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Scale and Scope in Integrated Assessment: Lessons from Ten Years with Integrated Climate Assessment Model (ICAM)

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ABSTRACT

Scale has traditionally been thought of in terms of the spatial extent and units of observation in a field. This is an excellent convention in the study of physical processes where scale also differentiates between the dominant forces at play. For example at the scale of planetary distances gravitation is the dominant force of interaction and the only thing that matters is mass, while at the atomic level electromagnetic forces dominate and charge of the bodies is critical. In this paper I would like to offer other criteria for scale selection in studies involving the interaction of social and natural systems.

In this paper the focus is on integrated assessments where we hope to understand and capture the interaction between natural and social systems. By applying the same paradigm for scale identification as before, namely factors that dominate the dynamics and landscape of the system I would like to persuade the reader that we need to define two additional scales for integrated assessments: one to capture human cognitive processes and another to capture our social organization. The rationale for wanting to add these scales is simple. Awareness of the interface between nature and us is determined by our cognitive processes and technologies invented and employed to enhance these. Our ability to act on what we would like to do about the interface is shaped by the way our societies are organized and institutions invented and maintained to enhance them.

Keywords: scale, cognition, perceptions, knowledge, integrated assessment.

1. INTRODUCTION

Often, it is asserted that human activity is leading to environmental impacts of unprecedented scale. Here, scale presumably means phenomena that extend through space and time. I am not sure though, if such statements are helpful in analysis of our interactions with nature. In absolute terms, these impacts are more extensive today than ever before. This is because: (a) many of our activities grow ever more synthetic, (b) measurements of change in the environment are more sensitive and (c) our more sophisticated understanding of the underlying processes leads to attributions of these changes to our own actions. For example, we invented CFCs as a miracle industrial gas and fluid. No such chemical existed in nature before and for three decades we used it without any knowledge of its potential environmental impacts. During that period, our growing understanding of environmental science allowed us to speculate and later measure the impact of CFCs in the stratosphere above Antarctica! Yes, our reach is global (as we understand the term "global" today).

In relative terms history is replete with episodes of human action whose impacts extended to the boundaries of the contemporaneously known universe. Today, we know a good deal more about the earth. For Paleolithic villagers, the impact may have been limited to the valley in which they had lived for generations. Cognitively, these two are not differentiable in terms of "the known interface" between humans and the environment. What matters is whether what we know influences what we do.

In general, while our impact is rarely limited to the space we know, the impacts we neither see nor postulate may exist rarely, if ever, limit our actions. Furthermore, there is little doubt that our actions today have impacts beyond the space/time we know. For example, the earth is an extremely bright source of radio emissions in the sky. Our radio, TV and telephone conversations are finding their way to the farthest reaches of the universe. The earliest TV signals are already more than 60 light years away. If and when we grow sensitive to the impact of these stray emissions into the electromagnetic spectrum of deep space we may choose to control these also. Meanwhile, there is nary a concern about

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such impacts. In summary, the decisions about our patterns of activity are taken in recognition of what we know at any given time. This is an irrefutable aspect of humanity. *The scale of our knowledge about change is determined by our cognitive capacity.*

Even though I think the above argument is pretty persuasive, others would argue that there is a fundamental difference between then and now. Today, we are witnessing motivations for human activity that extend beyond local geographic scales and there is an imbalance between "global demands" and "local capacity to provide" in a sustainable manner. This too has historic precedent. The empires often aggrandized in history books are all about institutions that imposed control over far flung resources. Arab, Ashante, Aztec, British, Chinese, Greek, Mayan, Mogul, Persian, Portuguese, Soviet and Spanish empires conquered vast areas of the known world, extending trade networks, imposing belief systems and collecting resources. Did they consider the impact of their demands on local systems and their viability? What is the difference between these historic empires and our current concerns about the Global Agreement on Tariffs and Trade (GATT)? Economic superpowers and global markets, even while well-meaning, embody a promise and an ill-wind that come about from mismatches in the scales of pressure and responses. *The scale of human activity is determined by the characteristics of social organizations and institutions.*

There is no prerequisite that our knowledge of change (cognitive scale) and our knowledge of manipulation (organization scale) be spatially the same or dynamically in harmony. Scale mismatches are part and parcel of the struggle of living on earth as social beings. Exploiting these mismatches is a major determinant of heterogeneity between and within different societies. These heterogeneities are beyond those that can be explained in terms of each community's endowments. Utilization of these resources impose different collateral effects (externalities) on individuals, households, neighborhoods, communities and regions. Forces external to the region are increasingly the determinant of demand for these resources. These tensions lead to an imbalance of pressure and response in different regions. Consequently, winners and losers emerge. These differences in outcomes are now shown to be linked to how "happiness" and "welfare" are experienced. Here again, our cognitive and perceptive functions determine how we evaluate outcomes. Happiness of individuals and communities are defined relative to outcomes for others. Thus, in these societies, happiness is essentially being a winner, relative to others, even when the world as a whole or a neighboring society may be worse off.

There is a clear pathology implied in the above paragraph. It suggests that even awareness of adverse impacts on nature does not necessarily lead to wise action on the part of humans. This is not simply a restatement of a tragedy of commons problem. It is one that associates the individually important phenomenon of "winning in relative terms" with actions that can knowingly lead to the overall deterioration of the commons. By extension we can fuel the fire of concern about systematic collapse – socially, economically and/or ecologically. My immediate reaction to such worries is if humanity is so afflicted, then why worry about its demise. On a more positive note however, I believe catastrophic outcomes are only likely under two circumstances: (a) where the system has become so homogeneous that the same affliction can spell doom for all, (b) where the different components of the earth system are so strongly interconnected that the failure of one will lead to the collapse of all. Winners and losers (be they ecological or social) define heterogeneity within a system and hence resilience to the first type of challenge. The interacting elements of the system (society, ecology, ...) lead to ever changing conditions, but it is their self-perpetuating interactions that leads to an identifiable system being created. Therefore change and heterogeneity are part and parcel of a more stable system, even though individual state variables may be transitory and unstable. In other words, while Welsh coalmining communities are a feature of our past, the villages are still there, and the people are engaged in different activities and the ecology is again flourishing in species that are sensitive to mine runoff.

