Climate Change, Facts and Hype: Hazards and Impacts and What does the Future hold?

Abstract: The Earth is continuously undergoing global change. Part of this change constitutes variability of the climate system. For the last several thousand years, the Earth's climate has been naturally warming up. However, it is the recent changes and potentially humanly-induced global warming that are attracting a lot of attention at all levels of societies and are an intense subject of study by the scientific communities. It appears that global change and its effects are proceeding at ever increasing rates. It is also obvious that the impacts of climate change are felt locally, at regional and local levels, yet the influences of change tie different parts of the Earth together. Natural hazards are impacted by climate change, whether natural or anthropogenic, and in turn affect the global system with regional climate impacts. Anthropogenic hazards, such as pollution and fires near populated areas, can create feedback mechanisms, exacerbating the changes. For example, wild fires create land cover changes, impacting vegetation, which in turn impacts local climate and even weather. The same fires can affect air quality and transport aerosols over large distances. Large urban centers are impacted by aerosols, both natural and anthropogenic, and in many cases are themselves sources of aerosols, such as pollution from automobiles and coal power. We know that the impacts of clouds and aerosols on the climate system are not well understood. We also believe that global warming probably results in extreme weather phenomena but the feedback mechanisms are non-linear and hard to quantify in the current climate models. The "clear and present danger" of 21st century global change is the hazards, and pollution, and the havoc they are causing on both human societies and nature. However, as we will show, the connections of the entire physical-biological Earth system, as complex as this system is, to human societies, and associated socio-economic factors, energy, economic issues, and policy agreements at the national and international levels, are even more complex and even less understood. These issues constitute not only a great scientific challenge, they even more pose a great challenge on how to address them at all levels, and discern what is real and what is not, in the face of massive uncertainties and accelerating changes and what the future may hold. There are some tendencies based on expediency, to sidestep careful analysis, and to refuse to acknowledge that there is still so much to know. At the same time, to deny that the Earth and societies are currently being affected by global change, and probably will be affected even more in the future, is not prudent. As such, scientists have to continue working on these exciting but also tough questions, teaming up with economists, law, policy and other experts, developing new interdisciplinary approaches, and not taking anything for granted. The stakes are too high to rely on simple and quick "fixes". One of the most exciting future developments will be connecting economic models with climate models and observations. Coordinated observing systems from space may be one of the surest ways to shed light on the entire, highly complex physical-societal system. The only way forward is to *develop a systems approach*.

The recent failure or at least the diminished results of the Copenhagen COP15 summit in December 2009 have raised new levels of uncertainty in the attempts of world governments to

rein in potential runaway climate impacts. The so-called "Copenhagen Accord" is a political declaration which many observers believe even produced less than the Kyoto Protocol. It also pitched developing nations, which want a strong verifiable treaty within the United Nations framework, nations primarily in Africa, South America and various island nations, against the developed nations led by the United States. The European Union is somewhere in the middle, while China, and to a certain extent India, like the United States, favor voluntary cutbacks and declaration of principles (to keep emissions to a level that would not increase temperatures above 2 C, without though any specifics on how this will be achieved). The complex international political landscape, coupled with the recent revelations of some scientific errors in the Intergovernmental Panel on Climate Change (IPCC) reports, put together by teams of scientists under the auspices of the United Nations, as well as the so-called "Climategate" controversy, have all put the entire process of controlling greenhouse emissions into question. Despite charges and counter charges by camps on both sides of the climate debate, it appears that the international political process is not as much influenced by the science and is more in tune with economy and energy concerns, even though the climate change science has itself faced these recent challenges. It is, therefore, important to examine the various issues in perspective in this staggeringly complicated problem of estimating what the future of the Earth will be, given, among others, the energy production and consumption in societies, along with the impacts of humans on the climate and the environment. Some basics are in order.

