not agree with trends derived from surface data (Goklany 2009a). The latter typically show greater warming. Klotzbach et al. (2009a, 2009b) have shown that surface temperature data sets from the National Climate Data Center and the Hadley Center show larger trends over the 30-year period than the lower troposphere data from satellites (after adjusting for the expected differences between trends in the lower troposphere and the surface). The differences between trends observed in the surface and lower-troposphere satellite data sets are statistically significant in most comparisons, with much greater differences over land areas than over ocean areas. This would be consistent with the notion that the surface network data are contaminated by spurious warming on land due to the urban heat island effect, and/or changes in land use and land cover, or other factors.

Also contributing to this spurious warming may be the fact that surface monitoring stations are not distributed at sites that are representative of the land mass. For example, 160 (or 13%) of the 1,221 USHCN station are apparently located at airports (Watts 2009b), but airports occupy less than 1% of US land area.[4] Clearly, the network data are not from a representative sample of the US. In fact, one would expect that over time that there would be a pronounced real

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[4] There were 20,341 airports in the US in 2007, of which 75% were for private use (DOT 2008, Table 1-3). Assuming that the average airport occupied 1.5 square miles, then the combined area of all airports is about 1% of the US.

warming in their immediate vicinity due to airport growth, increased air traffic, and expansion in paved area around the airports — factors that have nothing to do with anthropogenic greenhouse gas emissions. Watts (2009a) also notes that monitoring sites are located preferentially at waste water treatment plants, fire stations and other types of sites that too are not representative of the land surface.

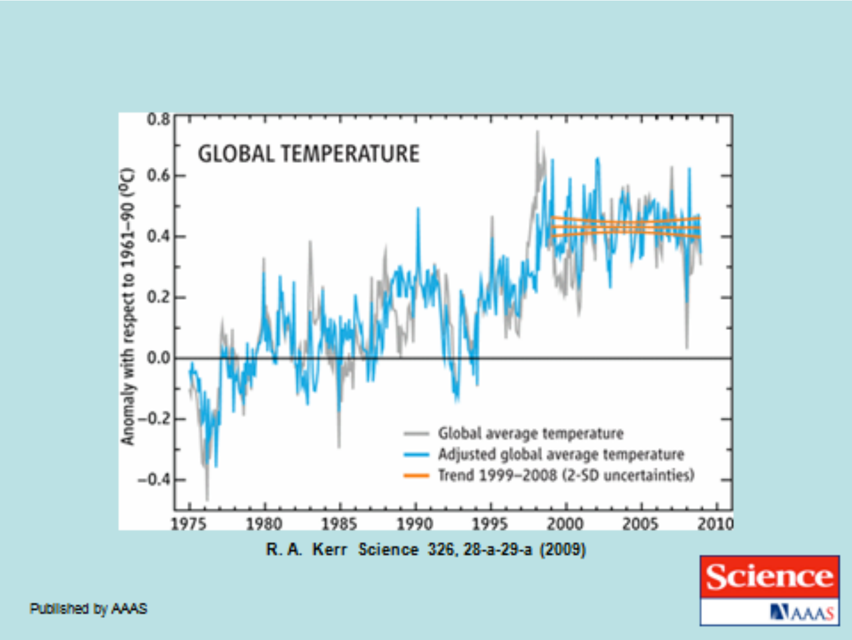

Figure 6: Global Temperature Trends, 1999–2008. Gray line is based on the Hadley Center's surface temperature dataset; the blue line is the data adjusted to account for the El Niño phenomenon of 1998; the orange lines indicate the linear trend line and error bars. Source: Kerr (2009).

The above findings suggest that the amount of warming that has occurred since the 1850s may have been overestimated, and that AOGCMs that are calibrated using the surface data may be overestimating the sensitivity of temperature increases to carbon dioxide, or underestimating the role of natural variability, or both. That this might be the case is supported by the fact that contrary to the IPCC's claim — derived from the results of several AOGCMs — that global temperatures should increase by 0.2°C per decade under "Business as Usual"(BAU) scenarios (AR4WG1: 12), global surface temperature data do not show any significant global warming since 1998 (as indicated in Figure 6; Kerr 2009). This, despite the fact that since the 1990s, emissions have grown more rapidly than were projected under any of the BAU scenarios mainly because of the spectacular economic growth in China and India. Hence, if anything, we should have seen an increase larger than that projected by the IPCC.

The fact that the IPCC models seem to be failing ought not come as a major surprise, since these models have not been validated using out-of-sample data under conditions of high greenhouse gas concentrations. Just as a mathematical model for a human being (for instance) should be able to show that he can not only breathe but walk, talk and chew gum at the same time, for a climate model to be valid, it should be able to **simultaneously** forecast with reasonable accuracy the spatial and temporal variations in a wide variety of climatic variables including temperature, pressure and precipitation, as well as endogenously produce the patterns and rhythms of ocean circulation (among other things). But we know from the AR4WG1 that models are unable to do this even for "in sample" data. As it states, "Difficulties remain in reliably simulating and attributing observed temperature changes at smaller [that is, less than continental] scales" [AR4WG1: 10.] And this what it says about projections of climate change:

> "There is considerable confidence that climate models provide credible quantitative estimates of future climate change, **particularly at continental scales and above**. This **confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes**. **Confidence in model estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation)**." (AR4WG1: 600, emphasis added)

This tacitly acknowledges that confidence is low for model projections of temperature at less than continental scales, and is even lower for precipitation — perhaps even at the continental scale. Notably, it doesn't provide any quantitative estimate of the confidence that should be attached to projections of temperatures at the subcontinental scale. This lack of confidence in temperature and precipitation results at such scales is reaffirmed by recent reports from the US Climate Change Science Program (CCSP):

> "Climate model simulation of precipitation has improved over time but is still problematic. Correlation between models and observations is 50 to 60% for seasonal means on scales of a few hundred kilometers." (CCSP 2008:3).
>
> "In summary, modern AOGCMs generally simulate continental and larger-scale mean surface temperature and precipitation with considerable accuracy, but the models often are not reliable for smaller regions, particularly for precipitation." (CCSP 2008: 52).

The IPCC does not say that “all” features of current climate or past climate changes can be reproduced, as a good model of climate change ought to be able to do endogenously. In fact, it notes:

> “Model global temperature projections made over the last two decades have also been in overall agreement with subsequent observations over that period (Chapter 1).
>
> “Nevertheless, **models still show significant errors. Although these are generally greater at smaller scales, important large scale problems also remain**. For example, deficiencies remain in the simulation of tropical precipitation, the El Niño-Southern Oscillation and the Madden-Julian Oscillation (an observed variation in tropical winds and rainfall with a time scale of 30 to 90 days).” (AR4WG1: 601; emphasis added).

Notably, although the absence of global warming for the decade (1999-2008) was not forecast by the models that the IPCC relied on, a number of peer reviewed papers have suggested there would be a cooling trend in the early 2000s based on their analysis of natural variability. These include Loehle (2004 and 2009); Zhen-Shan and Xian (2007) who in 2007 published a paper provocatively titled, “Multi-scale analysis of global temperature changes and trend of a drop in temperature in the next 20 years”; Tsonis et al. (2007); Swanson and Tsonis (2009); and Keenleyside (2008).

Time may reveal these projections to be flawed, but the fact is that currently there exists no empirical basis for concluding that the IPCC’s temperature projections are “optimistic”, as claimed by FG. To the contrary, such empirical evidence as exists suggests that natural variability is a much more significant factor in temperature swings than is credited in AR4WG1, and that the temperature sensitivity of the climate system to GHG emissions has been overestimated, which suggest that reducing such emissions will have a lower impact on temperature than estimated.

2. Impacts of Global Warming Are Overestimated

FG argue that models systematically underestimate the future impacts of global warming. In this section I will show that, in fact, current modeling studies vastly overestimate the net negative impacts (or damages) of climate change.

The major reason for this is that the magnitude of future damages depends critically on society's future adaptive capacity. But the methodologies used to estimate impacts underestimate individuals' and society's future capacity to make self-directed (or autonomous) adaptations to global warming.[5] In general, this adaptive capacity is determined by a variety of socioeconomic factors, including society's level of economic development (as measured by GDP per capita, which is also a surrogate for wealth or per capita income), available technologies, and human and social capital (Goklany 2000, 2007a). Therefore, in the future, if societies become wealthier, as is assumed under all IPCC emission and climate scenarios (Goklany 2007b), their adaptive capacity ought to be higher (Goklany 2007a). And, if history is any guide, due to secular technological change society should have a wider array of technological options available to them as existing technologies are perfected and new technologies come on line (Goklany 2007a, 2009b). This ought to further bolster adaptive capacity beyond the increase due to economic development alone (Goklany 2007a). However, some impact assessments ignore adaptive capacity altogether, e.g., Arnell's (2004) study of water resources (Goklany 2007b); others assume that future adaptive capacity will be the same as it was in the base year (generally 1990 in most assessments undertaken to date), e.g., van Lieshout et al. (2004) for malaria; yet others assume that existing technologies will become more affordable as society becomes wealthier but do not account for new technologies that may come on line over the next few decades, e.g., Parry et al. (2004) for agricultural production and hunger. To date, no impact study has fully accounted for both increasing wealth and secular technological change (Goklany 2007b). As a result they overestimate the negative impacts and underestimate the positive impacts. Therefore, they all overestimate net damages associated with global warming, with some studies overestimating a lot more than others.

Figure 7, taken from Goklany (2009f), provides estimates of net GDP per capita — a determinant of adaptive capacity — for four IPCC reference scenarios for areas that comprise today's developing and industrialized countries after accounting for any losses in GDP due to global warming for 1990 (the base year), 2100 and 2200. For 1990, the net GDP per capita is calculated assuming that any GDP loss due to global warming is negligible.[6] For 2100 and 2200, net GDP per capita is estimated assuming that (a) GDP per capita in the absence of global

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[5] Adaptations could include measures to either reduce any adverse effect of global warming or take advantage of any of its positive impacts.

[6] This assumption is appropriate since the Stern Review's estimates used 1990 as the baseline for estimating the average global temperature increase.

warming will grow per the IPCC SRES scenarios and (b) adjusting it downward to account for the costs of climate change per the Stern Review's 95th percentile estimate. According to the Stern Review, under the "high climate change" scenario, equivalent to the IPCC's warmest scenario (A1FI), the 95th percentile estimate for equivalent losses in GDP due to global warming is 7.5% in 2100 and 35.2% in 2200. Note that I use the Stern Review's estimates which, unlike most other studies, account for losses not only due to market impacts of global warming but also to non-market (i.e., environmental and public health) impacts,[7] as well as the risk of catastrophe, despite the fact that the Stern Review is an "outlier" that many economists believe overstate losses due to global warming (Tol 2008).[8] The precise methodology for developing Figure 7 is provided in Goklany (2009f).

This figure shows that under each IPCC scenario,

- For populations living within the present day borders of developing world, net GDP per capita will be over 11–65 times higher in 2100 than it was in the base year, even after accounting for global warming; it will be even higher (18–95 times) in 2200. For today's industrialized countries, net GDP per capita will be 3–7 times higher in 2100 and 5–10 times higher in 2200. It may be argued that such high levels of economic development are unlikely. But if that's the case, then economic growth used to drive the IPCC's scenarios are overestimated, as are the resulting temperature increases.
- Net GDP per capita in today's developing countries will be higher in 2200 than it was in industrialized countries in 1990 under all scenarios, despite any global warming. That is, regardless of any global warming, populations living within the borders of today's developing countries in the future will be better off than people currently inhabiting today's industrialized countries. This is also true for 2100 for all but the "poorest" (A2) scenario. In other words, developing countries will no longer be poor by today's standards.
- Under the warmest scenario (A1FI), the scenario that prompts much of the apocalyptic visions of global warming, net GDP per capita of inhabitants of developing countries in 2100 ($61,500) will be double that of the US in 2006 ($30,100), and almost triple in 2200

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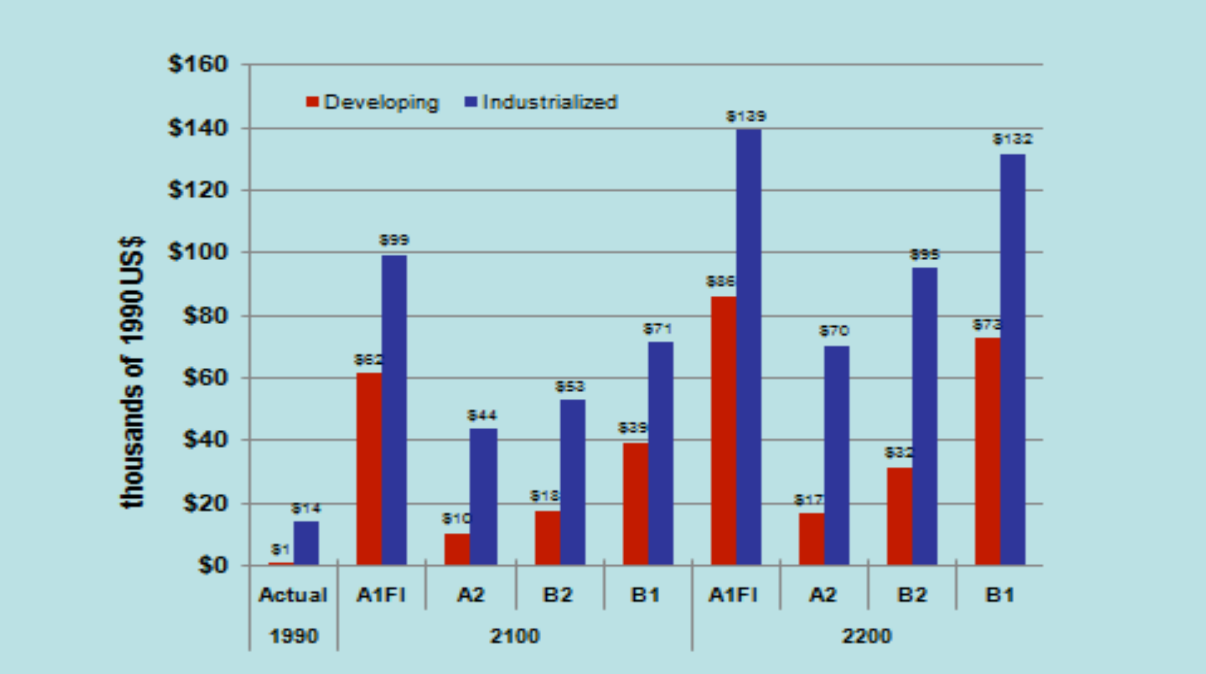
[7] "The only leading study to make a serious attempt to quantify loss of biodiversity is the Stern Review." (FG: 127).

[8] "[The Stern Review's] impact estimates are pessimistic even when compared to other studies in the gray literature and other estimates that use low discount rates." (Tol 2008: 9).

> ($86,200 versus $30,100). Therefore, by 2100, developing countries' adaptive capacity should on average be far greater than the US's today.

Thus, the problems of poverty that warming would exacerbate (e.g., low agricultural productivity, hunger, malnutrition, malaria and other vector borne diseases) ought to be reduced if not eliminated by 2100, even if one ignores any secular technological change that ought to occur in the interim. Tol and Dowlatabadi (2001), for example, show that malaria has been functionally eliminated in a society whose annual per capita income reaches $3,100. Therefore, even under the poorest scenario (A2), developing countries should be free of malaria well before 2100, even assuming no technological change in the interim. Similarly, if the average net GDP per capita in 2100 for developing countries is $10,000–$82,000, then their farmers would be able to afford technologies that are unaffordable today (e.g., precision agriculture) or new technologies that should come on line by then (e.g., drought resistant seeds) (Goklany 2007c: chapter 9, 2009d: 292–93). But, since impact assessments generally fail to fully factor in increases in economic development and technological change, they substantially overestimate future net damages from global warming.