Interestingly enough, even though systemic collapse on a local scale is all about us, we seem to be expending more effort in projecting and forestalling such futures as opposed to doing something about them now. This could be due to a number of reasons, among them: (a) collapse being more dreadful when unknown and more easily adapted to when in progress; (b) collapse being precipitated or marginalized by institutional dynamics. These simple observations, about our cognitive and institutional capacity, have led me to be skeptical about our ability to address climate change in a substantive fashion. Climate change is the poster-child of distant and uncertain concerns. Somehow, it is hard to imagine us finding a solution there where we continue to fail in removing the familiar blights of persistent hunger and trampled human rights.

2. LESSONS FROM DEVELOPING ICAM

I do not claim any knowledge about how the issue of scale has been treated in the literature. This paper is about a personal journey in integrated assessment of climate change. One might suspect that a global scale is all that such an assessment would be focused on. However, the nature of the problem, a global concern with differentiated local implications has led to successive iterations in which questions to consider and what solutions to explore. Over the period in question, the problem was redefined four times. Each

Table 1. Four successive generations of ICAM.

ICAM	Problem characteristics	Critical factors shaping outcomes
0	• Uncertainty in outcome • Uncertainty in efficacy of control measures • Subjective perspectives on costs and benefits of control	• Subjective views on costs • Subjective views on benefits
1	• Outcomes are simulated as a consequence of parametric uncertainty. • Regional differences in driving variables, manifestation of climate change and impacts of that change.	• Two geographical domains (high and low latitudes) used to depict differences in demographics, economics, and market/non-market impacts of climate change.
2	• Outcomes are simulated as a consequence of parametric and structural uncertainties. • Regional differences due to aerosols emissions and climate change that would ensue	• 12 world regions whose boundaries are defined by aerosol transport. • Differences in energy resources • Differences in pollution control • Differences in land use
3	• The key question is no longer what range of outcomes can happen, but what institutional framework can steer us clear of pathologically bad futures. This is explored through simulation of interactions between three groups: those who worry about nature, those who worry about development and those who are entrusted with policy implementation. These simulations explore the consequence of specific institutional frameworks.	• Sensitivity to control cost signals and economic disruptions. • Sensitivity to impacts attributed to climate change. • Institutions for social interactions and for monitoring and managing the interface with nature.

redefinition had implications for scale and scope of the analysis – see Table 1. This iterative approach to problem solving has been discussed by Root and Schneider [1]. I am now convinced that for problems like climate change, a "right scale" of analysis, based on space and time, does not exist. I believe that the cognitive and organizational aspects of our societies act locally, but their "location" is not coterminous with a spatial definition of locality. I believe that today, the high degree of exchange between geographic locations has led to shared goods, services, ideas, and social norms being the defining characteristics of a "locality."

In this paper, I plan to offer some insights about scale and integrated assessment through examples from three generations of ICAM modeling. In these examples, I will try to illustrate the added value of cognitive and organizational scales as adjuncts to the more familiar time and space scales. I will present:

- *Cognitive scale* issues, including how we define the relevant questions and the scales of analysis adopted for examining different options,
- *Organizational scale* issues, including which aspects of the dynamics of the system are represented.

I conclude this paper with a plea for design of integrated assessments that reflects the different scales at which human cognition and organizations operate. I believe these to be fundamental scales at which we perceive changes in the world around us and translate our desires for its manipulation and preservation into specific actions and interventions.

2.1. Questions, Scope and Scale

It may sound trite, but in any research endeavor, it is important to have a clear question in mind. In pure research, the question is gradually crystallized as one gropes around for understanding.[1] By contrast, in applied research, the objectives defined by a specific question identify the scope and scale of the analysis that should be undertaken. Often, we researchers fall between these two modes of inquiry and have difficulty defining the question appropriately. Failing to define the appropriate question often goes hand in hand with the research findings being ignored. I have tried to keep the research underlying ICAM relevant by repeatedly visiting the dual questions: *What is good climate change policy? What is good policy if climate changes*? The redeeming feature of these questions is that they are a constant reminder of the context in which climate change is taking place. In the examples offered below, I try to show how context dramatically changed the nature of the insights that could be gained from the study of climate change issues. However, while I thought this approach would provide the most useful information applied science could offer, it ignored whether such information was in demand by decision-makers. It also ignored whether such information would be easy to digest once demanded.

Three factors distinguished integrated assessment of climate change at Carnegie Mellon University (CMU), and my experiences over the past decade. These differences were:

- We had little expertise in climate change science.
- We tried to define the relevant questions from a decision-analytic basis before starting the research program.
- We insisted on characterizing the uncertainties hampering informed and assured decision-making.