The Earth is continuously undergoing global change. This is an obvious statement since the Earth is a dynamic planet that harbors life. An important aspect of global change is the variability of the climate system and, again, this should not surprise us. The Earth's climate is changing all the time. For example, long term cycles of more than 100,000 years between peaks of temperatures, or between minima of temperatures during the coldest ice ages, are due to combined effects of motions of the Earth, the tilt of the axis and the fact that most of the land masses are in the Northern Hemisphere, i.e. they are due to a combination of astronomical factors and the particulars of the Earth itself. It is important to remember that the difference between maxima and minima of these long term cycles are ~ 8 C, much larger than even the extreme scenarios of projected global warming. Over much longer times, over millions of years, rare but catastrophic events such as the Cretaceous-Tertiary extinction event (which refers to the massive extinction of the dinosaurs 65 million years ago), are associated with drastic climate change (this particular event was likely caused by a sudden astronomical event, likely the impact of an asteroid or a comet). For the last several thousand years, starting approximately 15,000 ago, the Earth's climate has been naturally warming up, as we have emerged from the last ice age and moving into the warm interglacial period. This is a naturally occurring global warming that has nothing to do with global warming due to human actions ("anthropogenic" global warming). How much human influences are increasing the warming, is of course a topic of great debate and the centerpiece of the above described international political process. It is interesting to note that natural periodic climate changes may be associated with drastic species changes and even extinctions, such as the likely disappearance of the *Neanderthals* during the peak of the last ice age, approximately 25,000 ago. The recent warming of the Earth's climate has allowed agriculture to be developed and along with it the rise of civilization and the dominance of *Homo Sapiens*. Even though *Homo Sapiens* likely appeared more than 100,000 years ago, the dominance of humans over other hominids, and of course the entire ecosystem of the Earth, are fairly recent developments. This dominance has taken on vast proportions in the last several thousand years, even before the Industrial Revolution (such as deforestation and presumably since antiquity, changes of regional climate in Europe).

We see that global change, climate change and global warming, each term being the more general encompassing the next terms in this order, are all related to each other but they are *not* identical to each other. Confusion results as, often, they are being used interchangeably. All three are due to natural causes. The question is, are there other causes besides natural cycles and events,

and specifically, anthropogenic releases of greenhouse gases, such as carbon dioxide and methane, producing and will produce massive climate changes, the worst to come in the next 50 to 100 years? I claim that the question itself is valid but so far, despite the strides of science, many uncertainties remain, unequivocal predictions that governments can use still elude us and the complexity of societal responses has become even more uncertain. Adopting drastic measures in the face of uncertainty may be quite unwelcome but equally not doing anything may produce equally unwelcome results for societies and ecosystems.

To summarize, it is the recent climate change and associated global warming perhaps above and beyond the warming from the last Ice Age (although precise values still lack, as we will see below), specifically since the rise of the industrial revolution, with potentially humanly-induced warming due to burning of fossil fuels (i.e. *Homo Sapiens* may now be affecting the climate of the Earth rather than the other way around), that are attracting a lot of attention at all levels of societies and are an intense subject of study by the scientific communities. The prevailing view of climate scientists is that global warming is now controlled primarily by human practices. This apparently simple statement is actually extremely complex: How much, if any, of the global warming is due to fossil fuel burning, which releases gigatons of carbon dioxide into the atmosphere, producing a greenhouse effect? (Note that greenhouse effect is itself a natural phenomenon because the Earth's atmosphere produces a blanketing process through which temperatures result that are much warmer than if the Earth did not have an atmosphere—today "greenhouse effect" refers to, the alleged, anthropogenically induced one, but it is important to keep remembering that the dominant greenhouse effect is natural). The specific question, better put, is such a humanly induced global warming producing runaway effects above and beyond natural processes? This is often referred to by scientists as "external forcing", above and beyond the external forcing of, e.g., solar cycles etc. Can we predict the future climate of the Earth? How much is the Earth's climate going to change in the next 50 – 100 years? How much warmer is the Earth going to get, etc. etc.?

Without going into the specifics and complexities of climate change and the role of humans, we should point out that there is really *no* direct way to unequivocally predict specific rises of global temperatures based on specific amounts of fossil fuels consumed. There are plenty of indirect indications and the science itself has achieved great strides. But if it comes down to the choices between the two extremes, doing nothing, doing very little; and taking drastic cuts in carbon emissions, one then enters the realm of massive uncertainty. Some *reasonable* responses that would not create havoc in the global economies and would not produce massive climate change disaster down the road, would appear prudent and in need to be undertaken. The problem is that there is no uniform acceptance what such "reasonable" responses or global actions might be. And unfortunately science itself cannot, and probably should not, prescribe actions of policy. It can only provide studies of potential scenarios. The rest is up to the public and their elected politicians, and even beyond national boundaries, to the entire international community.