Sources: Goklany (2009b), based on Arnell et al (2004), IPCC (2000), Stern Review (2006)

Figure 7: Net GDP per capita, 1990-2200, after accounting for losses due to global warming for four major IPCC emission and climate scenarios. For 2100 and 2200, the scenarios are arranged from the warmest (A1FI) on the left to the coolest (B1) on the right. The average global temperature increase from 1990 to 2085 for the scenarios are as follows: 4°C for AIFI, 3.3°C for A2, 2.4°C for B2, and 2.1°C for B1. For context, in 2006, GDP per capita for industrialized countries was $19,300; the United States, $30,100; and developing countries, $1,500. Source: Goklany (2009f).

Note that Figure 7 shows that through 2200, notwithstanding global warming, net GDP per capita will be highest under the warmest scenario, and lowest under the poorest scenario (A2). This suggests that if humanity has a choice of which development path it takes, it ought to strive to take the scenario that has the highest economic growth (Goklany 2007b).

The second major reason why the impacts of global warming are systematically overestimated is that few impact studies consider secular technological change (Goklany 2007a, 2007b) and most assume that no **new** technologies will come on line, although some do assume that greater adoption of **existing** technologies with GDP per capita and, much less frequently, a modest generic improvement in productivity (Parry et al. 2004). One can get an idea of the ways in which various impacts assessments treat technology through an examination of the suite of studies that comprise the so-called Fast Track Assessments (FTAs) of the global impacts of climate change. These British government sponsored studies, undertaken by a host of authors who were intimately involved in the IPCC's various assessment reports, were state-of-the-art at the time the IPCC's 4AR was compiled. A dissection of their methodologies in Goklany (2007b) shows that:

- The water resources study (Arnell 2004) totally ignores adaptation, despite the fact that many adaptations to water related problems, e.g., building dams, reservoirs, and canals, are among mankind's oldest adaptations, and do not depend on the development of any new technologies (Goklany 2007b: 1034–35).
- The study of agricultural productivity and hunger (Parry et al. 2004) allows for increases in crop yield with economic growth due to greater usage of fertilizer and irrigation in richer countries, decreases in hunger due to economic growth, some secular (time-dependent) increase in agricultural productivity, as well as some farm level adaptations to deal with climate change. But these adaptations are based on currently available technologies, rather than technologies that would be available in the future or any technologies developed to specifically cope with the negative impacts of global warming or take advantage of any positive outcomes (Parry et al., 2004: 57; Goklany 2007b: 1032–33). However, the potential for future technologies to cope with climate change is large, especially if one considers bioengineered crops and precision agriculture (Goklany 2007b, 2007c).
- Nicholls (2004) study on coastal flooding from sea level rise takes some pains to incorporate improvements in adaptive capacity due to increasing wealth. But it makes some questionable assumptions. First, it allows societies to implement measures to reduce the risk of coastal flooding in response to 1990 surge conditions, but not to subsequent sea level rise (Nicholls, 2004: 74). But this is illogical. One should expect that any measures that are implemented would consider the latest available data and information on the surge situation at the time the measures are initiated. That is, if the measure is initiated in, say, 2050, the measure's design would at least consider sea level and sea level trends as of 2050, rather than merely the 1990 level. By that time, we should know the rate of sea level rise with much greater confidence. Second, Nicholls (2004) also allows for a constant lag time between initiating protection and sea level rise. But one should expect that if sea level continues to rise, the lag between upgrading

protection standards and higher GDP per capita will be reduced over time, and may even turn negative. That is, adaptations would be anticipatory rather than reactive, particularly, for a richer society. Fourth, Nicholls (2004) does not allow for any deceleration in the preferential migration of the population to coastal areas, as might be likely if coastal flooding becomes more frequent and costly (Goklany 2007b: 1036–37).

- The analysis for malaria undertaken by van Lieshout et al. (2004) includes adaptive capacity as it existed in 1990, but does not adjust it to account for any subsequent advances in economic and technological development. There is simply no justification for such an assumption.

So how much of a difference in impact would consideration of both economic development and technological change have made?

If impacts were to be estimated for 5 or so years into the future, ignoring changes in adaptive capacity between now and then probably would not be fatal. However, the time horizon of climate change impact assessments is often on the order of 50–100 years or more. The Fast Track Assessments use a base year of 1990 to estimate impacts for 2025, 2055 and 2085 (Parry 2004). The Stern Review's time horizon extends out to 2100–2200 and beyond (Stern Review 2006).

It should be noted that some of the newer impacts assessments have begun to account for changes in adaptive capacity. For example, Yohe et al. (2006), in an exercise exploring the vulnerability to climate change under various climate change scenarios, allowed adaptive capacity to increase between the present and 2050 and 2100. However, they limited any increase in adaptive capacity to "either the current global mean or to a value that is 25% higher than the current value – whichever is higher" (Yohe et al. 2006: 4). Such a limitation would miss most of the increase in adaptive capacity implied by Figure 7.

More recently, Tol et al. (2007)'s analyzed the sensitivity of deaths from malaria, diarrhea, schistosomiasis, and dengue deaths to warming, economic development and other determinants of adaptive capacity through the year 2100. Their results indicate, unsurprisingly, that consideration of economic development alone could reduce mortality substantially. For malaria, for instance, deaths would be eliminated before 2100 in a number of the more affluent Sub Saharan countries (Tol et al. 2007: 702). This result is consistent with retrospective assessments indicate that over the span of a few decades, changes in economic development and technologies can damp down various indicators of adverse environmental impacts and negative indicators of human well-being (Goklany 2009b). For example, due to a combination of greater wealth and secular technological change, U.S. death rates due to various climate-sensitive water-related diseases — dysentery, typhoid, paratyphoid, other gastrointestinal disease, and malaria —declined by 99.6 to 100.0 percent from 1900–1970 (Goklany 2009b), that is, over seventy years. Similarly, as shown in Figure 8, average annual global mortality and mortality rates from extreme weather events have declined by 93–98 percent since the 1920s (Goklany 2009c), a span of almost ninety years. Thus, not fully accounting for changes in the level of economic development and secular technological change would understate future adaptive capacity which then could overstate impacts by one or more orders of magnitude if the time horizon is several decades into the future.

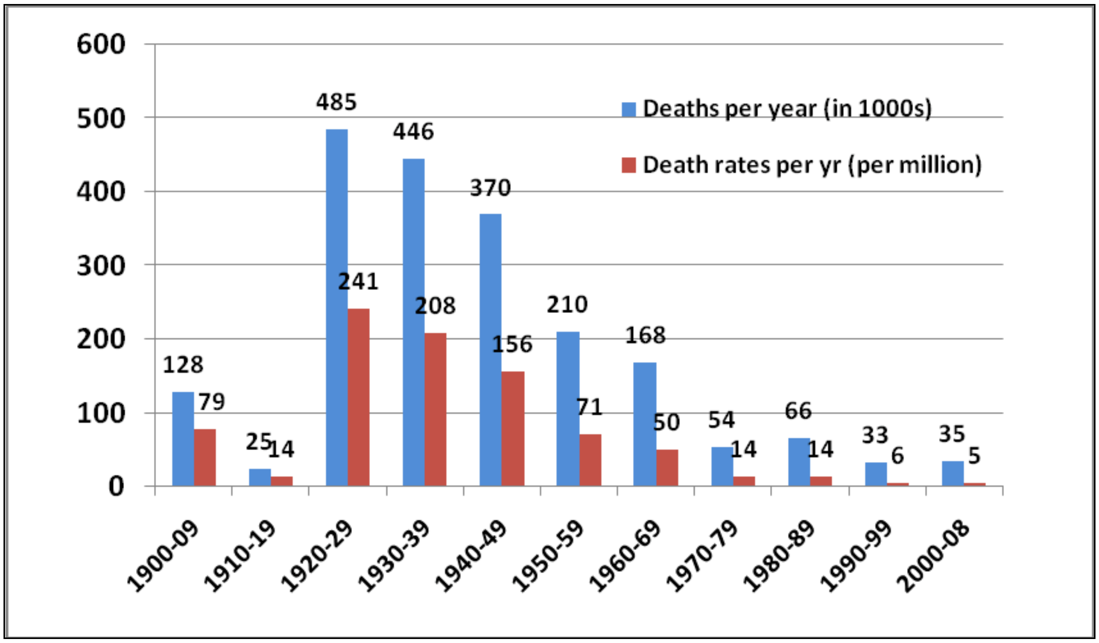


Figure 8: Global Death and Death Rates Due to Extreme Weather Events, 1900–2008. The extreme events include the following: droughts, extreme temperatures (both extreme heat and extreme cold), floods, wet mass movement (i.e., slides, waves, and surges), wildfires, and storms (e.g., hurricanes, cyclones, tornados, typhoons, etc.). Note that data for the last period are averaged over nine years. Source: Goklany (2009c), using data from EM-DAT (2009).

In fact, it is precisely the failure to account for the combination of economic and technological development that has caused high profile prognostications such as Malthus's original conjecture about running out of cropland, *The Limits to Growth*, and *The Population Bomb*, to fizzle (Goklany 2009b).

3. Impacts on Species and Biodiversity are Overestimated

Advocates of drastic greenhouse gas reductions, make much of modeled estimates which indicate that in the future global warming could cause substantial species extinctions and reduce biodiversity. But these estimates are projections rather than "predictions." As noted by Kevin Trenberth, the IPCC makes "no predictions … instead [it] proffers 'what if' projections of future climate that correspond to certain emissions scenarios."[9] This distinction, however, is often overlooked. FG, for instance, claim that, "A significant loss of biodiversity as a consequence of climate change is very likely to occur yet is rarely included in estimates of economic harm" (FG: 127). Note how a projection, which is not even a prediction, led to a "very likely" result!

As justification for the claim, FG notes:

> "One … study found that as global warming causes species to move northward and upward in search of cooler climates, patterns of habitat loss emerge.[118] This study found that the range limits of species have shifted on average 6.1 kilometers toward the poles per decade.[119] Utilizing these numbers, another study estimated that 15–37% of all species will be extinct by 2050 due to habitat loss attributable to 'climatic unsuitability.'[120] This finding is consistent with the most recent IPCC report which states that "[a]pproximately 20 to 30% of plant and animal species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels . . . ."[121] The estimates become 40–70% if temperature increases exceed 3.5°C.[122]" (FG: 128).

The studies cited by FG, and relied upon by the IPCC, for the most part employ "climate envelope models" (CEMs) (also known as "bioclimatic envelope models" or "ecological niche

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[9] Trenberth was referring to the results of climate models, but if one cannot predict changes in climate, how can one make predictions of its impacts?

models") to determine whether species will have suitable habitat available to them in order to persist. These models employ the statistical association between current climates and present-day species distributions to predict future ranges and extinction risks. Essentially, these studies are predicated on a very narrow kind of climatic determinism (Siddiqi and Oliver 2005) in which a few climatic variables (generally temperature and precipitation) determine species habitat, range, and ultimate survival.

But there are good reasons to be skeptical of these projections. First, these models use as climatic inputs the uncertain outputs from various AOGCMs. Moreover, envelope models should employ geographical scales that are finer than continental scales because the ranges of most species do not extend to entire continents. But, as noted above, the finer the scale, the lesser the confidence in AOGCM temperature results, and lesser still the confidence in precipitation results. To compound matters, the envelope models need to be driven by **simultaneous** projections for temperature and precipitation. But again, as noted, AOGCM results for precipitation are uncertain (CCSP 2008: 3). Second, not only is the ability of AOGCMs to simultaneously predict these variables inadequate (CCSP 2008: 52), bioclimatic models also have not been appropriately validated using out-of-sample data (see below).

Third, although envelope models employ the statistical association between current climates and present-day species distributions to predict future ranges and extinction risks, future climatic conditions are, according to the IPCC, likely to be radically different. In particular, atmospheric CO_2 concentrations are projected to be much higher, and rates of plant growth, water use efficiency, energy requirements of species, predator-prey relationships and, possibly, species-area relationships should all be different from what they are today (see, e.g., Thuillier et al. 2004; Guisan and Thuiller 2005; Schwartz et al. 2006; Araújo and Rahbek 2006). Fourth, future outcomes may also be confounded by unanticipated evolutionary changes (Botkin et al. 2007: 229–230, 234). Fifth, species may have broader climatic tolerances than indicated by their observed ranges (Malcolm et al. 2006). In addition, understanding of "trailing" edge dynamics, i.e., the ability of species to persist in established locations is poor (Hampe and Petit 2005, Tamis et al. 2005).

In a review paper on bioclimatic models in *BioScience*, Botkin et al. (2007) note:

> "Of the modeling papers we have reviewed, only a few were validated. Commonly, these papers simply correlate present distribution of species with climate variables, then replot the climate for the future from a climate model and, finally, use one-to-one mapping to replot the future distribution of the species, without any validation using independent data (Midgley et al. 2002, Travis 2003, Coulston and Riitters 2005, Hannah et al. 2005, Lawler et al. 2006). Although some are clear about some of their assumptions (mainly equilibrium assumptions), readers who are not experts in modeling can easily misinterpret the results as valid and validated. For example, Hitz and Smith (2004) discuss many possible effects of global warming on the basis of a review of modeling papers, and in this kind of analysis the unvalidated assumptions of models would most likely be ignored." (Botkin et al. 2007: 228)

Similarly, Dormann cautions that:

> "[T]he problems associated with the analysis of present distribution of species are so numerous and fundamental that common ecological sense should caution us against putting much faith in relying on their findings for further extrapolations" (Dormann 2007: 388).

A recent study comparing the predictive performance of sixteen bioclimatic models found that some of the most widely used models performed poorly (Araújo and Rahbek 2006). "[T]here is little consensus regarding the relative performance of these models …The models are based on some problematic ecological assumptions." Moreover, Randin et al (2008: 1557) also showed "that local-scale models predict persistence of suitable habitats in up to 100% of species that were predicted by a European-scale model to lose all their suitable habitats in the area."

Lack of resolution in the vertical scale can also lead to errors. In a comparison of model projections and observations for European butterflies, Luoto and Heikkinen (2008: 483) note that:

> "The inclusion of elevation range increased the predictive accuracy of climate-only models for 86 of the 100 species. The differences in projected future distributions were most notable in mountainous areas, where the climate–topography models projected only ca. half of the species losses than the climate-only models. By contrast, climate–topography models estimated double the losses of species than climate-only models in the flatlands regions. Our findings suggest that disregarding topographical heterogeneity may cause a significant source of error in broad-scale bioclimatic modeling."

This indicates that the modeling should be done at finer scales but, as noted, the finer the scale, the less reliable the climate change projections.

In a test of bioclimatic models, Duncan et al. (2009) tested whether bioclimatic models developed for five South African dung beetle species could predict the distribution of these species if they were transplanted to Australia. They found that for three of the five species, the models performed poorly, suggesting that climate determinism is no more valid for the rest of the natural world than it is for human beings. Similarly, Mittika et al. (2008) tested the ability of a bioclimatic model developed using European data for the map butterfly for range shifts in Finland, and found that it performed poorly.

In a recent paper on climate envelope models, recognizing the above shortcomings of bioclimatic models, Beale et al. (2008: 14908) noted that,

> "Because it is axiomatic that climate influences species distributions (8), the climate envelope approach of matching distributions to climate is intrinsically appealing. However, the use of such simplistic models is risky on both biological and statistical grounds: there are many reasons why species distributions may not match climate, including biotic interactions (10), adaptive evolution (11), dispersal limitation (12), and historical chance (13) … [T]here remains no quantitative information that would allow assessment of how well, or even if, species distributions match climate."