However, we were fortunate in having a team of colleagues who had substantial experience in developing integrated assessments starting in 1981. We were also blessed with a strong research program on public perceptions of risk and systematic risk communication. Our department had cut its eyeteeth on problems such as acid rain [2, 3], local air pollution [4] and radon and electromagnetic fields [5–9]. These differences in starting points, spared our effort from a common misstep in climate change research – *a narrow focus on climate change ignoring other forces of change acting on similar or shorter time scales.*

At first blush, a lack of domain expertise is a fatal flaw in any assessment effort. This is true under two conditions: (a) if we were shy about seeking-out expertise when needed; (b) if we were unable to identify when we needed such expertise. However, by not having experts in climate science, global economics, ecological and ocean dynamics we were not obliged to shape our effort to include a pre-existing set of models or adopt their natural scales into our integrated assessment. The advantage of not having to start with pre-existing models developed to address questions that have differed in scope and scale can hardly be overstated. Of course the drawback has been that by not adopting pre-existing models we have had a more difficult time persuading the domain experts that the features of their knowledge relevant to climate change decision-making are being faithfully reflected in our integrated assessments.

While an initial question capturing the challenge of climate change policy is simple to pose, its refinement into the concerns of different stake holder groups is critical to adopting an appropriate scale of analysis. This process of identifying the relevant questions involved many person-years of effort and took over six months to complete. In this exercise we explicitly identified different stakeholders and their varying ethical and political stances on climate change and climate policy (see Table 2). Thus, we defined the scope and scale of the problem that was not limited to dollar denominations of costs and benefits. This broader definition of variables relevant to decision-making and policy formation broadened our effort beyond reliance on economic ‘‘solutions’’ to the climate change problem.

The next step was to figure out how different social and natural processes interacted. This was accomplished by developing influence diagrams of increasing sophistication through which we explored scale and scope issues relevant to climate change and its context. These influence diagrams were used to explore how a snapshot of interactions would vary from short-term and long-term interactions and how a diagram of regional interactions would differ from one with a global focus. Figure 1 reproduces an influence diagram proposed by Granger Morgan and refined by the research team late in 1991.

Finally, decision-analysis requires an understanding of the uncertainties relevant to each choice. We spent much of our first year recognizing that there were parametric and

[1] Just consider any thesis or research project you are familiar with. Did it start with the questions that it finally answered, or did the questions that were answered emerge from the process of doing the research? In my case, the research has always revealed questions that were unknown to me before the research was started. Furthermore, these questions needed to be answered before the initial objective could be addressed.

Table 2. Climate questions climate change policy (developed during the first 6 months of the integrated assessment program)*.

1. What policy issues will drive the evolution of the climate change problem?

How big an issue is climate change?

1. What is the relative importance of climate change issues, compared with other issues, faced by groups around the US and the world?
2. What is the likely relative weight in US and global decision making of those groups for which climate issues are of significant importance? (the answer allows us to identify "key groups" in the climate change issue)

What are the alternative responses that might be used in dealing with climate change?

3. What options exist for avoiding or limiting changes through reducing the emissions of greenhouse gases and/or reducing anthropogenic changes to albedo and standing bio-mass?
4. What options exist for geoengineering to avoid undesirable climate change while continuing current loadings?
5. What options exist for adapting to climate change?
6. What are the relative advantages and disadvantages for alternative responses and their implementation strategies to "key groups?"

- What is the ethical acceptability of each to "key groups?"
- How well are the economic costs and risks of each known?
- How well are the political, social, ecological and other non-economic costs and risks of each known?
- What are the prospects for reducing key uncertainties about costs and risks of each through research?
- How well are the economic benefits of each known?
- How well are the political, social, ecological and other non-economic benefits of each known?
- What are the prospects for reducing key uncertainties about benefits of each through research?
- What are the most attractive options for each "key group" if groups must act alone?
- What are the most attractive options for each "key group" if groups could act collectively?

What choices will and should be made?

- What are the most likely policy responses for each "key group" given their current "decisions making culture?"
- What are the opportunities for improving individual or collective outcomes through various policy interventions?
- If collective action is required, how is it best achieved?

2. What are the determinants of how various "key groups" value the effects of climate change and of possible policy interventions and reach decisions about them?

What ethical framing does each "key group" apply in addressing these issues?

- What is mankind's relation to nature, to time etc.?
- To what domain of issues is "economics" considered applicable? What issues are framed in terms of rights, duties, etc.?
- What are the conflicts and contradictions between the ethical framing adopted and the constraints of physical reality?

What views does each "key group" hold about the nature of the climate and earth/biological system?

1. How is economic analysis done? How should it be done to be consistent with the group's basis ethical framing?

- How are various things priced or otherwise valued? How should they be?
- How are things valued over long time periods? How should they be?
- How is aggregate economic performance measured? How should they be?
- How are large (non-incremental) changes evaluated? How should they be?

What are the mechanisms for collective decision-making and dispute resolution?

- How are decisions made within the group?
- How are decisions made between groups?
- What options exist to "improve" collective decision-making and dispute resolution?

3. What are the human activities that can modify climate?

What are the emissions and activities of concern?
How are they distributed geographically?
How much have they changed in the past?
How might they change in the future (absent any intervention)?
How do they compare to non-anthropogenic emissions?

4. What changes in climate will occur?

What are the measures of global climate change?
How do greenhouse gas emissions cause changes in these measures?
What factors affect the rate of change?
Has change already resulted from human activity?
What magnitude of changes might result from increases in future emissions?

5. What effects will this climate change bring?

What is the magnitude of sea-level rise that might occur?
What is the effect on agricultural crops?

Table 2. (*continued*)

What is the effect on managed and unmanaged ecosystems?
What is the effect on water supplies?
How do the above effects change the prospects for (a) goods and services, (b) human health, (c) how time is spent, (d) the physical environment, (e) social justice, and (f) other social interactions?

Note. *Note that in contrast to many lists of "climate questions," this list begins with policy issues and moved on to matters of straight science only in its later stages.