Some model runs carried out into the future, indicate possible increases of global atmospheric temperatures by as much as 5 degrees Celsius over the next 50 – 100 years. However, other models yield more modest increases. Climate experts tell us anything above 3 C will have disastrous global consequences for droughts, agricultural productivity and sea level rise (this is why the much discussed 2 C limit in Copenhagen was taken as a threshold of safety). But, again, we have no statistical confidence, can we expect such predictions (or more accurately *forecasts*) at the 3 sigma or 2 sigma level? The models are not accurate enough to give us the exact scenario of what may happen, only some potential scenarios. All trends though point to increases of global atmospheric temperatures. There are other complications with the science: The most dominant greenhouse gas is water vapor itself but model runs cannot give us much information. Other unknowns are the role of the pollutants known as aerosols, the role of clouds, and the role of the biosphere and feedbacks from it into the climate system and vice versa. And last but not

least, the role of regional processes such as hazards, into the global climate system, mediated through regional climate changes are highly non-linear and not integrated into global models.

Governments in the world are increasingly under pressure from not just the scientific community but also the public to do something about curtailing the release of greenhouse gases from fossil fuels, which, most scientists believe, is the direct reason for the increase of global temperatures. But to reduce everything to an "average" temperature (whatever that means) for the atmosphere and to demand unspecified cuts in emissions, stretches the science as well as political will. It is here where global politics, development of new economic powers and associated industrial productivity, sustaining and expanding a modern way of life, and other factors, enter the picture and immensely complicate any possible "solutions": The Copenhagen Accord seems to have achieved even less than its predecessor, the Kyoto Protocol; the refusal of countries like the U.S. and China to agree to specific cuts (the two countries producing together about 50% of carbon emissions, China having just reached and expected to surpass the U.S.); the emergence of the rapidly developing economies of India, Brazil etc., and not just, but especially, China, as world economic powers, with their associated increasing need of energy production and thirst to find new energy sources; the lack of massive usage of alternative sources of energy production, which to compete with fossil fuels, will require years of development and economic viability; and the dream of billions of people in the world to enjoy the same modern way of life that we in developed nations take for granted, all play an effect here. Besides what the implications for the future environment, and human societies which cannot survive in a massively degraded environment, will be, the future environment may lead us to continued societal strife and, who knows?, maybe even global war. It is hard to make the case that somehow governments will abandon their usual ways and not use power to prevail over others when future resources become scarce and agricultural production and feeding of their own people are threatened.

I prefer to address here what seems to me to be obvious, and I suspect not only scientists but also the public are beginning to sense: Something is wrong with the global system as evidenced by the hazards. It is what I call the *clear and present danger is the hazards.* Climate scientists tell us this is expected in accelerated global warming. Anthropogenically-induced global warming deniers don't seem to be paying much attention to this danger, concentrating instead on the economic impacts of curtailed fossil fuel emissions. It is surprising to me that *both* sides seem to concentrate their debates on the carbon emissions and not to directly address the hazards, which irrespective of cause *are occurring now*. The public throughout the world and even experts may not understand the future dangers to human societies of global warming, precipitated as climate scientists would argue, by the uncontrollable and continuing in an ever increasing manner release of greenhouse gases such as carbon dioxide and methane. It is no wonder that massive political and economic actions based on uncertainties are not very appealing. However, one thing is obvious at least to me: There is no simple solution based on an approach of just one system, say the global climate model runs. We are dealing here with a *system of systems.* For all these reasons, any solutions are *extremely complex and will likely fail, unless we develop a new systems approach. What is needed is a systems approach for the combined climate system and the human systems encompassing economies and energy.* Such as systems approach is needed not just to put more rationality into the future scenarios but to also address the "clear and present danger" of hazards. The interrelationships of parts of this system approach are illustrated in Figure 1. What immediately emerges is that such a systems approach will have to examine *both* mitigation (the curtailment of greenhouse emissions) and adaptation (which is more directly tied to hazards, particularly important, but not limited, for developing nations).

In Figure 1, I list the "Four F's" of U.N. Secretary General Ban Ki-moon: Food and Water; Health (Flu, clearly flu is not the only health effect but it is used here because the word begins with F); Energy (Fuel); and Economy (Finance). The hazards can produce sudden effects (such as wild fires) or more gradual changes (such as sea level rise). The influences clearly have feedback effects and interrelationships. I envisage that the system approach advocated here will

have to produce many such *qualitative* charts and products and then turn them into *quantitative assessments and models.*