Accordingly they undertook a test of these models using data from three "high profile studies" (p. 14910). They found that results from such models were "no better than chance for 68 of 100 European bird species" (p. 14908), concluding that scientific studies and policies based on indiscriminate use of results of climate envelope methods "may be misleading and in need of revision" (p. 14908), specifically noting that a model that is "no better than a chance association… is certainly not a model that should inform policy." (Beale et al. 2008: 14910).

Similarly, in a study of 57 species of Spanish birds, Seoane and Carrascal (2008) found that half of the species exhibited positive population trends "which is good news from a conservation perspective" (p. 117) while only one-tenth showed a significant decrease (p. 111). Species that showed a "marked increase preferred wooded habitats, were habitat generalists and occupied warmer and wetter areas, while moderate decreases were found for open country habitats in drier areas" (p. 111). They conclude that:

> "The coherent pattern in population trends we found disagrees with the proposed detrimental effect of global warming on bird populations of western Europe, which is expected to be more intense in bird species inhabiting cooler areas and habitats. Such a pattern suggests that factors other than the increase in temperature may be brought to discussions on global change as relevant components to explain recent changes in biodiversity… These short- to medium-term population increases may be due to concomitant increases in productivity … Such patterns suggest that net primary production may be brought to discussions on global change as a relevant component to explain recent changes in biodiversity" (Seoane and Carrascal 2008: 111, 117)

While acknowledging some of these problems, the IPCC's 2007 WG II report (AR4WG2: 218). had claimed that:

> "these methods have nonetheless proved capable of simulating known species range shifts in the distant (Martinez-Meyer et al., 2004) and recent past (Araújo et al., 2005), and provide a pragmatic first-cut assessment of risk to species decline and extinction (Thomas et al., 2004a)."

But neither the Martinez-Meyer et al. nor the Araújo et al. studies cited by the IPCC dealt with periods during which CO_2 concentrations were as high as are projected for the future. Martinez-Meyer et al.'s test of ecological niche models was based on a comparison of species distributions under current conditions versus conditions that existed in the Last Full Glacial Period of the Pleistocene (from 14,500–20,500 years before present, BP), a period during which CO_2 concentrations probably did not exceed 240 ppm (Ahn and Brook 2008, Figure 1) . By contrast we are currently at 388 ppm and, if the IPCC projections are correct, could range from 730 to 1,020 ppm by 2100 (AR4WG1: 750).

Lapola et al. (2009) analyzed biome distribution in tropical South America under a range of climate projections and a range of estimates for the effects of increased atmospheric CO_2. Their results indicate that even if the CO_2 fertilization effect is halved, and is maintained in the long term, instead of large-scale die-back predicted previously for Amazonia, it overwhelms the negative effects of higher temperatures and any reductions in precipitation. On the other hand if the dry season exceeds 4 months — projected by two of fourteen AOGCMs — then large portions of Amazonia are replaced by tropical savanna.

Long term ecological monitoring of sites in Amazonia, however, suggests that CO_2 fertilization has indeed occurred in the forests. In a synthesis of long term ecological monitoring data across old growth Amazonia, Phillips et al (2008) find that from approximately 1988 to 2000 not only that the biomass of these tropical forests increased[10] but that they have become more dynamic, that is, they have more stems, faster recruitment, faster mortality, faster growth and more lianas. These increases have occurred across regions and environmental gradients and through time for the lowland Neotropics and Amazonia. They note that the simplest explanation for this suite of results is that improved resource availability has increased net primary productivity, in turn increasing growth rates, which can all be explained by a long-term increase in a limiting resource. They suggest that this no-longer-limiting resource might be CO_2, although other factors (e.g., insolation or diffuse radiation) may also play a role:

> "What kind of environmental changes could have increased the growth and productivity of tropical forests? Elsewhere we have discussed the candidate drivers in detail (Lewis et al. 2004a; Malhi & Phillips 2004; Lewis 2006). While there have been widespread changes in the physical, chemical and biological environment of tropical trees, the only change for which there is unambiguous evidence that the driver has widely changed and that such a change should accelerate forest growth (Lewis et al. 2004a) is the increase in atmospheric CO_2. The undisputed long-term increase in concentrations, the key role of CO_2 in photosynthesis, and the demonstrated effects of CO_2 fertilization on plant growth rates make this the primary candidate. However, a substantial role for increased insolation (e.g. Ichii et al. 2005) or aerosol-induced increased diffuse fraction of radiation (e.g. Oliveira et al. 2007) cannot be ruled out." (Phillips et al.: 1824).

Phillips et al.'s findings are consistent not only with Seaone ansd Carrascal's study of Spanish bird species but, more significantly, also with satellite data that indicate that the net primary productivity of the Amazon increased substantially from 1982–99, a period that experienced considerable global warming (see Figure 9; AR4WG1: 106; Myneni 2006: 5).

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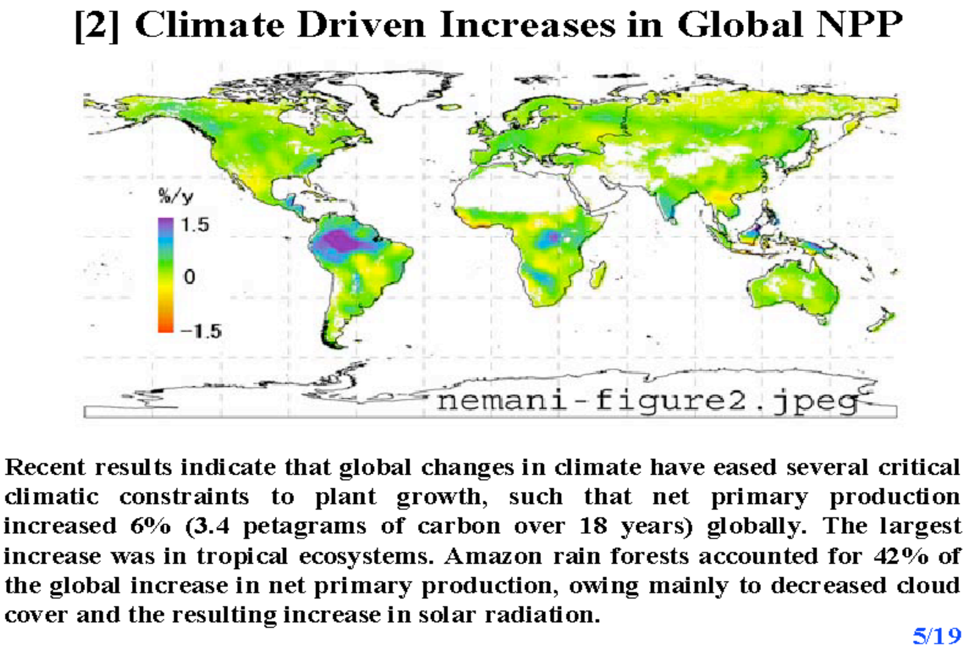
[10] Gloor et al. (2009), based on analysis of data from 135 forest plots in old growth Amazonia from 1971 to 2006 show that the observed increase in aboveground biomass is not due to an artifact of limited spatial and temporal monitoring. They conclude that biomass has increased over the past 30 years (p. 2427).



[2] Climate Driven Increases in Global NPP

Recent results indicate that global changes in climate have eased several critical climatic constraints to plant growth, such that net primary production increased 6% (3.4 petagrams of carbon over 18 years) globally. The largest increase was in tropical ecosystems. Amazon rain forests accounted for 42% of the global increase in net primary production, owing mainly to decreased cloud cover and the resulting increase in solar radiation.

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Figure 9: Climate driven changes in global net primary productivity. Source: Myneni (2006).

Using a mixture of observations and climate model outputs, Lloyd and Farquhar (2008), find no evidence that tropical forests are currently “dangerously close” to their optimum temperature range. They found that increases in photosynthetic rates due to CO_2 fertilization should over forthcoming decades more than offset any decline in photosynthetic productivity due to higher temperatures. They also found “little direct evidence that tropical forests should not be able to respond to increases in [CO_2] and argue that the magnitude and pattern of increases in forest dynamics across Amazonia observed over the last few decades are consistent with a [CO_2]-induced stimulation of tree growth.”

In addition, the AR4WG2 overstates its claim that Araújo et al. (2005) showed that bioclimatic models can simulate range shifts for the recent past. In fact, Araújo et al. found that:

> “Among the 74 British-bird species that contracted during the reported period, species were correctly projected to contract in … 50% of the models … For the remaining 42 species that expanded during the reported period, species were correctly projected to expand in 56% of the models ... In short, **assessment of all projections indicates a performance in terms of**

> **predicting the direction of range shifts no better than tossing a coin**." (p. 531; emphasis added).

To get around this problem, Araújo et al. (2005) recommend using a "consensual modeling" or "ensemble modeling" approach. Although the theoretical basis for such an approach is unclear, their study indicates that consensual modeling improved the correspondence between models and observation. However, it's not clear whether the IPCC's AR4WG2 results were based on the consensual or ensemble modeling approach, since neither term appears in conjunction with species or habitat modeling in its ecosystems chapter. Certainly, it was not used in the landmark Thomas et al. (2004) study cited by the IPCC above as providing a "pragmatic first-cut assessments of risk to species decline and extinction" (AR4WG2: 218). Notably this study is also a mainstay of FG's claims regarding the impacts of climate change on species and ecosystems (their reference 120).

In any case, the IPCC's claim that bioclimatic models provide a first-cut assessment is a stretch. And even if it does, that begs the question whether enough confidence can be attached to the results to use them as a basis for supporting trillion dollar policies, as opposed to generating hypotheses and testing sensitivities to different variables. This issue also needs to be addressed with respect to results based on ensemble modeling before using them for formulating policies.

Yet another problem with Thomas et al (2004) is that it modeled extinctions based on species-area relationship, which is based on the assumption that the number of species that can be supported on a piece of real estate would be reduced as the size of that real estate shrinks, based on a power law relationship.[11] However, recent studies suggest that habitat size may be a poor predictor of extinction In a study of 785 animal species in 1,015 population networks surveyed in 12,370 discrete habitat patches on 6 continents, Pruigh et al (2008) found that fragment size was a poor predictor of patch occupancy. Area alone accounted for a median of 13% of the deviance in occupancy (Pruigh et al. 2008: 20770), adding that the quality of the matrix surrounding the fragment may have a greater influence on occupancy and persistence.

In a recent paper in *Science*, Willis and Bhagwat (2009: 807) take note of Pruigh et al.'s study, adding that:

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[11] This power-law relationship is $S=cA^z$, where S is the number of species, A is area, and c and z are constants (Thomas et al. 2004: 145).

> "This ability of species to persist in what would appear to be a highly undesirable and fragmented landscape has also been recently demonstrated in West Africa. In a census on the presence of 972 forest butterflies over the past 16 years, Larsen found that despite an 87% reduction in forest cover, 97% of all species ever recorded in the area are still present … For reasons that are not entirely clear, these butterfly species appear to be able to survive in the remaining primary and secondary forest fragments and disturbed lands in the West African rainforest. However, presence or absence does not take into account lag effects of declining populations …" [Citations deleted.]

On the other hand, the loss of terrestrial and freshwater habitat to agricultural uses in particular, has generally been considered to be the most significant threat to global biodiversity (Goklany 1998, Millennium Ecosystem Assessment 2005). If that is the case, changes in cropland could either exacerbate or relieve the consequences of global warming. To the extent higher CO_2 concentrations, global warming, and human adaptive responses increase agricultural and forest productivity and water use efficiency (Idso and Brazel 1984; Gedney et al. 2006), the diversion of land and water to human uses would be reduced (Goklany 1998, 2003). Lower habitat loss would also conserve carbon stocks and sinks as well as migration corridors, a mechanism to aid species adapt to changed circumstances. Levy et al. (2004), for instance, indicate that because of increases in productivity due largely to CO_2 fertilization, under the IPCC's A1FI (warmest) scenario the amount of global cropland could decline from 11.6% in 1990 to 5.0% in 2100, substantially increasing the amount of habitat available to the rest of nature. Such reduction in cropland could also restore and preserve migration corridors. Similarly, if human adaptive responses free up more water for in-stream uses, that would reduce pressures on freshwater species. Thus at moderate levels of global warming, the overall pressure on biodiversity, ecosystems and species might well decline (Goklany 1998, 2001), only to increase once again if temperatures keep escalating, although higher CO_2 concentrations may help compensate for that (Lloyd and Farquhar 2008, Saurer et al. 2004).

4. Will the Deserts Expand and the Landscape Become Bleaker?

In the previous section, I showed that empirical data indicates that Amazonia and the world as a whole is greener today than it used to be. Notwithstanding that, one of the concerns regarding global warming is that deserts will expand, and that earth will be a bleaker place.

Popular wisdom is that, “Desertification, drought, and despair—that's what global warming has in store for much of Africa” (Owen 2009). However, satellite Imagery shows that parts of the Sahara and Sahel are greening up consistent with the trend recorded in Figure 9 (Owen 2009). The United Nations’ Africa Report notes:

> “Greening of the Sahel as observed from satellite images is now well established, confirming that trends in rainfall are the main but not the only driver of change in vegetation cover. For the period 1982-2003, the overall trend in monthly maximum Normalized Difference Vegetation Index (NDVI) is positive over a large portion of the Sahel region, reaching up to 50 per cent increase in parts of Mali, Mauritania and Chad, and confirming previous findings at a regional scale.” (United Nations 2008: 41).

Similarly, an Australia-wide analysis of satellite data for 1981–2006 indicates that vegetation cover has increased average of 8% (Donohue et al. 2009).

With respect to the northern latitudes, 22% of the vegetated area in Canada was found to have a positive vegetation trend from 1985–2006. Of these, 40% were in northern ecozones (Pouliot et al. 2009).

III. CHERRY PICKING CATASTROPHES & TIPPING POINTS

Advocates of strict greenhouse gas controls frequently argue that, unchecked, global warming might lead to catastrophes as various thresholds and “tipping points” are crossed. Favorite candidates for catastrophes are a “rapid collapse” of the Greenland Ice Sheet (GIS) and West Antarctic Ice Sheet (WAIS), which contain water equivalent to 21 meters of global sea level rise (FG: 118); a halting of the thermohaline circulation (also known as the Atlantic meridional overturning circulation, or MOC) which was the inspiration for the deep freeze depicted in the movie, *The Day After Tomorrow* (FG: 126); and the warming-induced melting of methane hydrates (known as clathrates) in the Arctic which would then increase methane in the atmosphere that would further reinforce the warming (FG: 118-119, 126).

Much of the rationale for considering such low-probability-but-potentially-high-consequence events can be traced to Weitzman’s estimate that “**eventually**” there could be, according to the probability density function (PDF) based on the IPCC's climate change estimates, a 5% probability that average global temperature increase (ΔT) will exceed 11°C and a 1% probability that it could exceed 20°C. However, as already discussed, these models have not been validated, and are, in fact, failing their validation. According to these models, global temperatures should have risen at least 0.2°C over the past decade but they have not (see Figure 6). This indicates that the sensitivity of ΔT to increases in carbon dioxide may have been, for whatever reason, substantially overestimated by the models and, therefore, Weitzman's (2008) probability estimates are overblown.