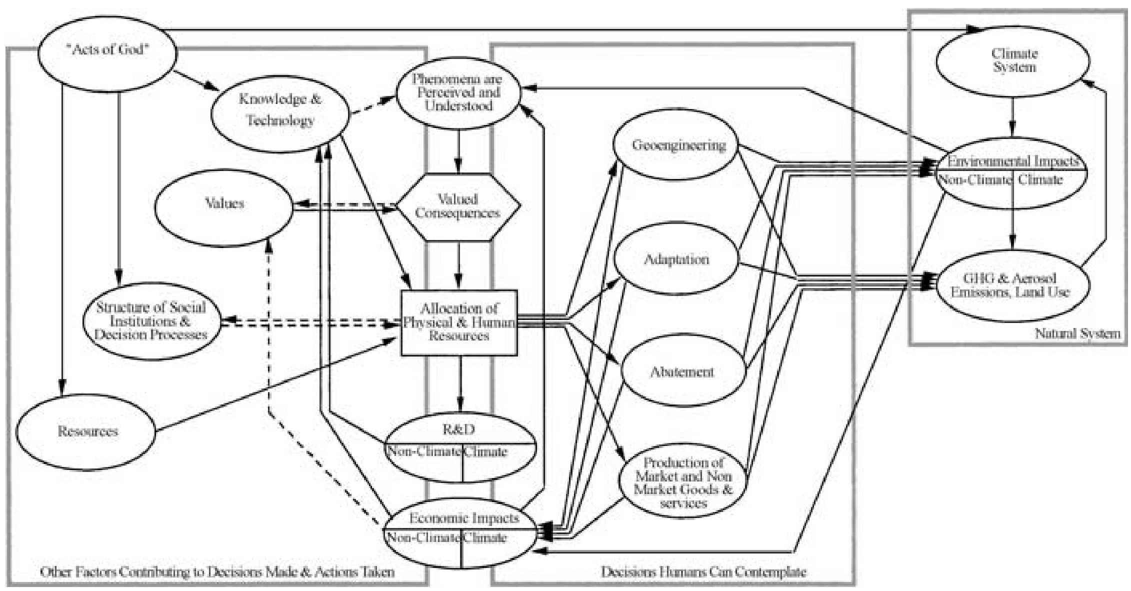

Fig. 1. A global influence diagram of the climate change problem (see textbox for further explanation).

This framework treats the problem as being divided into four broad domains. These domains are, from left to right: the setting of the climate problem, the apparatus of the human decision making and sustenance, the options available for dealing with the climate change issue; and the natural system.

- The setting of the climate problem has five major components. These are:

  i) The stock of knowledge, science, and technology.
  ii) The values held about change in various elements of the human and natural system.
  iii) The structural of social institutions & decision processes.
  iv) The stock of resources, which are a "god given endowment." At any given time only a fraction of this is available to the allocation model. The size of this fraction is determined by the state of our knowledge and technology.
  v) Acts of god which occur in both the natural and the human systems and can be characterized as volcanic eruptions and revolutions respectively.

- The human sustenance and decision making apparatus is made up of three elements. These elements are:

  i) Humans perceive phenomena, understand these and identify potential problems/hazards.
  ii) The latter initiate an enquiry which requires assessment of a value for the various consequences being pondered.
  iii) The valuations dictate a paradigm and (possibly a strategy) for resource allocation.

- The resources available can be distributed among the various options based on the valued consequences and the current state of knowledge. The options available at any given time fall into five categories:

  i) Invest in more R&D and learn about the potential problem and possible solutions.
  ii) Continue with the use of resources and economic development.
  iii) Adopt a GHG and land use change abatement policy, so that the magnitude of climate change can be kept in check.
  iv) Adopt a strategy for adapting to climate change of a given magnitude.
  v) Engage in geoengineering options designed to keep climate parameters of consequence within prescribed bounds.

- These actions will all have impacts on the natural system. Here this system is divided into two elements:

  i) The climate system.
  ii) The environment.

Finally it should be noted that changes in the climate system and the environment are either directly or indirectly (via economic impacts of change) picked up by the human decision making and sustenance apparatus.

structural uncertainties in our understanding of the natural and social systems that make up life and its environment on earth. We also noted variability among different actors in how different aspects of life are valued. These uncertainties were so large that we spent the first eight months of the project wondering whether a quantitative model of climate change would serve any useful purpose when uncertainties were so large. However, we as a group felt more comfortable using quantitative rather than qualitative modes for expressing our ideas and we did build a series of models to discuss the useful and the feasible features of such models. By this stage we were ready to discuss an iterative approach to integrated assessment that would start with the simplest framing that captured the relevant features of the problem and cycled through different iterations to refine the information needed to answer specific questions [10]. Having defined the scope of our research through these questions, we had to adopt a scale at which to study them.

An overwhelming feature of the questions listed in Table 1 is that climate change and its impacts, as well as the various response policies we may adopt (i.e., adaptation, mitigation and geoengineering) will be manifested in different ways in various regions of the world and perceived differently by different people. This heterogeneity in outcome and in perceptions about these outcomes has dictated the scale adopted for ICAM.

Our research group's conclusions about the scale and scope of the climate problem were first published in reaction to the analyses already in hand. The most prominent studies of climate change and policy up to 1991 featured:

- unitary global actors,
- time horizons spanning a century or more,
- no admission of uncertainties in understanding of possible climate change processes, and,
- no admission of how options to abate greenhouse gas emissions, adapt to climate change impacts or engineer the climate system would be valued by different interested parties.