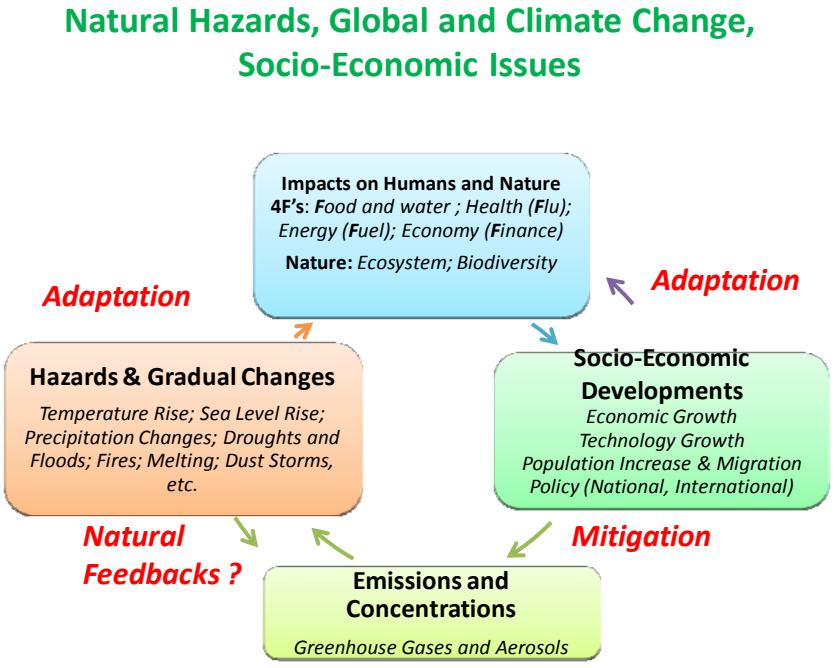

Figure 1: An example of systems interrelationships

To illustrate why I believe that hazards can be the pivotal elements that should be developed and examined in such a systems approach is because by definition, hazards involve everything from science, to economic and policy responses *and* at the same time they are occurring now. Any collection of socio-economic data as illustrated in Figure 1, becomes much more feasible once we have developed the systems approach, compared to undisclosed and uncertain future scenarios of a global system 50 to 100 years from now. It may or may not be the case that the increased number of strong hurricanes in 2005, one of which was Katrina, was due to climate change but no one can deny that they occurred. If we understand the socio-economic aspects of Katrina, Rita, Wilma etc., we may not understand future climate impacts but at least we will have better tools than we now have. Some climate models forecast more category 3-5 tropical cyclones while expecting a smaller number overall. Again, whatever the case may be, studying the socio-economic impacts of Katrina (e.g. its impact on the U.S. economy), understanding the interplay of regional climate and such hazards, seems to be a prudent and more immediate approach. We should be striving for *clear and present solutions to the clear and present danger of hazards.* Other major concerns are the collapse of ecosystems in many parts of the world: An event can happen in an ecosystem. Sometimes the effects of that event are not immediately obvious but they still affect other ecosystems. Once these kinds of events occur, their effects spread uncontrollably. These hazards are caused by human activities or are influenced by human activities. They are a challenge because they are occurring *now* and not tens of years into the future. They are the manifestations of the system of systems outlined here. Let's examine them in detail.

Natural hazards include: Wildfires, sand and dust storms, tropical cyclones (known as hurricanes and typhoons), severe weather, floods as well as droughts (and also earthquakes). With the exception of earthquakes (although even in that case some hold the view that changes in surface conditions may precipitate earthquakes), it is possible that increases in occurrence and

severity of all or most of the above are somehow associated with human activities. The increase in these hazards may be directly tied to global climate change but, again, quantitative scenarios are lacking for the simple reason that global warming scenarios refer to the global system while hazards are by definition regional. The IPCC 2007 report outlines several connections between global climate change and hazards, however, we still do not understand all the complex interactions of the systems involved. *Until we have a global climate system that includes a reasonable number of regional processes such as hazards, and ties regional climate systems to the global system*, we may be, at best, developing a massively uncertain global climate system. What of course this will require are not just more computing power (to produce high resolution forecasts) but also a lot more physics (such as the physics of aerosols—do they produce a net warming or a net cooling? How will water vapor change in the future and how will it impact regional climate? How will the physics of clouds be integrated? To just name a couple of examples). Nevertheless, the severity and increase of natural hazards, producing "hot spots" are like an alarm (see Figure 2). This alarm is telling us to pay attention now, because if we do not, there will likely be disastrous consequences. What if, instead of one Katrina we were to have 4 or 5 Katrinas, each producing $100B of damage and thousands of deaths? Would such a system of storms produce irrevocable effects to the economy of a State like Florida? Would it drag down the entire U.S. economy? Would prolonged droughts in California kneel the economy of the most populous State even beyond its current status? How would we develop adaptation responses to such future, increased disasters? The scenarios themselves may be uncertain but in a systems approach we can study several such scenarios as we *have the data now*.