Weitzman (2008) used PDFs derived from 22 IPCC models, giving each one equal weight. These models subscribe to the same paradigm with respect to the influence of carbon dioxide on temperature, although they may differ on the magnitude of the temperature sensitivity. It is also not clear that these models do not share components, assumptions, parametrization and other features. So the 22 "models" may be more appropriately viewed as 22 variants of the same basic model. Equally important, alternate models such as those derived in Zhen-Shan and Xian (2007), Tsonis et al. (2007), Swanson and Tsonis (2009), and Loehle (2004 and 2009), which forecast a cooling period in the early 2000s, are not represented; nor are models incorporating Svensmark's theory of galactic cosmic rays (Knudsen and Riisager 2009), Lindzen and Choi's (2009) theory on feedbacks, or alternative specifications of the residence time of CO_2 in the atmosphere. If one is skeptical about these alternative models and formulations, they ought to be given lower weights, but to ignore them is inappropriate for the purposes of developing a PDF.

Note that while global warming studies sometimes make projections that extend to 2100 and beyond, to the extent the results are sensitive to socioeconomic factors —and IPCC's emissions and climate change estimates are driven by socioeconomic assumptions — one cannot and should not give them much credence (Lorenzini and Adger 2006: 74). In the following I will restrain my skepticism on this score.

In this section I will first look at the evidence that the potential catastrophes listed above are likely over the next century —a time horizon that goes well beyond what is reasonably foreseeable — before addressing broader issues associated with the advocates' appeal to catastrophism.

1. The Greenland Ice Sheet (GIS) and West Antarctic Ice Sheet (WAIS)

According to the IPCC's WG I Summary for Policy Makers (AR4WG1: 17) neither the Greenland nor West Antarctic Ice Sheets are in danger of melting away any time soon. Regarding the latter, it notes:

> "Current global model studies project that the Antarctic Ice Sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall."

With respect to the former, it also notes:

> "If a negative surface mass balance were **sustained for millennia**, that would lead to virtually complete elimination of the Greenland Ice Sheet and a resulting contribution to sea level rise of about 7 m" (emphasis added).

This statement, based on thermodynamics, applies equally well to the West Antarctic Ice Sheet. But whether one is concerned about the GIS or WAIS, what is the probability that a negative surface mass balance can, in fact, be **sustained for millennia**, particularly after considering the amount of fossil fuels that can be economically extracted and the likelihood that other energy sources will not displace fossil fuels in the interim, given claims of "peak oil," and that renewable energy sources are on the verge of paying for themselves?

Notably, Willersleev et al. (2007) found that during the Eemian (~ 125,000-130,000 yrs ago), a period during which average global temperatures were 3-5°C higher and sea level was 4-6 m higher than it is today [IPCC AR4WG1: 9], Greenland was much warmer, but still not ice free.

Second, for an event to be classified as a catastrophe, it should occur relatively quickly precluding efforts by man or nature to adapt or otherwise deal with it. But if it occurs over millennia, as the IPCC says, or even centuries, that gives humanity ample time to adjust, albeit at some socioeconomic cost. But as indicated by Figure 7, if the assumptions behind the IPCC's projections of global warming are valid, then humanity will be much wealthier in the future even after accounting fully for the effects of global warming, and the cost need not be prohibitive (see below).

More importantly, if it does take centuries or millennia, the toll on human life, limb and property may well be minor if: (1) the total amount of sea level rise (SLR) and, perhaps more importantly, the **rate** of SLR can be predicted with some confidence, as seems likely in the next few decades considering the resources being expended on such research; (2) the rate of SLR is slow relative to how fast populations can strengthen coastal defenses and/or relocate; and (3) there are no insurmountable barriers to relocation, if that is the preferred response.

This would be true even had the so-called “tipping point” already been passed and ultimate disintegration of the ice sheet was inevitable, so long as it takes millennia for the disintegration to be realized. In other words, the issue isn’t just whether the tipping point is reached, rather it is how long does it actually take to tip over and for its effects to be manifested. Take, for example, if a hand grenade is tossed into a crowded room. Whether this results in tragedy — and the magnitude of that tragedy — depends upon how much time it takes for the grenade to go off, the reaction time of the occupants, and their ability to respond.

Lowe, et al. (2006: 32-33), based on a “pessimistic, but plausible, scenario in which atmospheric carbon dioxide concentrations were stabilised at four times pre-industrial levels,” estimated that a collapse of the Greenland Ice Sheet would over the next 1,000 years raise sea level by 2.3 meters (with a peak rate of 0.5 cm/yr or 0.5 m per century). If one were to arbitrarily double that to account for potential melting of the West Antarctic Ice Sheet, that would result in total SLR of ~5 meters in 1,000 years with a peak rate (assuming the peaks coincide) of 1 meter per century.

A rise of 5 m/millennium would not be unprecedented. Sea level has risen 120 meters in the past 18,000 years, an average of 0.67 meters/century or 6.7 meters per millennium. It may also have risen as much as 4 meters/century during meltwater pulse 1A episode 14,600 years ago (Weaver et al. 2003). Neither humanity nor, from the perspective of millennial time scales, the rest of nature seem the worse for it. Coral reefs for example, evolved and their compositions changed over millennia as new reefs grew while older ones were submerged in deeper water (e.g., Cabioch et al. 2008). So while there have been ecological changes, it is unknown whether the changes were for better or worse. For a melting of the GIS (or WAIS) to qualify as a catastrophe, one has to show, rather than assume, that the ecological consequences would, in fact, be for the worse. Notably, such a showing is never explicitly made. It is generally assumed that an ecological change is necessarily worse for man and nature. This is theology, not reason.

Finally, history from the past several decades indicates that human beings can certainly cope with sea level rise of such magnitudes if they have centuries or millennia to prepare and adjust. In fact, if necessary, human beings could get out of the way in a matter of decades, if not years.

Can a relocation of such a magnitude be accomplished?

Consider that the global population increased from 2.5 billion in 1950 to 6.9 billion this year. Among other things, this meant creating the infrastructure for an extra 4.4 billion people in the intervening 59 years (as well as improving the infrastructure for the 2.5 billion counted in the baseline, many of whom barely had any infrastructure whatsoever in 1950). These improvements occurred at a time when everyone was significantly poorer. (Global per capita income today is 3.8 times what it was in 1950.[12]) Therefore, while relocation will, no doubt, be costly, tomorrow's much wealthier world ought to be able in theory to relocate billions of people to higher ground over the next few centuries, if that were necessary. In fact, once a decision is made to relocate, the cost differential of relocating, say, 10 meters higher rather than a meter higher is probably marginal. It should also be noted that over millennia the world's infrastructure will necessarily have to be renewed or replaced dozens of times, which effectively can help reduce premature losses of committed capital (and overall costs). For example, the ancient city of Troy, once on the coast but now a few kilometers inland, was built and rebuilt at least 9 times in 3 millennia.

2. Thermohaline Circulation

A popular myth about climate is that winters of Western Europe are mild relative to those of eastern North America because of the thermohaline circulation (THC), so-called because it is driven by differences in the density of seawater due to changes in temperature and salinity (salts are halides in Latin). The thermohaline circulation, sometimes called the "Great Ocean Conveyor Belt" or "Meridional (i.e., north-south) Overturning Circulation," conveys heat from the lower latitudes in warm surface waters towards the poles. The Gulf Stream (and its tentacle, the North Atlantic Drift), which is part of this circulation, moves heat from the tropics to the northeast Atlantic. This heat is picked up by the mid-latitude westerlies over the Atlantic

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[12] This is estimated using data from Maddison (2008), and World Bank (2009d). Per capita income in 1990 International dollars increased from $2,117 in 1950 to $7,725 in 2006 per Maddison (2008), and another 3.8% from 2006 to 2007 per the World Bank.

which warm western Europe. Thus as the surface water moves north, it cools. Some of it also forms sea ice, which increases the salinity of the remaining water. Both cooling and sea ice formation, therefore, increase the density of the water, which then sinks toward the ocean depths becoming part of the North Atlantic Deep Water. This deep water travels south across the Atlantic between the New and Old Worlds toward the Antarctic and then northward into the Indian Ocean or north east around Australia to the Northern Pacific where, mixing with warmer waters, it rises and generates a warm, counter-current close to the ocean's surface. The counter-current from the Pacific travels south and west through the Indonesian archipelago where it joins the countercurrent established in the Indian Ocean. It then goes around the Cape of Good Hope into the Atlantic, where it becomes, once again, part of the Gulf Stream.

One of the favorite doomsday scenarios about global warming is that melting of the Greenland Ice Sheet or the permafrost or increased runoff could inject extra freshwater in the North Atlantic which could, then, substantially halt the sinking of the water into the North Atlantic Deep, and halt the conveyor belt sending Europe, if not the world, into a deep freeze. This was essentially the premise behind the movie, *The Day After Tomorrow*. However, these fears seem to be overblown (Wunsch 2004; Kerr 2005).

First, most of the winter warming of Western Europe seems to be due to atmospheric circulation and seasonal release of heat stored in the ocean rather than heat transported by the ocean circulation (Seager et al. 2002; Weaver and Hillaire-Marcel 2004).

Second, Gregory and co-workers (2005) compared the response of the THC to a quadrupling of CO_2 concentrations over 140 years using 11 different models.[13] All the models indicated a gradual decline in the strength of the THCs by between 10 and 50 percent. However, none showed a rapid or complete collapse. None of the models shows a cooling anywhere that would more than offset any resulting warming.

These points were picked up in the IPCC WG I Summary for Policy Makers, which notes (AR4WG1: 16),

> "Based on current model simulations, it is very likely that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. The multi-model average reduction by 2100 is 25% (range from zero to about 50%) for SRES emission

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[13] See, also, Schmittner et al. (2005), which reports that 28 projections from 9 different coupled global climate models of a scenario of future CO2 increase projected a gradual weakening of the North Atlantic THC by 25(±25)% until 2100.

> scenario A1B. **Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases in greenhouse gases**. It is very unlikely that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence." [Emphasis added.]

Not much has changed since then. A shut down of the MOC doesn't look any more likely now than it did then. Based on observations spanning 1957-2004, Baehr et al.(2007) found "no MOC trend over the past 50 yr." Latif et al (2006) note that instead of a sustained THC weakening, "a strengthening since the 1980s is observed." Their "combined assessment of ocean hydrography data and model results indicates that the expected anthropogenic weakening of the THC will remain within the range of natural variability during the next several decades." Finally, Boyer et al. (2007) find that the "North Atlantic freshened from the 1950s to the 1990s but has since become more saline."

Clark et al. (2008: 316) offer the following summary:

> "… all available model simulations, including those with estimates of maximum Greenland Ice Sheet (GIS) melting rates, indicate that it is very unlikely that the MOC will undergo an abrupt transition during the course of the 21st century … 14 coupled models simulated a 100-year 0.1-Sv freshwater perturbation to the northern North Atlantic Ocean—17 times the recently estimated melt rates from the GIS—and the MOC weakened by a multimodel mean of 30% after 100 years; none of the models simulated a shutdown. Another model simulated greenhouse gas levels that increased to four times preindustrial values and then remained fixed; the resulting GIS displayed a peak melting rate of about 0.1 Sv, with little effect on the MOC. One model simulation uses the SRES A1B scenario but adds an additional 0.09-Sv freshwater forcing as an upper-bound estimate of potential GIS melting. In this case, the MOC weakened but subsequently recovered its strength, indicating that GIS melting would not cause abrupt climate change in the 21st century." [Citations deleted.]

Finally, if the slowing of the thermohaline circulation would only partially offset any global warming per the IPCC's assessment, then it could offset some of the consequences of global warming, such as extended heat waves, hypothetical increases in climate-sensitive diseases, or threats to biodiversity. Thus, such a slowing down, were it to occur, is more appropriately viewed as an "anti-catastrophe" than a catastrophe.

To summarize, as Carl Wunsch (2004), a climatologist at MIT, put it:

> “The only way to produce an ocean circulation without a Gulf Stream is either to turn off the wind system, or to stop the Earth's rotation, or both.
>
> “Real questions exist about conceivable changes in the ocean circulation and its climate consequences. However, such discussions are not helped by hyperbole and alarmism. The occurrence of a climate state without the Gulf Stream any time soon — within tens of millions of years — has a probability of little more than zero.”

3. Methane

Another global warming bogeyman is that warming might lead to release of methane from methane clathrates (or hydrates) stored in the Arctic permafrost which would increase its concentration in the atmosphere. But methane has a “global warming potential” averaged over 100 years of 25, that is, methane, ton-for-ton, is 25 times more powerful a greenhouse gas than carbon dioxide (AR4WG1 Technical Summary: 33). Thus, such releases of methane would constitute a positive feedback for global warming.

The initial concerns about methane stemmed from the fact that by the 1990s the atmospheric concentration of methane, which had been growing rapidly, had exceeded 1,730 parts per billion (ppb), almost twice the maximum amount measured over the past 650,000 years in ice cores (AR4WG1: 3).

Concern of runaway methane feedback was also stoked by a number of modeling studies which suggested rapid disintegration of the permafrost with global warming (e.g., Lawrence and Slater 2005, Zimov et al. 2006). However, in a modeling study which took into consideration the thermal profile of the permafrost, and the fact that the melting effect of warm air surface temperatures on the upper layers of permafrost would be countered by cooling due to colder deeper layers of permafrost, Delisle (2007) showed that “massive releases of methane in the near future are questionable.”

Even more compelling is that the growth in atmospheric concentrations has slowed substantially. As noted by the IPCC AR4WG1 (p. 796):

> “Recent measurements show that CH_4 growth rates have declined and were negative for several years in the early 21st century … The observed rate of increase of 0.8 ppb yr^{-1} for the

> period 1999 to 2004 is considerably less than the rate of 6 ppb yr^{-1} assumed in all the [IPCC] SRES scenarios for the period 1990 to 2000."

The latest observations indicate that the rate of change is not increasing, and that they "are not consistent with sustained changes … yet" (Dlugokencky et al. 2009: 4). They also indicate that the geographical pattern and the isotopic signature of methane increases suggests that the major sources are wetlands — probably tropical wetlands —rather than Arctic permafrost.

Petrenko et al. (2009) examined the source of isotopic methane in a glacial ice core from West Greenland to determine the probable source of the large increase in methane during the abrupt warming of +10±4°C that occurred during the transition from the Younger Dryas to the Preboreal (~11,600 years ago) (Grachev and Severinghaus 2005). They concluded that "wetlands were the likely main driver of the [methane] increase and that clathrates did not play a large role," a finding they noted "is in agreement with findings from previous ice core CH_4 isotopic studies" (Petrenko et al. 2009: 508). This study essentially reiterated the results of another paper by many of the same researchers that appeared in *Nature* the previous year (Fischer et al. 2008). Notably the Petrenko et al. study's publication was accompanied by an announcement titled, "Ancient Greenland methane study good news for planet, says CU-Boulder scientist" (Eureka Alert 2009).

So it seems that while methane emissions might increase if there is warming, there is no evidence of catastrophic releases from clathrates.

4. Selective Catastrophism

The foregoing examination of the three most frequently cited sources of climate change catastrophe indicates that there is no evidence that they are likely to occur, if at all, any time in the foreseeable future and, possibly, not even for centuries and millennia. Moreover, the approach embodied in FG toward potential catastrophes is fundamentally flawed in several respects.

First, it is selective about the potential catastrophes that it chooses to focus upon. But why consider some but not other potential catastrophes?

If one wants to develop rational policies to address speculative catastrophic events that might (or might not) occur over the next few centuries or millennia (e.g., melting of ice sheets, or the shutdown of the MOC), as a start one should consider the universe of potential catastrophes and then develop criteria as to which should be addressed and which not. Rational analysis must necessarily be based on a systematic review of catastrophes, and not on cherry picking one's favorite catastrophes. This means examining not only the catastrophes that additional warming may bring, but also the catastrophes that warming may avoid. It also means considering the possibility that over the time frame of interest (namely, centuries or millennia), an increasingly wealthy and technologically more sophisticated society will devise new technologies to negate, defuse or cope with any resulting catastrophe.