We were certain that it would be erroneous to start an integrated assessment with these assertions [11, 12] and hence developed a framework explicitly representing differences in subjective perspectives on costs and benefits of climate policy and uncertainties in climate science [13]. In this particular study (ICAM 0), the scale at which the problem is resolved is that of the values humans bring to climate change mitigation and climate change impacts.

2.2. Perceptions, Impacts and Adaptation

The most important driver of our evolving perspective on scale has been the issue of subjective perspectives and heterogeneity of experience. In other words, even though we are considering global climate change, different locations will experience different changes to their climate and different people will evaluate the desirability of the same change in their climate differently.

The initial steps to reflect these realities in integrated assessments led to ICAM 0. In this version, while climate change was globally homogenous, nine different perspectives could be entertained on climate policy costs and climate change impacts [13]. We found that subjective perspectives dominated scientific uncertainties in such analyses. Today, a decade after we first framed this question, while scientific opinion has gradually solidified around the reality of anthropogenic climate change, the policy divide has remained intractable. There are those who believe mitigation is more costly than realizable benefits, while others believe the benefits are so large that draconian controls must be undertaken immediately. There is fundamental polarity of opinion on these issues. This polarity drives the dynamics of any policy initiative regarding climate change. While our efforts have been aimed at providing higher and higher resolution scientific models of climate change, we do not know how such increased detail affects the perspectives of different individuals. What we need is a better understanding of how additional information may change the positions adopted by the different parties. In a democracy, the challenge we face is to provide credible and targeted information to move the debate forward. Finer geographic scale simply leads to modeling results (regardless of relevance or accuracy) being believed more readily by the public – simply due to their realistic depiction of familiar geographic outlines.

In ICAM 1 we allowed for different manifestations of climate change in a world with two regions (low latitudes and high latitudes), even though the people in each region had similar judgements about climate policy and climate change impacts [14]. Since that time, successive generations of ICAM have had finer spatial and temporal scales, primarily to increase the accuracy with which specific spatial heterogeneity is reproduced. Fundamentally however, the original insights of ICAM 0 (which had no spatial scale) prevail – people's subjective perspectives dominate scientific uncertainties in choosing an appropriate climate policy.

Beyond the insights from ICAM 0, I have come to recognize that a focus on subjective experiences should dictate a much finer scale of resolution for realistic analyses of the issues at hand. Cognitively, change will be experienced on a local level. Slow trends, may never be consciously noted and are likely to be swamped by our efforts to adapt to the large and inevitable changes we all undergo – e.g., aging. In other words, while we age, our perceptions of what is changing in our local and more distant environment and whether that is desirable evolves through time. For example, we recall much higher snow fall from when we were children (partly because we were shorter). We also tend to grow less tolerance of cold weather as we age, and reconsider the ideal climates to live in.

One of our team members, Shane Frederick [15], explored how much people think they change as they age. For example, he asked 15-year-olds how similar they thought they would be to their current selves when 50, and he asked 50 year olds how similar to their current selves they were as teenagers. His findings show that people expect significant changes in their personal activities and preferences over time. Many believed that they would retain less than half of their personality traits over the span of three decades [15]. These levels of personal change are clearly far larger than environmental changes that we seek to forestall or prepare to adapt to. Therefore, it is not unreasonable to expect almost sub-conscious adaptation to environmental trends that take place more slowly than the personal changes we inevitably experience.

I am not suggesting that all slow changes in environmental conditions go undetected, but some are likely to be lost in the noise. Furthermore, when the underlying factors shaping environmental conditions are complex, the interpretation of detected changes is open to misinterpreted. For example, changes in local land cover and air pollution affect local climates. In Pittsburgh, average annual temperatures fell by 3 °C from 1950 to 1970 and rose again by a similar amount from 1970 to 2000. When surveyed, the public was perhaps too young to have experienced the former cooling trend but readily noted the warming trend. Furthermore, they readily attributed this warming to "global climate change." It is more likely though that the warming in Pittsburgh is due to much lower atmospheric concentrations of sulfate aerosols brought about by the demise of the local steel and coke industries and successful implementation of the Clean Air Act. Correct attribution is critical to taking appropriate actions. Today, our institutions have prepared the public to worry about climate change. Various phenomena will be tied to climate change by the public whether or not such conclusions are scientifically valid.

This issue is even more pronounced for extreme events, and these leave lasting psychological impressions. Extreme events are easily detected and often attributed to phenomena that the public psyche has been primed to accept. The wrath of this or that god common in polytheistic cultures is in response to some human misdeed. Today's sin is often assumed to be our despoiling of the environment, but the wrath remains the same: storms, floods, droughts and so on.

Studies of the available evidence do not support the notion that extreme events have changed dramatically in their frequency and severity over the past century [16]. Nevertheless, over the past decade extreme events have routinely been attributed to anthropogenic climate change. Our social organizations have adopted climate change as their favorite cause for any detected changes in adverse environmental conditions. Furthermore, improved newsgathering and dissemination has allowed information about extreme weather events (which are essentially local in nature) to be broadcast worldwide. This has blurred geographic factors (which have a significant bearing on the possibility of specific extreme events occurring locally) and contributed to the sense of public dread about climate change. This provides further evidence of cognitive dimensions of the problem dominating geography.

Social institutions not only play a role in our interpretation of environmental changes, but also the dominant modes of response. As noted above, there is little statistical support for the notion that extreme weather events have increased in their frequency or severity. There is little doubt that they would persist whether there is a climate treaty or not. Sadly, the global response to these events has not been a call for better warning and response measures for dealing with extreme weather events (especially in less industrialized countries), but a clarion for mitigation of climate change. Schelling [17–19] is eloquent in arguing for promotion of development as the most effective measure to address the vicissitudes of climate. However, environmental activists use the extreme events to feed the fires of our remorse for being insatiable consumers of the earth's exhaustible bounty. Integrated Assessments are about how problems are framed and solutions explored. The scale of analysis needs to reflect who is active in proposing interventions to protect life and property and what measures they are promoting. An early warning system and response needs to be adapted to local geographical conditions and suitable for implementation using local resources. A global carbon dioxide control strategy rarely considers factors beyond large players in the energy markets.