Figure 2: Hazards produce hot spots around the world and they are part of the global change

As we develop our systems approach, we will have to look at the interplay of regional processes and human activities not only between them and the global system itself but also between them and how societies can and will respond (which by definition are regional). For example, recent droughts and heat waves as well as willful human activities in Europe have led to massive fires in several countries, such as Portugal, Spain, France, Italy and Greece. It is now

known that regional fires can profoundly affect regional climate, producing greater temperature increases (in excess of 1 C) than some future global warming scenarios. Many deaths in heat-stricken countries like France during past summer seasons are also on the increase. Wildfires often rage in many States in America, threatening houses and communities in general, from Georgia, to Florida, to New Mexico and California, just to mention a few. Tropical forests are being burned by people for the sake of agricultural development. They burn trees to make grass fields to feed cows and other livestock. These animals are then slaughtered to feed humans. This system may be highly inefficient and environmentally degrading. Trees are also burned down to make way for new human communities. Forest fires in one country affect not just that country but also many neighboring countries. Neighboring countries can be affected through the spread of smoke aerosols. Examples of this include the Indonesian fires which affected major nearby cities like Kuala Lumpur. The burning started by humans, affects Nature because weakened forests are more likely to subsequently burn by natural causes. For example, the effect of humans burning forests in Africa is to promote natural desertification, which decreases available forests even more. All these are systems which can be studied in themselves but also need to be linked to each other.

Desertification in Africa has worsened droughts. It has also caused the collapse of local agricultural production and resulted in unabated famines, which have killed millions of people. In addition to droughts, there is another apocalyptic dread, war. These may become a common occurrence in other parts of the world as current hazards may turn many agricultural areas dry. As areas become drier, the more water resources will be depleted in attempts to save them. Desertification often causes fires but also causes increases in sand and dust storms and such phenomena in Australia are now threatening the water supplies of most Australian cities, particularly Perth. There are current data that show an increased level of droughts, warming of many areas of the Earth, and related risks to the Earth's forests. It is possible that the increasing scarcity of water will pitch countries against countries, even leading to major wars, for control of this most important commodity, particularly in arid and semi-arid regions. Will a future, possibly warmer world, have more such consequences? We don't know for sure but we can certainly study the current situations and try to link them together.

The increase of severe weather often leads to floods, and even though they are the opposite of droughts, these also seem to be on the rise. Often some areas are afflicted by droughts while other areas by floods. The extremes may become more severe: Flooded areas will get more floods and dry areas will become drier as it seems to be already happening. Recent floods in Central Europe might be caused by the cutting of forests and not necessarily by global warming but what if both were acting together? Severe weather causes floods in India, Pakistan, Bangladesh, the Philippines, South American countries, and China. These floods affect economies and lead to massive deaths and, particularly in Bangladesh, have led to government adaptation policies. Countries like Korea are increasingly experiencing the wrath of floods. Severe rains make large rivers overflow, and they also cause sudden flash flooding in major urban centers, trapping or drowning many people. Even traditionally dry areas such as Athens, Greece, are ironically experiencing flash floods in the fall and winter seasons, while at the same time getting drier and hotter in the summers. This kind of severe weather has a particularly devastating effect in megacities, like the recent example of Mumbai, India, striking without notice and killing many people. Is climate change responsible for the increase of severe weather? Prediction models seem to indicate that this may indeed be the case. But it is important to note that just because these are future forecasts of models, this does not mean it is a future problem. These things are happening right now in front of our eyes. And, again, we have the data to study them now.

Desertification in Asia and strong wind patterns have led to an increase of the so-called "yellow sand" phenomenon. This phenomenon affects several East Asian countries, particularly China, Korea, and Japan. During the spring months, many cities in East Asia become are affected by yellow sand, leading to economic losses and increases in respiratory ailments. Desert dust from Africa crosses the Mediterranean and this causes bad weather and affects agriculture and

living conditions in many European and Middle Eastern countries, in addition to Northern Africa itself. Forecasting dust storms is difficult because of the relationship with a complex interaction of winds. It is also difficult to predict dust storms because there are local conditions such as the nature of soil and the changing weather patterns. Once a dust storm develops, satellites from space can track it. Using the satellites, weather and dust propagation models can be used to provide important information to authorities downstream of the storm. This is not a future global warming scenario, it has implications and usefulness right now.