Specifically, absent global warming, the Little Ice Age (LIA) might return over the next few centuries or millennia. How can one make such a claim? For one thing, we know there was an LIA. It has been extensively documented in history, literature, and art (Fagan 2000; Lamb 1982), and that it ended around a century and half ago. Since it occurred in the past, history may indeed repeat itself, particularly if one considers timeframes of the order of centuries or millennia. Historical documentation indicates that the consequences of another ice age, Little or not, could range from the severely negative to the positive (if that would buffer the negative consequences of warming).

Second, so long as we are concerned about low probability events, we should also consider equally low or higher probability events that might either forestall these catastrophes on relatively short notice[14] or negate their impacts when the time comes. Specifically, it is quite possible — in fact, probable, considering the amounts being expended on research and development of such technologies — that somewhere between now and 2100 or 2200, technologies will become available that will deal with global warming much more economically and rapidly than currently available technologies. Such technologies may include ocean fertilization, carbon sequestration, other geo-engineering options (e.g., deploying mirrors in space), more efficient solar or photovoltaic technologies which would indeed pay for themselves, unlike current versions of these technologies which, being uneconomic, need

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[14] If one is concerned about catastrophes that might occur or unfold over centuries or millennia, "short notice" would be on the order of a century or so.

regulation or subsidies to "compete" in the market place, except under limited circumstances. In addition, it may include technologies that have not yet been conceived.

Similarly, there is a finite, non-zero probability that future new and improved adaptation technologies will substantially reduce the net adverse impacts of global warming. This has occurred over the past century for virtually every climate-sensitive sector that has been studied. For example, from 1900-1970, U.S. death rates due to various climate-sensitive water-related diseases — dysentery, typhoid, paratyphoid, other gastrointestinal disease, and malaria —declined by 99.6 to 100.0 percent (Goklany 2009b: 14). Similarly, over the centuries, poor agricultural productivity exacerbated by drought led to massive famines in India and China, killing millions (Davis 2001; Becker 1997). But such famines have not recurred since the 1970s despite any global warming, and notwithstanding the fact that populations are substantially higher today (Goklany 2009c: 104). Similarly, by the 2000s, deaths and death rates due to droughts, floods and other extreme weather events had dropped worldwide by 93–98% since they peaked in the 1920s (see Figure 8).

Third, a full analysis should also consider that greenhouse gas controls may themselves cause catastrophes. First, CO_2 not only contributes to warming, it is also the key building block of life as we know it. Human beings are 18% carbon (Mallery, undated), all of which can be traced directly or indirectly to vegetation created by the photosynthesis of CO_2. In fact, as shown in Figure 9, according to the IPCC WG I report (2007: 106), net primary productivity (NPP) of the global biosphere has increased in recent decades, partly due to greater warming, higher CO_2 concentrations and nitrogen deposition.

Increased NPP not only means more food for humanity, it also provides a double dividend for biodiversity and conservation. First, higher NPP means the biosphere can support greater and wider variety of species (e.g., Lloyd and Farquhar 2008; Seoane and Carrascal 2008). Second, by increasing agricultural and forest productivity it reduces the human demand for land, which is the single largest threat to biodiversity today (Goklany 1998; MEA 2005). Thus, there is a finite probability that reducing CO_2 emissions would have potentially severe negative consequences not only for the conservation of nature but also for the prospects of eliminating hunger.

There is also a finite probability that costs of GHG reductions could reduce economic growth worldwide which, then, may reduce the adaptive capacity of developing countries, which are generally acknowledged to be most at risk from global warming (Goklany 2000b). Even if only industrialized countries sign up for emission reductions, there could be negative economic consequences in developing countries because they derive a substantial share of their income from aid, trade, tourism, and remittances from the rest of the world (see Section V). Tol (2005) examines this possibility and although the extent to which that study fully considered these factors (i.e., aid, trade, tourism, and remittances) is unclear, it concludes (p. 577):

> "… for an emission abatement policy costing $1/tC, which is roughly the price of the Kyoto Protocol without the USA but with Russian hot air [,] Africa and Latin America would prefer money to be spent on development rather than on emission reduction—that is, their climate-change impacts fall further if money is invested in development rather than in abatement."

Finally, one of the problems with the argument that society should address low-probability-but-potentially-high-impact events is that that there is a much higher probability that the resources expended on addressing such problems would have been squandered. This would not be a problem but for the fact that there are opportunity costs associated with this, as demonstrated by the above quote from Tol.

According to the 2007 IPCC Science Assessment's Summary for Policy Makers (p. 10), "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." In IPCC parlance, "very likely" means that its authors believe there is at least a 90–95% likelihood that anthropogenic greenhouse gas emissions (AGHG) are responsible for 50-100% of the global warming since 1950, assuming that "most" denotes anywhere between 50–100%. In other words, anthropogenic GHGs are responsible for 45–95% of that warming.[15]

This means there is an up to 55% chance that resources expended in limiting global warming would have been squandered to little or no effect. Since any effort to significantly reduce global warming will cost trillions of dollars (see Nordhaus 2008: 82), that would be an unqualified disaster, particularly since those very resources could be devoted to reducing more urgent problems humanity faces here and now (e.g., hunger, malaria, safer water and sanitation) — problems we know exist for sure unlike the global warming bogeymen that may well be figments of the imagination (Goklany 2000, 2005, 2009a; Lomborg 2004, 2008)

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[15] The lower number is calculated as 50% of 90%, and the higher number as 100% of 95%.

According to estimates from the World Health Organization (2002) of the contribution of over 26 risk factors to the global burden of disease for 2000, global warming contributes less than 0.3% of the global mortality burden.[16] Not surprisingly, in 2000 it ranked below the top 20 global threats to public health—behind more mundane but much more consequential problems such as hunger (underweight), unsafe water and poor sanitation, vitamin A deficiency, poor nutritional intake, and indoor air pollution (Goklany 2009a: 70). Looking toward the future, on the basis of health impacts, global warming will continue to be outranked by other environmental and health risks through the foreseeable future (Goklany 2003, 2007b, 2009a).

It is critical to understand that the concern for opportunity costs is not merely theoretical. At the 2009 World Food Summit, developed countries rejected the U.N.'s call to commit $44 billion annually for agricultural development for developing nations, which would have helped reduce hunger for hundreds of millions. According to the Associated Press (2009*)*, the UN Food and Agricultural Organization's Assistant Director-General Alexander Mueller said that governments kept away from firm commitments to reduce hunger, "due to the economic crisis and **because they expect they will need to channel money to the developing world at next month's summit on climate change in Copenhagen**" (emphasis added).

Spending money on low probability catastrophes instead of problems we know exist for sure is like a starving man giving up a fat juicy bird in hand while hoping that he will catch other birds in the future even though he does not know whether those birds exist today or will exist in the future. It is rational only if one ignores opportunity costs, and advocates' appeal to potential catastrophes and tipping points only serves to tip the discussion from being based on rational analysis to one dominated by our fears.

IV. "THINGS ARE WORSE THAN EXPECTED/THOUGHT"

Proponents of drastic greenhouse gas controls frequently claim that "climate change is worse than we thought." (PBS 2006). The Lancet-University College of London Commission (2009: 1,701), for example, asserts (p. 1701) that "Work done after the IPCC 2007…found that CO_2

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[16] Although these estimates are based on suspect methodology (see Goklany 2009a: 70), by virtue of their provenance they have been very influential in the public policy debate. They were for example, picked up wholesale in a review article in Nature (Patz et al. 2005), and adopted by several influential reports, e.g., the report of the Lancet and University College London Institute for Global Health Commission (2009).

emissions growth rate increased from 1.3% to 3.3% every year, suggesting that the current carbon cycle is generating more severe climate change sooner than expected." Indeed, it is true that the spectacular economic growth across Asia and elsewhere was beyond most expectations in the 1990s, when the IPCC scenarios were formulated. But emissions increases should not be conflated with global warming. The relevant question is whether global temperatures and other more robust indicators of warming have risen more rapidly than anticipated in the IPCC (2007) assessment, or if the climate sensitive indicators of well-being have deteriorated faster.

The IPCC assessment estimated that if emissions stayed within the range of the IPCC scenarios, then global average temperature should increase 0.2°C per decade in the near term (AR4WG1: 12). Therefore, higher CO_2 emissions should, if anything, result in higher temperature increases. But neither the satellite (e.g., RSS 2009) nor surface temperature data (Hadley Centre 2009) show significant global warming since 2000, let alone an increase at a rate greater than the IPCC's projected 0.2°C per decade (see also Figure 6). Of equal importance is the fact that ocean heat content has not increased significantly in recent years (Dickey et al. 2008; Levitus et al. 2008), and sea level rise has slowed since 2003 (University of Colorado 2009).

A counter argument is that several of the highest global average temperatures have occurred in the 2000s. Whether this is the case, it is less remarkable than it seems because one would expect warm (or cold) years to occur in bunches due to the inertia of the climate system (that is, because of persistence).

Admittedly, the empirical trends cited above are based on short-term trends, but so is the claim that we should be more concerned because of a (short-term) increase in CO_2 emissions. More importantly, the divergence over the most recent decade between the IPCC's projections and empirical data with regard to global temperature anomalies coupled with reductions in ocean heat content and the rate of sea level rise at a time of unprecedented increases in CO_2 emissions, suggests that the sensitivity of climate to CO_2 emissions might have been overestimated in the models relied upon by the IPCC for its projections of future warming and its impacts, or that natural variability may be a larger influence on climate than acknowledged by the IPCC, or both. Some argue that this could be due to natural variability and that when natural variability swings the other way warming will return with a vengeance. See Section II. Perhaps that will happen, but it also means that reducing GHG emissions will have a much smaller influence than indicated by the IPCC models, and that greater attention should be focused on adaptation.

Also, as will be discussed in greater detail below (Section V.5), contrary to prognostications of GHG control advocates, climate sensitive indicators of human well-being have generally advanced over the long term despite any global warming. For instance, despite claims that hurricanes would get more intense if not more frequent, total accumulated cyclone intensity for a season are at historic lows (Maue 2009); instead of increasing, death tolls from extreme weather events have continued to decline (see Figure 8); property damage from cyclones has increased but only to the extent that more property is at risk (Pielke et al. 2008a, 2008b); generally, agricultural productivity is higher than ever while hunger is generally lower (notwithstanding an increase in the past couple of years because of increased demand in the fast developing Asian countries and diversion of crops to biofuel production) (Goklany 2007c, FAO 2008); and the world continues to get greener (Figure 9).

V. ECONOMIC SPILLOVERS

It is generally accepted that developing countries are more at risk from global warming than industrialized countries (see, e.g., UNEP 1993; Goklany 1995: 435). This is largely because: (a) global warming is projected to exacerbate the problems of poverty that currently afflict many developing countries, and (b) they lack the financial, technological and human resources needed to cope with these problems today (Goklany 2000; Lancet Commission 2009). The problems of poverty that are generally cited as worsening with global warming are malaria and other vector-borne diseases, hunger, water shortages, and vulnerability to extreme weather events and sea level rise. The IPCC, among others, claim that global warming could, therefore, hinder sustainable development of developing countries (AR4WG2: 13, 20). In a similar vein, FG argue that weak or poor governments may be swamped by the impacts of climate change such that their economic productivity would suffer, leading to economic instability which, in turn, would result in large — and negative — economic spillovers on the United States. The economic instability would, then, lead to political instability, breed terrorism and precipitate mass migration with adverse consequences for US's economic well-being and national security (see, e.g., FG: 134-137).

Implicit in the claims noted above is the notion that future adaptive capacity, particularly of developing countries, will not be much different from today. But as was discussed in Section II, this notion is inconsistent with the socioeconomic assumptions built into the IPCC's emissions and climate change scenarios.

No matter, FG claim (p. 138) that because of climate change, "First, and most obviously, trade flows will diminish." They suggest, for example, that:

> "… supply [of foreign products to the US] might be affected by severe economic and social dislocation in South and Southeast Asia caused by flooding, drought, and extreme weather events. Affected countries, including China and India, may be unable to maintain production levels in the face of these impacts. This sort of disruption in supply would lead to a rise in prices, which would be harmful to American economic welfare" (FG: 138–39; citations have been deleted).

Other factors that could "permanently reduce productivity levels" are a disruption of water or energy supplies due to global warming (FG: 139). They then argue that "Climate change also threatens to interrupt the free flow of trade in critical resources such as oil, gas, and other essential commodities on which the United States depends" (p. 147).

The arguments made by FG seem plausible if one ignores the fact that future adaptive capacity will most likely be substantially greater than it is today. They, moreover, rely on a surfeit of speculation as betrayed by their repeated appeals to readers to "imagine" the numerous ways by which global warming could lead to economic spillovers on the U.S. (emphases added):

> "Consider, for example, some obvious ways in which American interests are negatively affected by climate change abroad. **Imagine major economic downturns in the most important trading partners of the United States**, including Europe and China. **Now imagine that these downturns last decades**. What would be the effect on the United States? How would the United States be affected by violent conflict in the Middle East prompted by disputes over water resources? What if drought and disease, exacerbated by climate change, topple already unstable governments in Africa, creating safe havens for terrorist groups? What happens if migration pressures from Latin America increase dramatically as living conditions there deteriorate? Or if the emergence of contagious disease in Asia (recall the SARS scare in 2003) threatens to or actually comes to the United States? **None of these scenarios is particularly farfetched. Indeed, each of them is reasonably likely**. Each of them would also

> have a significant economic and/or political impact on the United States. Yet the possibility of such events is not taken into account by existing IAMs. As we show below, once one takes into account the likely spillovers from climate change, the costs to the United States are clearly much larger than typically portrayed." (p. 135-136)
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> "The inability to generate precise numerical estimates of the economic impact of climate change spillovers from other states does not mean, however, that they are unlikely to occur. Indeed, we can readily **imagine a number of channels through which events elsewhere might have an impact on the American economic system.** The discussion that follows **confirms the intuition** that American integration into the international economic system virtually guarantees that broad-based and substantial hardship abroad will lead to welfare losses in the United States." (p.138)
>
> "**Imagine, for example, how supply might be affected by severe economic and social dislocation** in South and Southeast Asia caused by flooding, drought, and extreme weather events." (p. 138-39)
>
> "**Imagine** a highly plausible scenario in which conflicts might arise over water resources in the Middle East or Nigeria, which affects the supply of oil to the rest of the world, including the United States" (p. 140)
>
> "**Imagine further what would be required to address the outbreak of infectious disease in Indonesia**, a country of 222 million people and seventy one airports (seventeen of which are international)." (p. 163)

In this section, I will examine whether these speculations are likely to transpire in the foreseeable future, which I define, very optimistically, as 2085–2100, despite Lorenzini and Adger's (2006) cautionary note. As part of this examination I will explore whether future adaptive capacity of developing nations will continue to be low, whether global warming would overwhelm economic development in developing countries, the effect of considering cross-sectoral impacts, and whether current trends indicate that developing nations are experiencing increasing impacts from disease, hunger, floods, droughts, and other extreme events, as some fear would occur in a warming world (FG: 147.) Based on this examination, I will address whether it is likely that global warming would in the foreseeable future cause economic instability in developing countries which might then destabilize weak governments in developing countries.