2.3. Sea Level Rise Revisited

One of the more thoroughly studied impacts of "global warming" is sea level rise. Global mean sea level is expected to rise due to thermal expansion and a net release of water from glaciers worldwide. There is no doubt that rising sea level will inundate low-lying lands.[2] However, there are three processes of local importance that will define our capacity to adapt to sea level rise. The scale and scope of climate change assessment must be sufficiently fine and broad to capture these processes. Otherwise, the information provided to decision-makers will be erroneous. These three processes are:

- Factors affecting relative sea level in specific locations (physical and cognitive)
- Factors affecting local development of coastal areas (cognitive and institutional)
- Factors affecting recovery from storms (cognitive and institutional).

[2]There is also no doubt in my mind that we will not implement a climate policy that will save the populations and resources at risk from sea level rise in the next few decades.

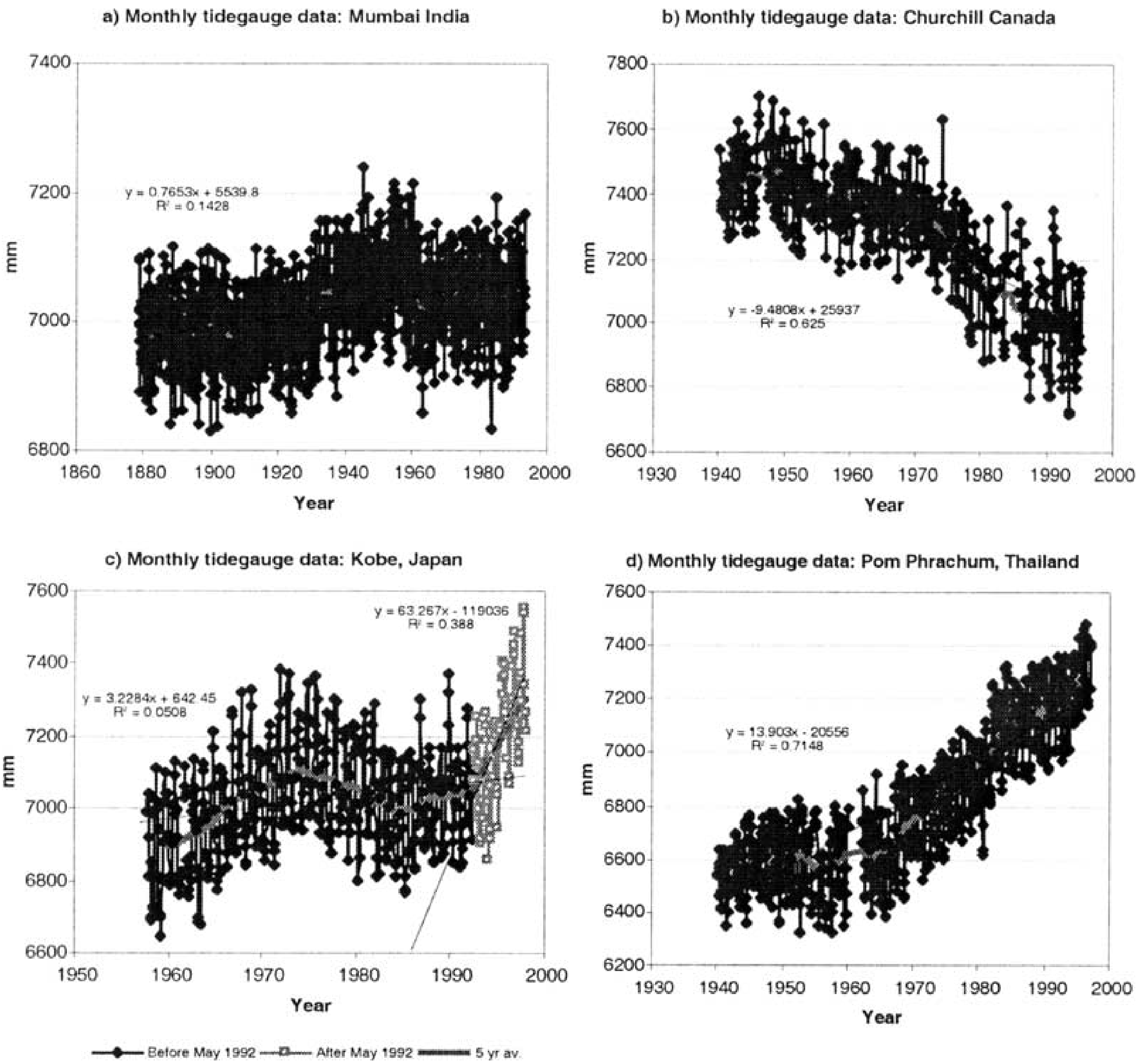

Fig. 2. local trends in relative sea level. Figure 2(a) shows that while the long-term trends in monthly tide-gauge data for Mumbai suggest a relative sea level rise of .7 mm per year. But the raw data suggest two periods of relative stability in relative sea level with more rapid changes in sea level during periods of transition from one level to another. In Figure 2(b) we observe that tide-gauge data for Churchill, where the glacial rebound of the Canadian Shield is argued to be continuing leading to relative fall in sea level. In Figure 2(c) we can observe that tide-gauge data in Kobe, Japan are recording rapid changes in relative sea level with the trend changing sharply in the wake of the massive earthquake suffered there in 1994. Figure 2(d) reflects tide-gauge data for Pom Prachum in Thailand where surface water management in Bangkok and withdrawals from the water table have influenced a much more rapid rise in local sea level in the past four decades. The rate of change in sea level here is 18.5 times faster here than in Mumbai.