It is clear that deserts (from where sand and dust storms originate) existed independently of recent global climate changes, whether natural or anthropogenic. However, human activities in global change (not necessarily global warming) will increase the strain on the Earth's ecosystems. Global warming may turn many areas that are presently green into arid areas or even deserts. However, current agricultural practices, although part of global changes, are not per se part of the physical climate system. Yet, they will have a profound effect on it. Current climate models just don't have the capacity or physics or even the framework to include these processes and interplay of processes. It is unlikely that deserts will become smaller in the future because of human activities. That means that natural hazards like sand and dust storms will continue to increase in the future (again a global change phenomenon but not a climate change or global warming per se). These kinds of storms ignore know political boundaries and borders. Dust storms from Asia and Africa often travel thousands of kilometers, crossing the great oceans, affecting distant regions, far away from their places of origin. Will there be a discussion of how to tackle such hazards internationally? The lesson of Copenhagen is, unfortunately, probably not, unless things get really much, much worst.

The connection between tropical cyclones and (anthropogenically-produced) global warming is still under intense debate. However, as stated above, many scientists believe climate change is partially responsible for the increase in cyclones. The recent increase of tropical Atlantic storms or hurricanes seems to be tied to an increase in the sea surface temperature. The present author has himself been involved with others in such work. For example, it has been convincingly shown that abnormally high temperatures occurred in the Gulf of Mexico in summer 2005, higher than the average temperatures, and that these high temperatures led to the formation of the devastating hurricanes Katrina, Wilma, and Rita. However, beyond stating the obvious, that higher ocean temperatures cause more severe storms, to tie them to increased carbon emissions becomes a much more challenging question. For example, the summer of 2006 did not prove as disastrous for the U.S. coastline because fewer storms developed. Was 2005 the exception? Was 2006 the exception? Perhaps this is because of the development of more dust storms off the coast of Africa near Sahara, and these dust storms might have curtailed the growth of hurricanes in the U.S. This is a topic that scientists are currently investigating. However, the Pacific Rim countries did feel the effect of more typhoons. It seems that regarding tropical cyclones, when the Atlantic is quiet, the Pacific often is not. And vice versa. Global models even predict that areas that were quiet up to now (such as the Persian Gulf region in the Middle East) may be subject to tropical storms in the future. This might threaten the world's supply of oil. How would the global energy and economic systems react? Specific storm occurrences cannot be predicted, however, we now have a general idea how busy a given season may be based on data. These data include statistics and monitoring of parameters such as the sea surface temperature using satellites. Observations with space-born satellites and detailed modeling are becoming new tools to better understand these phenomena. We know such regional processes and have studied the relevant science to a great extent. But to *tie them all into a global system of systems* has not yet occurred.

Warmer oceans are already occurring, perhaps outpacing the expected atmospheric warming. It was predicted that by 2050, there would be no polar ice during the summer season. Unfortunately such predictions seem to be accelerating. On the one hand IPCC models may have missed the obvious changes occurring now. On the other hand, to completely ignore what is

happening now would not be a prudent approach either. Besides the obvious effect to polar ecosystems, such as the possible extinction of polar bears, it may have disastrous consequences for the climates of Europe and North America as global warming might disrupt the flow of the Gulf Stream. Sea rise will continue as result of the warmer oceans. Although not classified as a natural hazard, sea rise will have disastrous consequences for many low-level coastal areas and islands of the world. Under extreme scenarios, many major coastal cities may find themselves under sea water. What would the regional economic impacts of such changes will be and how will they in turn affect the global economic system? We have present data (e.g. from Bangladesh), can we extend the data and models in a systems approach?

Besides sea level rise and warming of the oceans, which are usually attributed to global change (but they may have partially occurred anyway because we are in an interglacial period) human activities are responsible for the pollution of huge parts of the oceans. These are *not* modeled in the global climate system but are part of global change. Such pollution in extreme cases kills fish and disrupts marine ecosystems. An ironic result is that humans cannot harvest affected fish and other marine life. Pollution of seas causes coral bleaching and the disappearance of vast areas of coral reefs. We still do not know the implications for marine ecosystems, which are in delicate balance with the environment. Each species serves an important role for the benefit of the whole. In addition, the extreme overfishing of many seas has led to the prediction that there will be no more available fish reserves left in the open oceans by 2050.