1. The Future Adaptive Capacity of Developing Nations

The lynchpin to FG's above thesis is that developing nations lack the adaptive capacity to cope with global warming. This may be true today if the impacts of global warming projected for the future are imposed on **today's** developing world because, for any given level of technology, adaptive capacity is determined by socioeconomic conditions (Goklany 2007a). But the real question is whether their adaptive capacity will continue to be low in the future under the socioeconomic conditions assumed under the scenarios used to generate future global warming. Figure 7 provides the answer.[17]

It shows that even if one adjusts future GDP per capita downward to account for the Stern Review's upper bound estimates of the damages of global warming, today's developing countries will be far wealthier in the future than they are today. As the discussion surrounding Figure 7 indicates, under the IPCC's warmest scenario, in 2100 the **net** GDP per capita (a proxy for wealth) in today's developing countries will, on average, be double that of the US in 2006, notwithstanding any global warming. In 2200, it will be triple that of the US in 2006. That is, by 2100, developing countries' adaptive capacity should be far greater than the US's today, even if one ignores the secular technological change that ought to occur in the interim (Goklany 2007a, 2009e). Accordingly the problems of poverty that would be exacerbated by global warming ought to be, more or less, history by then. These problems are generally not endemic to any nation with a GDP per capita more than a third that of the US today (WRI 2009). Tol et al. (2007) essentially confirm this in a paper that explores the sensitivity of deaths from malaria, diarrhea, schistosomiasis, and dengue to the level of global warming, economic development, and other determinants of adaptive capacity. Notably, their analysis ignored secular technological change, which would have reduced deaths from such diseases earlier (Goklany 2007a). Hence, FG's narrative that due to low adaptive capacity, global warming might cause economic or political instability around the world due to the cumulative impact on death, disease, extreme events and so forth, seems farfetched.

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[17] For the sake of brevity, the following discussion will focus on the warmest (A1FI) scenario, not because it's the most likely case — see the discussion surrounding Figure 6 — but because this is the one that is most feared.

However, some may argue that global warming will prevent developing countries from reaching the levels indicated in Figure 7. But Figure 7 takes global warming into consideration fully. In fact, for 2100 it starts with the IPCC's assumptions about economic growth between 1990 and 2100, and subtracts from that the most extreme estimates for the damages due to warming using a study that itself is considered by many economists to be an outlier (Tol 2008; see, also, Goklany 2007b: 1041, fn 11).[18] Thus, this counterargument fails.

Alternatively, it may be argued that the IPCC scenarios are not credible, that they overestimate developing countries' future level of economic growth. That may well be the case —recall Lorenzini and Adger's remark that socioeconomic scenarios "cannot be projected semi-realistically for more than 5–10 years at a time" (Lorenzini and Adger 2006: 74). But if the IPCC scenario assumptions for economic development are too high, then so are its emissions and climate change estimates because they are generated using those very assumptions. For internal consistency, one cannot use one level of economic growth to estimate emissions and climate change, but then ignore that economic growth in the estimation of future adaptive capacity. The failure to fully account for future adaptive capacity is endemic to the current generation of impacts assessments.

2. Cross-Sectoral Impacts

One of the arguments FG (p. 106) make is that cross-sectoral impacts of global warming are not considered, that cumulatively they could be more-than-additive. Although this sounds plausible, it's unclear whether that would indeed be the case.

Consider, for example, the case of energy in England. Once upon a time a good share of its energy was obtained from forests. Over time they got depleted, but England did not run out of energy —it turned to coal (Clay 1984: 47–48). If an analysis had been done of the forestry sector in the 16th and 17th centuries they would have shown that England's economy had exceeded "peak wood," and would sooner or later grind to a halt. But with the benefit of hindsight we know it did not because a new economic sector was created. Essentially the same story was repeated on the continent. Similarly, substitutions for numerous everyday products

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[18] For 2200, Figure 7 uses assumptions that are more conservative than the Stern Review. See Goklany (2009f).

have occurred over time with the substitutions coming from seemingly unrelated sectors. For example, clothing was once totally produced by the agricultural or hunting sectors, but today much of it comes from hydrocarbons (Goklany 2009e).[19] Notably, the movement toward both coal and hydrocarbons for energy, transportation, textiles, building materials, and synthetic fertilizers has reduced humanity's vulnerability to climate-sensitive natural resources, and helped insulate their economic well-being from climatic swings.

Moreover, as societies become wealthier, the share of GDP and employment that is dependent on climate-sensitive natural resource sectors — agriculture, forestry, fisheries — declines (Goklany 1992: 18-19). Thus, consideration of cross-sectoral effects would reveal that over time as societies become wealthier, they become more insulated from the effects of global warming. That is, "richer is more resilient" (Goklany 1999).

Thus, appropriate consideration of cross-sectoral impacts may reveal that their cumulative impacts may just as easily turn out to be less-than-additive as it could be more-than-additive. But just as no one could have forecast or modeled the above noted cross-sectoral substitutions a century in advance, neither can today's models forecast them with any confidence. This is yet another reason to be skeptical of models.

3. Global Warming and Development

On the issue of the relationship between global warming and sustainable development, the IPCC notes that sustainable development "can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways" (AR4WG2: 20). FG, on the other hand, dwell on the latter (downside) aspect of economic development while generally ignoring the upside. This raises the issue of whether global warming hinders sustainable development or does sustainable development make it easier to cope with warming, and which effect, if either, is predominant?

It is possible to answer these questions using results from the British-government sponsored "Fast Track Assessments" (FTAs) of the global impacts of global warming (Parry 2004; Arnell et al. 2002, 2004). From the point of view of proponents of greenhouse gas controls, these FTAs

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[19] Additional examples of technological substitutes for ecosystem services are provided in Goklany (2009e).

have an impeccable provenance. Many of the FTA authors were major contributors to the IPCC's Third and Fourth Assessments (IPCC 2001, AR4WG2 2007). For instance, the lead author of the FTA's hunger assessments (Parry et al. 1999, 2004), Professor Martin Parry, was the co-chair of IPCC Work Group 2 during its latest (2007) assessment. Similarly, the authors of the FTA's water resources and coastal flooding studies were also lead authors of corresponding chapters in the same IPCC's Fourth Assessment Report.

The FTAs provide estimates for 2085, which is realistically beyond what is reasonably foreseeable, for the contribution of global warming to the total populations at risk of malaria, hunger, and coastal flooding due to sea level rise. Goklany (2009a, 2009d) converted these estimates of populations at risk into mortality by comparing historical mortality estimates from the World Health Organization against FTA estimates of populations at risk for the base (1990) period. The results indicate that under the IPCC's warmest scenario — the so-called A1FI scenario, which gives an increase in average global temperatures of 4°C above 1990 levels — global warming would contribute no more than 13% of the total mortality from malaria,[20] hunger and coastal flooding in 2085 (Goklany 2009a: 71). The remaining 87% or more is due to non-global warming related factors.

However, had improvements in adaptive capacity been appropriately accounted for, the 87% contribution from the latter would have been much smaller, but then so would have the 13% share attributed to global warming (by a like amount).

FTA results also indicate that:

- By 2085, global warming would **reduce** the global population at risk of water shortages, although some areas would see increases (Arnell 2004; see Goklany 2009a: 72–74).[21]
- Partly due to increases in net primary productivity because of CO_2 fertilization, the amount of habitat devoted to cropland would be reduced by global warming under the A1FI scenario, at least through 2100 (Goklany 2007b). Since diversion of habitat to cropland is perhaps the single largest threat to species and ecosystems (Goklany 1998;

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[20] Malaria accounts for about 75% of the global burden of disease from vector-borne diseases (IPCC 2001: 463). Therefore , it serves as a good surrogate for the latter.

[21] This information is not readily apparent from the abstract in Arnell (2004), but see Goklany (2009a, pp. 72-74) and Oki and Kanae (2006).

MEA 2005), this means that global warming could actually **reduce** pressures on biodiversity (Goklany 1998; 2005).

All this shows that lack of economic development would be a greater problem than global warming, at least through 2085–2100. No less important, it is far cheaper to advance economic development than mitigate climate change (Goklany 2003, 2005, 2009d). This is essentially what Bjørn Lomborg's two Copenhagen Consensus (2004, 2008) exercises also find. It is also consistent with the Tol et al. (2007) analysis of various climate-sensitive infectious diseases. That analysis suggests that

> "[D]eaths will first increase, because of population growth and climate change, but then fall, because of development … As climate can only be changed with a substantial delay, development is the preferred strategy to reduce infectious diseases even if they are exacerbated by climate change. Development can … increase the capacity to cope with projected increases in infectious diseases over the medium to long term."

Thus, it is most unlikely that under the IPCC's warmest scenario, global warming will overwhelm economic development, notwithstanding the Stern Review's upper bound damage estimates. Second, economic development should be given priority over reducing greenhouse gas emissions.

4. Inconsistencies in the Economic Spillover Argument

The economic spillover argument is founded on the notion that the direct or indirect adverse impacts of global warming on the economies of the US's trading partners will, in turn, reduce the US's economic well-being. Folded within this argument is that global warming could reduce the US's ability to obtain oil and other natural resources by affecting, in one way or another, the production capacities of the world's oil and natural resource exporters (FG: 134–39).

However, if either economic output and/or oil consumption were to be reduced, greenhouse gas emissions and temperature estimates would also have to be lowered below what is assumed in the IPCC scenarios. Such outcomes would be internally inconsistent with the assumptions used to drive the IPCC scenarios. Moreover, such an adjustment would provide an albeit involuntary measure of self-correction to global warming.

Also, it is schizophrenic to lament the reduction of economic activity, which is a major driver of emission estimates, even as one is arguing for substantial and unilateral emissions control. Similarly, FG (p. 133) bemoan that "It is hard to believe, for example, that higher energy prices … will not affect agriculture costs."

It is also worth noting that FG (p. 147) claim that GW could affect the US's ability to obtain oil, natural gas and other resources. But were this to occur, it does not follow that reducing greenhouse gas emissions would be the most economically efficient solution. It could be more efficient to extract more of these resources from areas within U.S. jurisdiction, where these are abundant (CRS 2009).

Yet another inconsistency is one contained in the speculation that "conflicts might arise over water resources in the Middle East or Nigeria, which affects the supply of oil to the rest of the world, including the United States" (FG: 140). Such a scenario is unlikely if for no reason other than the fact that countries rich in hydrocarbons, having easy access to energy, would have no difficulty in resorting to desalination[22] or, alternatively, importing food which is tantamount to importing the water needed to grow it.[23]

5. Reality Check: Empirical Trends vs. Model Results and Other Claims

Much of FG's discourse is based on extrapolations from the results of impact modeling studies for periods 50–100 years or more into the future. In other cases, it is simply asserted or imagined that some adverse consequences could occur (see below). But as noted in the foregoing, little confidence can be placed on the model results because the socioeconomic assumptions used to drive emissions estimates are uncertain; the AOGCMs produce results that are not reliable for average temperature at less than continental scales even during the model calibration period, and they are even less reliable for precipitation; the AOGCMs have apparently overestimated temperatures for the latest decade; the biophysical and bioclimatic

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[22] Goklany (2007c: 362) notes that one of the barriers to desalination is that it is an energy intensive process, and that is why it is more prevalent in oil rich countries than elsewhere. Moreover the costs of desalination have been dropping.

[23] Water that is used to make a product is sometimes called "virtual water" (Hoekstra 2003, p. 13).

models have generally not been validated; and impacts models have done a remarkably poor job of accounting for changes in adaptive capacity.

In this subsection, I will compare recent (decades-long) empirical trends against model projections and assertions regarding the adverse impacts of global warming for various climate-sensitive aspects of human well-being.

Hunger. FG (p. 116 , fn 62) claim: "At lower latitudes, crop productivity is expected to decrease in any event, increasing the risk of hunger and famine." But, in fact, the portion of the developing world's population suffering from chronic hunger declined from around 33% in 1969-1971 to 16% in 2003-2005 (FAO 2009: 11). However, it increased to about 17% in 2008 and is projected to be higher for 2009, partly due to climate change policies that subsidize and/or mandate biofuels (FAO 2009: 11).

Disease. FG (p. 157) warn that, "The global disease burden will likely increase as a result of climate change." First, they argue that "the resources necessary to contain disease are likely to be less available, making the spread of contagious disease more probable." But the notion that there will be fewer resources available to deal with future problems in general and contagious diseases in particular is, as indicated by Figure 7 and discussed previously, completely inconsistent with the scenarios developed by the IPCC, even after accounting for the damages from global warming per the Stern Review's upper bound estimates.

FG's second argument is that global warming will increase the probability of pathogens causing more diseases (p. 157). They also argue that global warming impact estimates do not account for disease due to drought and famine, among other things (p. 157). But do empirical data show an overall increase in diseases over the past century, a period of warming?

First, average life expectancies around the world have increased from 31 years in 1900 to 47 years in the early 1950s to 69 years today (Goklany 2007c; World Bank 2009). For developing countries life expectancies increased from 25–30 years in 1900, to 41 years in the early 1950s and 69 years at present (Goklany 2009b). This indicates that for practical purposes, there has been less disease in aggregate, humanity is much better able to cope with diseases, or both. In any case, disease is less of a problem today than it used to be. In fact, in virtually every country, "health-adjusted" life expectancies currently exceed unadjusted life expectancies from just a few decades ago (Goklany 2007c: 40). In other words, we are not only living longer, we are also living healthier.

Second, contrary to what might be surmised from FG's claim, the ranges of the most critical climate-sensitive infectious diseases have actually shrunk despite any long term warming that may have occurred. Malaria, which as noted accounted for a disproportionately large share of the global burden of vector-borne disease, is a case in point. As indicated in Figure 10, the area in which malaria is endemic has been reduced substantially since the start of global warming. However, this figure does not show the rebound in malaria that occurred in the 1980s and 1990s due to a combination of poor policies (e.g., cessation of indoor spraying of DDT in many countries), development of resistance to drugs and insecticides, and a deterioration of public health infrastructure in many African countries coincident with a period during which their economies deteriorated and AIDS was ascendant (Goklany 2007c: 178–181). Since then, however, matters have, for the most part, been turned around. The Living Proof Project (2009: 3–4) reports that not only are malaria cases declining, but it is killing fewer people. For example, between 2001 and 2006, deaths from malaria declined by 45% in Rwanda, 50% in Cambodia, 76% in the Philippines, 80% in Eritrea and Zanzibar, and 90% in Sao Tome and Principe.

Third, FG's concerns regarding droughts and famines also seem misplaced considering that deaths and death rates from these events have declined markedly since the early 1900s (see below).

Droughts and Water Shortages. The possibility of water shortages leading to droughts and hunger are, understandably, recurring themes in the climate change literature (e.g., FG: 139). Droughts, which are a manifestation of severe water shortages, have plagued humanity from time immemorial, and deaths from droughts are probably the best indicator of the socioeconomic impact of such water shortages. In fact, droughts were responsible for the bulk (58%) of the global fatalities due to extreme weather events from 1900–2008 (Goklany 2009c: 104). However, long term trends in global deaths and death rates from droughts indicate that they peaked in the 1920s. Since then they have declined by 99.97% and 99.99%, respectively (Goklany 2009c: 104). Also, to the extent there is a concern that global warming might have reduced access to safe water, note that between 1990 and 2006 an additional 1.6 billion people gained such access (UN 2008: 42).

Floods and Extreme Weather Events. Data from 1900–2008, indicate that since the 1920s, cumulative annual deaths from all extreme weather events declined globally by 93% on average while the death rate dropped by 98% (see Figure 8; Goklany 2009c: 104). With respect to floods, the second most deadly form of extreme weather event, deaths and death rates crested in the 1930s. By 2000–2008, they were down by 98.7% and 99.6%, respectively (Goklany 2009c: 104). Notably, extreme weather events nowadays contribute only 0.06 percent to the global and U.S. mortality burdens in an average year, have, by and large, declined even as all-cause mortality has increased (Goklany 2009c: 102).