Figure 2 depicts local relative sea level for four different locations. The differences between these are staggering. The local sea level is rising 18 times faster near Bangkok than near Mumbai. The reason behind the dramatically faster local sea level rise near Bangkok is fresh water withdrawal and surface water management causing land subsidence. It is clear that in this case sea level rise due to climate change is a secondary issue. Rapidly growing demand for fresh water is not unique to Bangkok. In many low-lying islands and coastal areas the same challenge exists. The problem is local. The condition is repeated globally. Thailand is in the process of implementing programs promoting water table recharge to slow local subsidence. It is not clear that in other locations encountering the same challenges, the institutions to respond are in place.

Coastal developments are another example of a local phenomenon globally repeated. Safe harbors gave shelter from storms and made it possible to have a sustained fishing effort or establish trade centers at the mouth of inland waterways. If the location was not safe it could not prosper long. Now, shorelines are being developed for leisure and housing. Many of the locations being developed today were not developed historically because of their vulnerability to storms. Unfortunately, developers rarely consider this in locating new homes and communities. Their goal is to develop property, sell it and move on. Their exposure is being hit by a storm between setting the foundation and handing the key to an unsuspecting immigrant to that location. This clearly increases exposure to extreme events on the coasts, but again, the factor that is leading to rapid increases in risk is not climate change but ill-considered location of new developments on the coast.

The news is not all gloomy. The ability to forecast storms and the ability to move people out of harm's way have improved dramatically over the past century. From 1900 to 1910 more than 8000 people perished in storms pounding the coastline of the United States. During the 1990s, this number had fallen to $1/50$th of 80 years earlier. Meanwhile, property damages quintupled from \$4 billions in the 1930s to \$20 billion in the 1990s. This is because so much more property was placed in harm's way in coastal developments.

How much damage is inflicted by storms in the future is dictated by how much of our resources we place in harm's way. This is a repeated game. Each storm brings information about places where property is at higher risk. We can reduce future exposure to this risk by not rebuilding there. This iterative process of locating our developments where they are safe from storms is key to reducing the impacts of future sea level rise.

In our studies of impacts and adaptation we have learned that where it is possible to create institutions to "learn and respond to natural extremes" impacts from climate change can be significantly reduced [20]. We have learned three important lessons from this work:

- *Local development patterns determine the initial conditions and exposure to risk.* There is no reason to believe that current development patterns are optimal in their reduction of risk to coastal dwellers.
- *Local regulations governing recovery from storm damage determine the persistence and cumulative damage from storms through time.* Where storms send strong signals of inappropriate development, rebuilding is unwise. If regulations limit such rebuilding, total damages from storms and sea level rise combined can be reduced by an order of magnitude over a century time-scale.
- *If rebuilding regulations prohibit rebuilding in risky locations cumulative damages from small storms far exceeds those from large storms.* Should climate change lead to more extreme storm events, the long-term impacts in coastal areas will be lower.

These insights all point to the role our perceptions play in the design of institutions created to address our concerns. We worry about households who suffer the impact of coastal storms and riverine flooding but create institutions that often help them rebuild their property in harm's way. We worry about the impact of more severe storms, but it is the small and frequent storms that inflict the greater cumulative damage. Perceptions are critical to our ability to recognize what contributes to the risks we face and how best to reduce these. Climate change impact assessments need to be developed with a scale and scope appropriate to capturing the essential features of human perception of natural events and their impacts, and how best to limit their initial impacts and recover from their consequences.

2.4. Energy Markets and Technological Progress

I would like to use energy markets and technical change to highlight the issue of co-existing and competing scales of organization as a fundamental feature of social systems.

The single most important factor in determining future atmospheric concentrations of greenhouse gases is technical change. Technical change determines the pattern and extent of economic activity. Technical change determines the types and magnitude of resources we harness to meet economic needs and our expectations about lifestyles. Climate policy is our attempt to influence the direction of technical change so that a given level of economic activity can be achieved at lower levels of greenhouse gas emissions. Interestingly though, technical change is more often than not treated as an exogenous factor in studies of climate change [21, 22]. The inadvisability of treating technical change as an exogenous variable aside, scale plays a significant role in how technical progress evolves.

In ICAM-3, technical change has been formulated as an endogenous process [23]. I am a believer in the old saying: "necessity is the mother of invention." Therefore, I believe that purposive technical progress is brought forth to solve a perceived problem. Scale enters the picture because of the way in which I believe technical progress is diffused. For example, whenever energy prices rise, technical change is unleashed to come up with a solution. But there are at least two solutions to this challenge: (a) discovery of lower cost ways to produce energy, (b) search for more efficient ways of using energy. I believe that evolution of the pattern of energy use is then shaped by competition between technological innovation and diffusion on the supply side and technological innovation and diffusion on the demand side of energy markets. There are however, significant differences in organizational coherence on the two sides of this market. This, difference in organizational scale leads to a particular pattern of dynamics that needs to be taken into account when considering long-term policies affecting energy use.