Extinction of species and collapse of ecosystems may be the way of the future and are currently on the increase. These, again, are not tied to humanly-induced global warming (whatever that magnitude may be) but their cause is uncontrolled human activities. In areas such as the Amazon, where a large percentage of the world's species reside, the collapse of tropical ecosystems may have unpredictable effects for the Earth, beyond just the local habitats. Global change is more encompassing and perhaps more threatening than specific global warming scenarios. Humans depend on a healthy environment and the Earth's biosphere is an immense system of checks and balances, a system of systems. No individual species can survive separated from the rest of the biosphere, not even humans. Disregarding the well-being of other species may ultimately be the most foolish act that humans can perform.

A possible consequence of global warming is the migration of tropical diseases from the equator to more northern and southern regions. Again, this migration is already occurring but its exact causes need to be studied. If accelerated in the future, it may threaten temperate species and humans that have no immunity to tropical diseases. For example, malaria may migrate northward from poorer tropical regions to affluent countries.

Along with the effects of natural hazards, the Earth's environment is experiencing increased (anthropogenically-induced) pollution. Aerosols may heat *or* cool the environment. They go beyond a pure global warming scenario. So do the clouds. Aerosols from dirty coal burning plants, smoke aerosols from agricultural practices, burning of forests, city pollution and dust storm aerosols, are all on the increase but it would be a hard case to make that they are all tied to carbon releases. Their combination can prove harmful and even deadly to many humans. Megacities of the world such as Beijing and Cairo, and regions such as the Indo-Gangetic plains of India housing more than 600 million people, are subject to the deadly combination of all natural and human-created aerosols. No major city is free of all aerosols. Scientists are now studying the propagation of such pollutants and their effect on and feedback mechanisms from regional and global climates. They are part of the global system (and subject to global change).

Scientists are increasingly using satellites from space to study hazards. Satellites may also be the most reliable (only?) means to verify the connection between carbon emissions and warming. The world governments should ask for more observations and proponents and opponents of global warming should welcome such observations. Yet, this has not happened. It appears that both sides are somewhat limiting their arguments to the models themselves (with all their uncertainties) and at most to station observations, instead of *proposing massive*

observational systems from space. I would advocate the latter. Models are clearly a necessary complement to observations but by themselves are giving us only part of the picture.

What we are saying here is not meant to lead to despair and inaction but to point out that the system we are examining is immensely complex and easy answers are not possible. We need to have a system to study what may happen, so we are prepared to face the challenges, many of which constitute the clear and present danger. Whether or not we will be able to sustain our current way of life and have our brothers and sisters in other developing countries enjoy the same benefits is still an open question. This is because unchecked and ever-increasing energy consumption (which will at some point threaten the environment and ultimately all of humanity) is at the same time necessary to enjoy a modern lifestyle for more and more people. However, one thing is clear: If we do nothing and continue things as they are, we may be facing a future that is only hinted by the effects of present hazards. A prudent approach would be (as in health insurance) to "buy" ourselves the insurance of developing adaptation scenarios based on science, economics and policy. For us to continue business as usual is like insisting to watch TV in a room, while the rest of our house is on fire. However, to also spring into action without adequate and honest examination of consequences may produce equally devastating results. Would global warming be the greatest threat to humanity? Would a hastily devised response of drastic cutbacks of energy production be the greatest threat to human well-being and economic development? These are good questions and rather than based on politics, they should be based on sound policies, assisted by good science.

The complexity of the systems approach discussed here rests in linking different, by themselves, complex systems, to a system of systems. As we undergo this building process, we have to understand the uncertainties in each system, how they tie together and how complexities and uncertainties propagate in the hierarchy of systems. Interrelationships have to be understood and built, feedbacks and policy effects integrated into a gradual system. Part of what we imply here is illustrated in Figure 3, this being only one of a multitude of such systems of relationships. Along with global change challenges, great opportunities also await us. For example, hazards cause economic losses but also present great business opportunities, in mitigation and adaptation. We need economic systems that address both the challenges (e.g. losses) and opportunities (business development, new products such as modeling of different outcomes, etc.).