Clearly, the direction of long term empirical trends for aggregate hunger, disease, deaths from droughts, floods, and extreme weather events, are not consistent with what one would expect based on FG's narrative regarding the impacts of global warming. One factor contributing to the divergence between real world trends and model projections may be that, as discussed previously, the trend in average global temperature for the most recent decade is lower than what the IPCC had projected based on its "accepted" climate models. Yet another factor may be that the agencies responsible for anthropogenic greenhouse gas emissions are, in fact, also responsible for the increases in human well-being, as discussed in the next section.

It could be argued that the current trends described above do not show a deterioration in human well-being because temperature change is still in a zone where the net effects of global warming are positive, and it is only a matter of time before it does. That might, conceivably, turn out to be the case, but how can we be confident that it will in the foreseeable future and, if it does, that it will be due to anthropogenic greenhouse gas emissions in light of the problems with the concatenated system of models outlined in Sections II–IV? And how can we be confident that the moneys — and socioeconomic well-being — expended to control greenhouse gas emissions will provide benefits especially considering opportunity costs? In fact, analyses that accept the FTA results as given, indicate that human well-being is likely to advance faster, farther and with greater certainty through the foreseeable future if climate change policies focus on advancing development or otherwise addressing present day problems that might be exacerbated by global warming (Goklany 2005, 2009d).

6. Fossil Fuels and Long Term Advances in Human Well-Being

Goklany (2007c) ascribes the documented improvements since the start of the Industrial Revolution in virtually every objective measure of human well-being — poverty; life expectancy; infant, child and maternal mortality; prevalence of hunger and malnutrition; child labor; job opportunities for women; educational attainment; income —to a **Cycle of Progress** composed of the mutually reinforcing, co-evolving forces of economic growth, technological change and freer trade. And fossil fuels have been integral to each facet of this cycle. Without the energy generated by fossil fuels, economic development would be much lower, many of the technologies that we take for granted and have come on line since the dawn of industrialization (e.g., devices that directly or indirectly use electricity or fossil fuels) would have been stillborn, and the current volume of internal and external trade would be impossible to sustain. Even trade in services would be substantially diminished, if not impossible, without energy to generate electricity to power lights, computers, and telecommunications.

In fact, no human activity is possible without energy. Every product we make, move or use requires energy. Even human **inactivity** cannot be sustained without energy. A human being who is merely lying around needs to replenish his energy just to keep basic bodily functions operating. The amount of energy needed to sustain this is called the basal metabolic rate (BMR). It takes food — a carbon product — to replace this energy. Insufficient food, which is defined in terms of the BMR, leads to starvation, stunting, and a host of other physical and medical problems, and, possibly, death.

Fossil fuel powered technologies underpin much of the economic development and associated improvements in human well-being that have occurred since the Industrial Revolution, as described in the following:

<u>Hunger</u>. Global food production has never been higher than it is today due to fertilizers, pesticides, irrigation, and farm machinery. But fertilizers and pesticides are manufactured from fossil fuels, and energy is necessary to run irrigation pumps and machinery.[24] This entire suite of energy-dependent technologies also enabled the Green Revolution. And in today's world,

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[24] "A much less recognized connection between water and energy are the vast amounts of energy used to treat, distribute, and use water. Water is heavy (1 liter weighs one kilogram), so moving it requires a lot of energy. Energy needs are particularly high for places where water is pumped from very deep wells, or where it is piped over long distances and steep terrain. Additionally, heating water is energy-intensive. In California, for example, 19% of the electricity use, 33% of the non-electricity natural gas, and 33 million gallons of diesel consumption is water-related." (UN Global Compact 2009, p.4).

willy-nilly, energy for the most part means fossil fuels. Additional CO_2 in the atmosphere has most likely also contributed to higher food production (IPCC 2001: 254–257, 285) because it provides carbon, the basic building block of life. Another factor critical to reining food prices and reducing hunger worldwide is trade within and between countries which enables food surpluses to be moved to food deficit areas (Goklany 1995, 1998). But it takes fossil fuels to move food around in the quantities and the speed necessary for such trade to be an integral part of the global food system, as it indeed is. Moreover, fossil fuel dependant technologies such as refrigeration, rapid transport, and plastic packaging, ensure that more of the crop that is produced is actually consumed. That is, they increase the overall efficiency of the food production system, which helps lower food prices and contain hunger worldwide, while reducing the amount of land under cultivation and helping conserve nature (Goklany 1998).

Health. Having sufficient quantity of food is the first step to a healthy population. It's not surprising that hunger and high mortality rates go hand in hand. In addition, even the most mundane medical and public health technologies depend on energy, most of which is derived from fossil fuels. Such technologies include heating for sterilization; pumping water from water treatment plants to consumers and sewage to treatment plants; and transporting and storing vaccines, antibiotics, and blood. In addition, energy is necessary to operate a variety of medical equipment (e.g., x-rays, electrophoresis, and centrifuges); or undertake a number of medical procedures. Moreover, economic surpluses generated by greenhouse gas producing activities in the US and other industrialized countries have helped create technologies to enable safer drinking water and sanitation; develop solutions and treatments for diseases such as AIDS, malaria, tuberculosis; and increase life expectancies through vaccinations and improvements in nutrition and hygiene (Goklany 2007c).

Child Labor. Fossil fuel powered machinery has not only made child labor obsolete in all but the poorest societies, but it allows children to be children and, equally importantly, to be more educated in preparation for a more fulfilling and productive life (Goklany 2007c).

Equal Opportunity for Women and the Disabled. But for home appliances powered for the most part by electricity, more women would be toiling in the home. Moreover, power tools and machinery allow women, the disabled and the weak to work on many tasks that once would have been reserved, for practical purposes, for able-bodied men. It also expands their options for employment and economic advancement.

Education. Today's populations are much more educated and productive than previous ones in large part due to the availability of relatively cheap fossil fuel generated electrical lighting. And education is a key factor contributing not only to economic development and technological innovation but also personal fulfillment (Goklany 2007c, 2009c).

Poverty. A substantial share of the income of many developing countries comes directly or indirectly from trade, tourism, developmental aid (to the tune of at least $2.3 trillion over the decades; Easterly 2008), and remittances ($338 billion in 2008 alone; World Bank 2009c) from industrialized countries. Moreover, it would be impossible to sustain the amount of trade and tourism that occurs today without fossil fuels. These factors, acting together, have helped halve the proportion of the developing world's population living in absolute poverty (i.e., living on less than $1.25 per day in 2005 dollars) from 52 percent in 1981 to 25 percent in 2005 (World Bank 2009a). Much of this would have been impossible but for the wealth generated in industrialized countries by fossil fuel powered economic development. Ironically, higher food prices, partly because of the diversion of crops to biofuels in response to climate change policies, helped push 130-155 million people into absolute poverty in 2008 (World Bank 2009b: 5). This is equivalent to 2.5–3.0% of the developing world's population.

Disaster Preparedness and Response, and Humanitarian Aid. Timely preparations and response are major factors that have contributed to the reduction in death and disease that traditionally were caused by or accompanied disasters from extreme weather events (Figure 8). Their success hinges on the availability of fossil fuels to move people, food, medicine and critical humanitarian supplies before and after events strike. Economic development also allowed the US (and other developed countries) to offer humanitarian aid to developing countries in times of famine, drought, floods, cyclones, and other natural disasters, weather related or not. Such aid, too, would have been virtually impossible to deliver in large quantities or in a timely fashion absent fossil fuel fired transportation.

Clearly, fossil fuels have advanced human well-being in both industrialized and developing countries. Not surprisingly, human well-being has advanced across the board despite any global warming that may have occurred since the inception of the Industrial Revolution (Goklany 2007c, 2009b).

7. Will Global Warming Cause Economic Instability in the Developing Counties?

To summarize the foregoing, if the IPCC's warmest emission scenario is to be given credence and one adopts the Stern Review's upper bound estimates of global warming damages, then well before 2100 the adaptive capacity of developing countries should on average exceed that of the US today. Accordingly, while global warming will have impacts on developing nations, it seems unlikely that they will, over the foreseeable future, cause economic instability. There is nothing in the empirical record that contradicts these findings.

VI. NATIONAL SECURITY SPILLOVERS

FG (pp. 146-47), drawing upon reports by the Center for Strategic and International Studies and the Center for a New American Security (2007) and Fingar (2008), amongst others, claim that climate change is a "threat multiplier" with respect to the US's national security (p. 146–47). They argue that economic instability due to global warming could lead to political instability around the world, which would adversely affect US economic interests, breed terrorism and spark mass migration with substantial negative consequences for US's economic well-being and national security (FG: 134-137). In their view:

> " … climate change is likely to exacerbate political instability around the world as weak or poor governments struggle to cope with its impacts.[202] In especially hard hit nations, deteriorating economic conditions could lead to the fall of governments, creating, at worst, safe havens and, at best, fertile recruiting grounds for terrorist groups. Floods, droughts, and conflicts over scarce resources are projected to create refugees—'climate migrants'—who will spill into neighboring countries, potentially inflaming political tensions and burdening the already-stressed economies in these host nations.[203] Climate change also threatens to interrupt the free flow of trade in critical resources such as oil, gas, and other essential commodities on which the United States depends. Such threats will require the United States to take costly action to protect itself. However, even with such action, the United States almost certainly cannot avoid all of the significant negative effects." (FG: 147.)

They point to the vulnerability of Bangladesh, China, India, and Africa as examples (FG: 148-150). They argue that:

> “With high risk of impact and low adaptive capacity, Africa stands to fare badly as global temperatures increase.[221] One might take the view that much of the suffering in Africa will not affect the United States unless we are inclined to support humanitarian relief,[222] yet this overlooks the increasing strategic importance of the continent. Africa possesses critical natural resources over which there is increasingly intense competition,[223] and various countries in Africa pose a risk to the United States as potential bases for terrorist groups.”

The above arguments all rest on the premise that global warming will lead to economic instability which, then, will lead to political and social instabilities. But, as shown in the previous section, the likelihood of a global warming caused economic instability is low, and, therefore, so is the likelihood of any descent into political and social instability, terrorism, and mass migration. In the foregoing, I also addressed claims specifically related to the impact of global warming on drought and water shortage, floods, hunger, and disease. In this section, instead of revisiting these issues, I will examine additional aspects related to the proposition that global warming could lead to water wars and other conflicts, and set off mass migration.

1. Water Wars

As noted in Section V, the FTA's water resource analysis, despite completely ignoring consideration of any autonomous adaptations, showed that global warming may well reduce the net global population at risk of water shortage, although some areas might experience greater shortage. This subsection will focus on the latter set of the world population.

Water is critical for growing crops and, worldwide, agriculture is responsible for 66% of the freshwater withdrawals and 85% of freshwater consumption (Goklany 2002). So water shortages, if any, are likely to have the greatest effect on agricultural production and on in-stream uses such as species conservation, fish, and recreation. Thus, the theory that water shortages could lead to food shortages in some areas, which could then exacerbate other societal problems and lead to economic and political instability, is very plausible.

Nordas and Gleditsch (2007: 631) note that, "There is, indeed, a literature that suggests a potential for water wars (see e.g. Gleick, 1993; Renner, 1996; Klare, 2001)," but then they add:

> "… other writers are very skeptical (Beaumont, 1997; Wolf, 1999). A statistical study finds that neighboring countries that share rivers experience low-level interstate conflict somewhat more frequently (Gleditsch, Furlong, Hegre, Lacina, & Owen, 2006), but a companion study finds that they also tend to cooperate more (Brochmann & Gleditsch, 2006). Yoffe, Wolf, and Giordano (2003) argue that cooperation consistently trumps conflict in handling shared international water resources."

This is essentially what the Nobel Prize winning economist, Elinor Ostrom finds, namely, that despite the potential for conflict, diverse cultures and societies have evolved institutions at different times to manage and allocate water (as well as other resources) without resorting to armed war (Ostrom 1990).[25]

There is, in fact, considerable scope for addressing water shortages short of resorting to armed conflict. Water conservation can help defuse the desire to go to war. Measures available to help societies cope with water stress include institutional reforms that would treat water as an

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[25] Similarly, with respect to fisheries, Nordas and Gleditsch (2007, p. 631) note that: "… on the issue of shared fisheries resource, also raised by the IPCC, Myers (1996: 9) notes that nations bordering on the North Atlantic have gone 'to the edge of hostilities over cod stocks'. But of course, the so-called 'cod wars' or 'turbot wars' (Soroos, 1997) of the North Atlantic are remarkable for their lack of interstate violence. Coast guard and naval forces have been involved in these disputes, but so far not a single casualty has been reported."

economic commodity by allowing market pricing and transferable property rights to water. Such reforms should stimulate broader adoption of existing but underused conservation technologies and lead to more private-sector investment in R&D, which would reduce water demand by all sectors. In addition, since future societies are expected to be substantially wealthier (see Figure 7), they should be better able to afford conservation technologies (e.g., technologies to enable precision agriculture or bioengineered seeds for drought resistant crops) as and when they become available (Goklany 2007c). Other technological fixes include desalination, the costs of which have been coming down (Goklany 2007c: 362), and recycling used water, which is becoming more acceptable (Goklany 2009d). Moreover, importing food, for practical purposes, "imports" the water that is used to grow that food. A variant of this approach is to outsource food production to area that have sufficient water resources (and arable land), as Indian and Saudi Arabian interests have started doing in Ethiopia (McCrummen 2009). Notably, a reduction of 18 percent in agricultural water consumption would, on average, double the amount of water available for all other uses (Goklany 2005).

FG (pp. 140, 150) also raise the specter of water shortages in the Middle East and Nigeria that could contribute or lead to conflicts and impact oil supplies. But these countries have access to energy to desalinate seawater, and many of them already have considerable experience with desalination. Of the more than 120 countries that employ desalination, it is most prevalent in oil producing countries that are also short on freshwater (Goklany 2007c: 362). And, it seems more than likely that the oil-rich countries would be able to import food, and other resources that they may lack. So if there is any war, terrorism or mass migration from oil producing countries, it will not be because of global warming.

Barnaby (2009: 282), writing in Nature, informs us that:

> "There are 263 cross-boundary waterways in the world. Between 1948 and 1999, cooperation over water, including the signing of treaties, far outweighed conflict over water and violent conflict in particular. Of 1,831 instances of interactions over international freshwater resources tallied over that time period (including everything from unofficial verbal exchanges to economic agreements or military action), 67% were cooperative, only 28% were conflictive, and the remaining 5% were neutral or insignificant. **In those five decades, there were no formal declarations of war over water**." (Emphasis added.)

Her conclusion:

> "It is time we dispelled this myth [of 'water wars']. Countries do not go to war over water, they solve their water shortages through trade and international agreements… Cooperation, in fact, is the dominant response to shared water resources." (Barnaby 2009: 282)

In the future, as countries become wealthier, they will be better able to obtain and utilize technologies to wring the most out of every drop of water, and recycle and reuse water over and over again if the alternative is war.

2. Migration and Climate Refugees

The specter of mass migration (FG: 135–37), like that of water wars, may be exaggerated. It stands to reason that migration is one option that people might use to deal with natural disasters, but it is unlikely to be the option of choice (Perch-Nielsen 2008: 381). It is more likely to be an option that is exercised after all other reasonable options have been exhausted. Therefore, the greater the adaptive capacity, the lower the likelihood of migration. Also, most migration is probably temporary (Perch-Nielsen 2008: 381) and local (Gilbert 2009).

Second, to the extent migration is motivated by economics, the incentive for migration from developing countries to the developed world may go down if the relative gap between the two groups were diminished, as they should per Figure 7. Reinforcing the reduction in migration pressure is the fact that the marginal utility of an extra dollar should go down as people get wealthier. This, for example, is one of the reasons why the Human Development Index uses the logarithm of per capita income rather than per capita income as one of its components (see Goklany 2007c: 53). Remarkably, as reported by *Nature*, estimates that between 200 million to 1 billion people may migrate by 2050 are "based on assumptions that are simplistic, if not outright dodgy." (Gilbert 2009).