In a previous work, I recommended that rather than prescribed political actions, which may end up being outdated by the rapidly changing system, that we become aware of the Earth, our place in it and how integrated human societies are to our home planet. This prescription is not for specific actions, it is rather a willingness to understand and adapt. If we maintain the simple awareness "I remember the Earth, my home", maybe this will lead us to realize and understand the unity of the Earth systems and how we methodically need to integrate different systems and processes. As global changes proceed, with or without warming increases, increased awareness by more and more world citizens may lead to sound solutions at all levels.

In conclusion, it is wise to remember that global changes are naturally occurring; at the same time, current trends seem to be telling us a lot about the impeding changes. But if we expect unequivocal answers with very little uncertainty as to the causes and what to do about them, we will be disappointed. It is time to perhaps remember the words of the great philosopher Socrates "one thing I know, is that I don't know anything" and inject a dose of humility and awe about how much is left to understand of the complex Earth system and even perhaps more complex societal system and their interaction, the combined physical system *and* societal system. In this spirit, this short paper and presentation have only scratched the surface and by no means can provide any definitive conclusions about precise outcomes. The answers to the question raised in the title are not simple and perhaps not even unique. What we instead *need is a methodology that can adapt to large uncertainties in the combined physical societal system*. It is still important to raise the issues and create a dialogue among policy makers, economists, business leaders, scientists, international law experts and others, to try to bridge the gap of how much still needs to

be learned. Some future changes may turn out to be positive. To give an example, the growth of population residing in cities (expected to reach 2/3 of the world's population by 2050) will produce major problems to be tackled. However, as the experience of an increasing number of "green cities" indicates, such concentration may accelerate green solutions and protect the rural areas of the Earth, setting aside vast areas of protected environment.

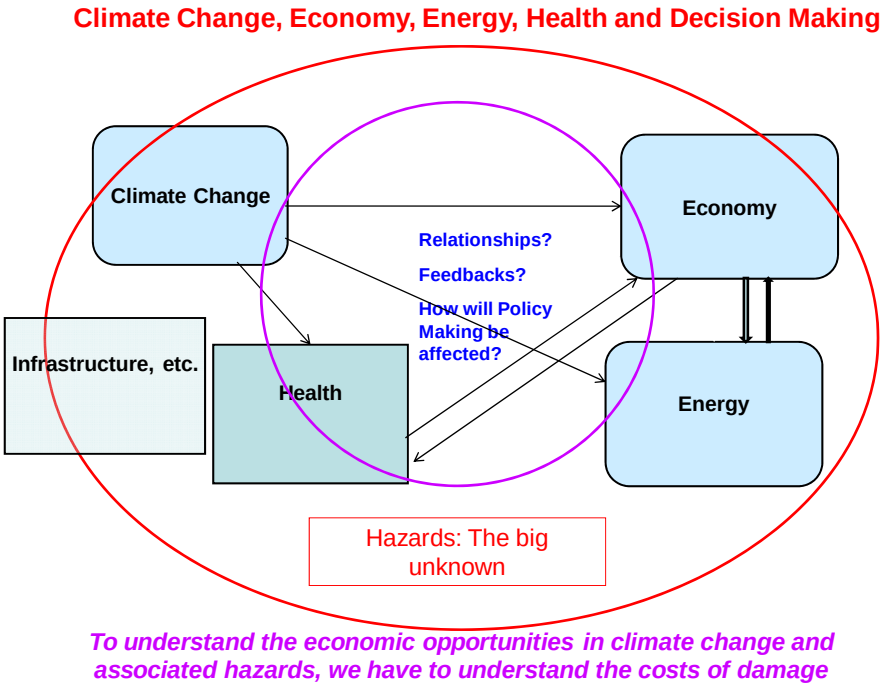

Figure 3: A possible scenario for hazards in a systems approach

Support for the scientific efforts outlined here is crucial now and for the future. We need more observations from space, more regional processes and full integration of regional processes into a full, high resolution global climate modeling framework. However, no matter what scientists do, the above problems cannot be addressed by science alone. Since these problems are global, it is essential that different socio-economic systems are developed and put together. Global solutions and international agreements involving all societies may be of paramount importance but even before we attempt to reach some international agreements with unknown consequences, it would appear prudent that we should first try to build a *new generalized science of climate and society*. One of the most exciting future developments will be connecting *economic models with climate models and observations*. I plan to illustrate this system approach with the aid of sets of diagrams, which will show the interrelationships of the systems, how to model them, how to use observations, how adaptation and mitigation are tied to, e.g., hazards and their effects, in short, what are the main elements of such a system of systems.

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