It is also worth noting that implicit in FG's fears of mass migration is the notion that immigration fueled by mass migration would be unwelcome in host countries. But not all people in the host countries will necessarily be xenophobes, and there is an alternate narrative. Currently (2005–10), total fertility rates (TFRs) in 43 out of the 53 developed countries are below replacement rates, i.e., each woman of child bearing age has less than 2.05 children (WRI 2009). The average TFR for all developed countries is 1.69. Their populations are aging.

Similarly, 22 of 169 developing countries also have TFRs below 2.05, including the heavyweight, China, the two Koreas, and Thailand. To the extent these countries have social security nets for the elderly, they are already under stress (Goklany 1995: 434), and their elderly will need day-to-day help to take care of themselves, but because of the low TFR the countries could become depopulated, as is currently happening in Russia (World Bank 2009d). These countries may, in due course of time, welcome mass immigration as the solution to these problems. Conceivably, robots and other technologies could help meet some of the needs of the elderly, but one suspects that even a xenophobe might prefer a human touch, even if it's alien.

3. Conflicts

Water is not the only imagined source of conflict. Other contributing sources could include shortages of food and other critical resources. But as discussed in Section V, the adaptive capacity of future societies should be much higher, and it does not follow that low agricultural production in a country would necessarily lead to food shortages. This is because there is much more to maintaining or increasing food production than just agricultural productivity or, for that matter, expanding land under cultivation. As noted elsewhere, food production can be increased by reducing pre- and post-harvest crop losses, and reducing food losses at every step in the food chain from farm gate to the consumer's plate (Goklany 1998: 948–49). More importantly, trade and an increase in people's purchasing power allows non-producers and/or consumers in even food deficit areas to import food from areas with surpluses (Goklany 1995, 1998, 2009c: 104). This combination of factors helps explain trends over the last century that indicate major declines in hunger, and deaths due to droughts, which historically used to result in food shortages (see Sections V.5 and V.6). Deaths from droughts, for instance, declined by almost four orders of magnitude since the 1920s (Goklany 1998, 2009c: 104) and if the purchasing power of populations increases per the IPCC's scenarios (see Figure 7), it is likely to decline further. A destabilized world due to global warming induced famine and food shortages is farfetched.

There is also some literature that has looked at climate and conflicts. Zhang et al. (2007), in an analysis of China during the Little Ice Age (1400 AD–1900 AD) found that there were more conflicts during colder times in China. They note that cooling reduced agricultural production, which then led to a successive series of social problems: inflation followed by war, famine, and population decline. Tol and Wagner (2009), in a study of European conflicts during the second millennium find that conflict was more intense during colder periods. However, this relationship weakens in the industrialized era, presumably, partly due to increased adaptive capacity. They speculate that since the correlation is weakening, global warming would not lead to an increase in violent conflict. On the other hand, Burke et al (2009) find that warming has led to increased civil conflict in Africa for the 1980–2002 period.[26] However, it's unclear whether any of these studies would be relevant and applicable to the future risk of conflict since the socioeconomic conditions built into the IPCC scenarios are substantially different from what existed during the historical situations studied in these papers (see Figure 7).

Nordas and Gleditsch (2007: 635) note that despite increases in arguments that the effects of climate change are unfolding in conflicts in Africa and in Darfur in particular, the number of state-based armed conflicts have declined by one-third since their peak just after the end of the Cold War. They note that the severity of conflict, as measured by battle deaths, has declined worldwide since World War II, and there has been a decline in the number of conflicts in sub-Saharan Africa in the past decade. They conclude that:

> "While it is possible that climate change may lead to more conflict in the future, it has not so far caused a reversal of the current trend towards a more peaceful world." (Nordas and Gleditsch 2007: 631).

Adding to this trend is the fact that the global decline in birth rates signals that there will be fewer adolescents and young people in the future, which could mean that there would be fewer people eager to engage in armed conflict for a variety of reasons (Urdal 2006: 624).

Also, as TFRs go down, children and young adults become scarcer and more valuable assets for every country, and the body politic will be loathe to sacrifice them in armed conflict if alternate arrangements can be made.

VII. CONCLUSION

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[26] This study seems to have overlooked any confounding effects from the advent of AIDS, and the increase in the youth population during the 1980s (see Urdal 2006).

Like some advocates of aggressive GHG controls, FG argue that the costs of global warming to the US have been substantially underestimated; that a proper accounting would consider non-market impacts, the cost of catastrophe, and the fact that floods, droughts, famine and rising seas driven by global warming would create economic and political instabilities in countries with low adaptive capacity; and that these impacts entail economic and national security spillover costs for the US. They argue that such an accounting would show that aggregate costs to the US are sufficiently high so as to warrant unilateral GHG cuts by the US. This paper has shown that this proposition is fundamentally flawed, with little or no empirical support.

Contrary to FG's claims, model projections of the impacts of future global warming are not underestimated. First, over the past decade, surface global temperatures have been more or less flat despite IPCC model results that had projected an increase of at least 0.2°C (Figure 6). This may be due to the fact that climate models, which have not been validated, have been developed and calibrated using surface temperature data that some studies indicate might be biased upward, for whatever reason. Such models would have a tendency to overestimate, rather than underestimate, temperature change, and any resulting impacts of global warming (Section II.1).

That model results diverge from reality ought not to be a surprise. These models, as the IPCC admits candidly, are unable to accurately reproduce average temperature at less-than-continental scale, and their ability to reproduce precipitation is worse. In addition, there are major features of the climate that they cannot reproduce endogenously. Therefore, they are, at best, imperfect representations of the climate system (Section II.1). So if they are unable to reproduce the past with much accuracy, why should one expect them to accurately foretell the future?

Second, the current crop of impact assessments ignore or underestimate the increases in adaptive capacity that ought to occur as societies become wealthier per the IPCC's emissions and climate change scenarios. Even after accounting for upper bound estimates of losses in welfare due to global warming per the pessimistic calculations of the Stern Review (which consider not only direct impacts of warming but also losses due to non-market impacts and the risk of catastrophe), average net GDP per capita of industrialized countries in 2100 will be triple that of the US in 2006 under the IPCC's warmest scenario (Figure 7). For developing countries, average net GDP per capita will be double that of the US in 2006. Therefore, because of economic development alone, the average country's adaptive capacity should far exceed that of the US's today. On top of that, future societies will have superior technologies at their disposal. But these factors are generally overlooked or underestimated in the vast majority of impacts assessments. As a result, not only are these assessments internally inconsistent with the economic assumptions used to generate the IPCC's emissions and global warming scenarios, they substantially overestimate the net negative consequences of global warming. Historical analogies indicate that failure to fully account for increases in adaptive capacity due to economic and technological development can, over decades, overestimate net negative impacts by an order of magnitude or more (Section II.2).

Nevertheless, even under the IPCC's warmest scenario (which gives a temperature increase of 4°C beyond the 1990 level in 2085) and despite insufficient consideration of advances in future adaptive capacity, the contribution of global warming to the major problems facing humanity and the environment would, through the foreseeable future, be small relative to that of other factors. Specifically, global warming should (a) be responsible for less than a seventh of all deaths from hunger, malaria, and coastal flooding, (b) reduce the global population at risk of water shortage, and (c) increase the net primary productivity of the biosphere which should make more habitat and food resources available to both mankind and the rest of nature (Section V.3). This indicates that while global warming may be a problem, in some circumstances it may be also be a solution even under a global temperature increase of 4°C. In any case, it is not a first rank problem through the foreseeable future. Thus it does not merit extraordinary efforts, as is suggested by proponents of drastic GHG controls, so long as today's urgent problems remain unsolved.

FG also argue that non-market impacts, specifically, impacts on ecosystems and species, are generally ignored in cost-benefit analyses of global warming, and point to several modeling studies which indicate that it could cause major species losses and extinctions. However, these results are generally based on bioclimatic models that that use as inputs the uncertain outputs of unvalidated climate models. Equally importantly, the bioclimatic models generally have not been validated either, and have been shown to perform poorly, particularly at the spatial scales that are relevant to identifying species habitats and ranges (Section II.3).

They also ignore the fact that the models were developed using current conditions but future CO_2 concentrations and climatic conditions are going to be radically different. This alone would affect the rates of plant growth, water use efficiency, energy requirements of species, predator-prey relationships and, possibly, species-area relationships. Nor do the models consider evolutionary changes, or that species may have broader climatic tolerances than indicated by their observed ranges. No less important, they ignore the fact that there are other, more important threats to habitat and species that would be modified by additional CO_2 levels and the climate. Specifically, the major current threats to ecosystems and biodiversity are diversion of terrestrial habitat and freshwater to agriculture. But in the future, increased productivity, partly due to higher atmospheric CO_2 concentrations — a precursor to global warming — could reduce today's major threats by reducing human demand for cropland and timberland (Sections II.3 and V.3).

Moreover, while model results may be used to paint a bleak ecological future, the reality is that the earth has been largely greening, e.g., in the Amazon, the Sahel, and the Northern latitudes (Figure 9, Section II.3).

One of FG's arguments is that cross-sectoral impacts are generally ignored in most impact analyses. However, it is unclear whether their consideration would increase aggregate impacts or reduce them. This is because such consideration would open up large opportunities for substitutions that could provide services and goods currently fulfilled by the climate-sensitive economic sectors. Also, as societies become wealthier, the share of their GDP and employment dependent on climate-sensitive economic sectors is likely to decline, which is one reason why "richer is more resilient" (Section V.2).

Another argument that has been made is that impacts analyses generally ignore the potential for catastrophes. However, the potential catastrophes that are cited most frequently are unlikely to occur this century. It would take centuries if not millennia for either the Greenland or West Antarctic Ice Sheets to melt, if at all, and their socioeconomic impacts are likely to be minimal, given such lead times (Section III.1). There is no indication that the thermohaline circulation is weakening, but were that to occur, model projections do not indicate that any resulting cooling would overwhelm warming (Section III.2). So in the presence of global warming, a slow down of the thermohaline circulation is more appropriately considered to be an anti-catastrophe. Regarding catastrophic releases of methane from clathrates in the permafrost, analysis of past abrupt warming of the order of +10±4°C that occurred around

11,600 years ago have largely exonerated clathrates from a large role in an increase in methane concentrations (Section III.3).

Since these “catastrophes” are not imminent, humanity has time to develop and perfect backstop technologies that could forestall them, and there is a good likelihood that improved adaptation technologies will become available over the next century or more that will substantially reduce their net adverse impacts, if any. In any case, no analysis of catastrophes is complete if it does not include consideration of such developments (Section III.4).

Note that dwelling on some low probability catastrophes that may occur over centuries or millennia while ignoring events that may be just as, if not more, likely to occur over the same timeframe amounts to cherry picking. Since the Little Ice Age ended a century and a half ago, it could, absent global warming, return over the next few centuries or millennia. The possibility of recurrence of an Ice Age — Little or otherwise — and its potential consequences should be considered in any systematic analysis of potential catastrophes. Similarly, it is cherry picking to ignore the possibility that over the same time frame, new technologies may be created to forestall or cope with any catastrophe so as to negate its impacts, particularly since society ought to be wealthier and have greater technological prowess. Technologies to forestall catastrophes may include ocean fertilization, carbon sequestration, other geo-engineering options (e.g., deploying mirrors in space), as well as technologies that have not yet been conceived. These considerations should also be part of any systematic analysis of catastrophes (Section III.4).

Other potentially high consequence outcomes that advocates of drastic greenhouse gas controls overlook and which are no less likely to occur include outcomes that such controls may themselves cause (Section III.4). Since net primary productivity (NPP) of the global biosphere has increased in recent decades, partly due to greater warming and higher CO_2 levels, a reduction in CO_2 may have negative consequences not only for the conservation of nature but also for the prospects of eliminating hunger. In addition, the costs of GHG reductions could reduce economic growth worldwide which, then, may reduce the adaptive capacity of developing countries. Were either to result, it would not be the first unintended consequence of climate change policies. We know that subsidies for biofuels, which have been rationalized, in part, as efforts to reduce carbon emissions, have contributed to increases in poverty, hunger, and diversion of habitat from conservation purposes to cultivation (Sections V.5 and V.6).

However, there is no evidence that these policies have provided any benefit whatsoever to society, as opposed to having made a few producers wealthier.

Another problem with addressing low-probability-but-potentially-high-impact events is that that there is a much higher probability that the resources expended on such events would have been squandered. According to the IPCC, "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." This translates into an up-to-55% chance that resources expended in limiting global warming would have been squandered with little or no reduction in average global temperatures (Section III.4). This would be an unqualified disaster because the trillions that would go toward mitigation in order to reduce the already low probability of such catastrophes could instead be used to reduce today's urgent problems that we know exist with 100% certainty (e.g., poverty, hunger, malaria, water shortage, and diversion of land to agriculture). These urgent problems will continue to outweigh global warming through the foreseeable future, unless they are dealt with successfully (Goklany 2009a, 2009b). But dealing with them successfully would be made harder if we divert our resources toward deep greenhouse gas reductions.

FG also imagine that global warming could lead to economic and political destabilization of some countries, thereby spawning terrorism and mass migration. FG argue that such outcomes could have major spillover effects on the US economically and serve as threat multipliers for US national security interests. But the fundamental premise behind these claims — that developing nations lack the adaptive capacity to cope with the myriad impacts of global warming such as droughts, floods, other extreme events, hunger and disease — while true today, is invalid in the future as indicated by Figure 7, despite the fact that it doesn't consider any secular technological progress. Accordingly, it is unlikely global warming will cause economic or political instability, or lead to terrorism and migration over the foreseeable future (Sections V and VI).

Moreover, empirical trends indicate that threats from climate sensitive problems — deaths and death rates from droughts, floods, other extreme events, hunger and climate sensitive diseases — are actually declining (Section V.5). There is no suggestion in the empirical record that presages a breakdown of economic or political stability due to global warming. And while one can imagine countries going to war over water, oil and other natural resources, reality is, once again, much more subdued because people would rather resort to trade and cooperation, and develop institutions than engage in armed conflict (Section VI.1 and VI.3). If fertility rates continue to decline worldwide as they have been doing for the past few decades, this tendency should be further reinforced as populations age, and societies become more averse to risking their children's lives for such resources (Section VI.3).

In contrast to claims based on prognostications from unvalidated and inadequate models, empirical data show that the critical climate-sensitive indicators of human and environmental well-being have been improving over the past few decades. Specifically, long term trends indicate that agricultural productivity has increased; hunger has declined; deaths from hunger, malaria and other vector-borne disease have dropped; as have deaths from extreme weather events. As a result human beings are living longer and healthier (Section V.6). Regarding environmental well-being, the Amazon and the Sahel are becoming greener, as is most of the world (Figure 6). There is nothing in these trends that gives confidence in the projections of impact models. Much of this improvement in human and environmental well-being has been enabled, directly or indirectly, by technologies dependent on fossil fuels or economic surpluses generated by the use of fossil fuels and other greenhouse gas generating activities (Section V.6). Thus, efforts to reduce greenhouse gas emissions could prove to be counterproductive, just as efforts to replace gasoline with ethanol have been.

To summarize, FG have overestimated the impacts of global warming, partly because they gave their imagination free rein in identifying the terrors that global warming might visit upon society, but reined in their imagination when it came to identifying solutions. Specifically, if one is to give credence to the IPCC's estimates of emissions and global warming, then willy-nilly one has to accept that adaptive capacity in the future should be much higher than it is today. But this undermines the claim that inability of future societies to cope would lead to disaster, and economic and political instability.