Energy supply is a fairly concentrated and large-scale activity. Energy costs are the primary concern of this industry and their innovative activities are unlikely to be captured by other concerns. Therefore, innovations are directly aimed at improving energy discovery and production and are rapidly adopted when needed. On the demand side however, energy is used in order to gain a large variety of services and labor savings. For the innovator and adopter, the services delivered are the primary concern and energy use is secondary. Furthermore, the scale at which technology is adopted is household-by-household and business-by-business. Therefore, adoption is a far slower process and rarely motivated by energy (or carbon) saving considerations. This leads to a particularly interesting dynamic process of technical progress and diffusion in energy markets. In the wake of a crisis that raises energy prices, there is innovative activity in both the supply and the demand technologies. However, the more rapid adoption of technical breakthroughs on the supply side lead to more plentiful supply (of a resource or its substitute) and lower energy prices. One example of such technical breakthroughs is in oil drilling and production. We are now able to direct the drilling process in any desired direction. When this capability is combined with monitoring of chemical gradients in the well, the drill can be piloted towards the smallest of reservoirs. This has permitted economic oil recovery from reservoirs previously considered too small to exploit or even include in reserve assessments. Rapid adoption of technology on the supply-side often lowers energy prices before the technologies promising better end-use energy efficiency are broadly adopted in the market. Such technological progress is not lost, but is more often used to deliver a wider range of services for which energy is being used.[3] Here the diffusion of technical progress may be slower, but can persist even when energy prices are low or falling. The reason for this paradox is that the technical progress in question (e.g., variable valve timing for internal combustion engines) is no longer solving the problem for which is was invented (higher fuel efficiency), but by providing more services (a broader and higher torque curve from the same engine displacement) is a weapon in the auto industry's competition for the consumers' pocket book.

2.5. Scale, the Study of Climate Policy and its Evolution

At the outset I argued that climate change is not a problem of unprecedented scale. I argued that humanity has a long history of affecting its environment to the limits of its known extent. In contrast to climate change, I believe organizational scale and persistence needed to implement an effective climate policy has no historic precedent. Greenhouse gases are long lived. The climate system responds with a lag of something between 10 and 50 years. The dynamics of terrestrial ecosystems and carbon storage are on the century time-scale and ocean processes have elements whose temporal extent can span more than a millennium.

In order for us to entertain a successful solution to the climate problem, we need to recognize the required longevity of an effective policy. Such a policy needs to stabilize greenhouse gas concentrations in the atmosphere. Doing so requires century-scale persistence in control of emissions. Few human endeavors have spanned such time-scales unchanged. Political systems rarely last more than a decade. Even fundamental social movements rarely last more than half a century. For example, consider the social programs that shaped the governments of Europe in the decades following WWII. All have come to be reviewed and redefined in the closing decade of the twentieth century. Sovereign nations also seem to have a longevity that rarely exceeds a century.[4] It is hard to imagine how a climate policy will be made stable over such long time-scales. Even the signatories to the treaty will change over its requisite duration. The only feasible approach to making sure climate policy can survive this underlying pattern of instability is to make sure there are irreversible steps in the path to lower greenhouse gas emissions. This irreversibility would ensure continuation of reduced emissions even when the forces making climate policy desirable fail to see through their vision.

Beyond unprecedented longevity, a successful climate strategy needs to involve all major emitters of greenhouse gases. Without the participation of the OECD, Former Soviet States, India and China, emission reduction efforts have little chance of assuring stabilization of greenhouse gas concentrations in the atmosphere. At present, climate change is one of the last concerns of most less-industrial countries. They face the danger of instability as they have raised the expectations of their populace with visions of plenty and wealth in the wake of liberalized markets and globalized trade. It will be difficult to meet these expectations. It may be possible to implement climate policy as a means of reducing expectations. Just as at times of war, the general public willingly adopts austerity and hardship in order to achieve a greater good. Whether this approach will or can be adopted remains to be seen.

It is possible that a clever government can translate public concern about extreme events into adoption of a climate policy. Imagine a setting in which the above has been achieved and a fairly comprehensive emissions control program is in place. The public is likely to continue to

[3]Take the efficiency of internal combustion engines. Today's, average engine is twice as efficient as an equivalent engine (of similar output) 30 years ago. However, as energy prices stabilized and then fell during the 80 s and 90 s, the performance of engines was nudged up, almost every year, in order to attract customers.

[4]Religious movements probably last the longest, but evolve considerably over time.

associate extreme weather conditions as manifestations of climate change. How will they respond when we continue to have extreme events even after a decade or more of self-imposed austerity? I believe there will be strong local forces to break global compacts to control emission. Here again, cognitive forces dominate the dynamics of policy formation and dissolution.

If a large enough party to the global climate accord steps away from the agreement, resuming a growing emissions trajectory, the burden of control for the remaining parties to the agreement can grow to the point of extreme economic discomfort and further defections. A domino effect would then take over and the mitigation policy would collapse. The mechanism and probability of such policy failures are reflected in ICAM-3 and discussed and elsewhere [24]. This is an example of how at the international level the cross-scale organizational features of initiatives for climate policy implementation dominate the dynamics of their stability and success.

An interesting aspect of the climate change challenge is that mitigation is not the only policy option. There is likely to be adaptation to climate change, whether or not there is a mitigation policy. This can be undertaken at different scales appropriate to representation of different aspects of climate change and its impacts. However, geoengineering of the climate system is also a possibility. A possibility that can be launched unilaterally by a nation that perceives a sufficient threat from climate change. The requisite technology is not too sophisticated, the scale of the impact can be limited to one region and the persistence of the effect can be as short as a few weeks. This policy can be launched with little prior preparation, yielding almost immediate relief from some aspects of climate change. In summary, different policies require different scales of participation and persistence. For mitigation (the policy most often talked about) to be successful requires a scale of participation that has no historic precedent.

3. CONCLUSIONS ON SCOPE AND SCALE

The examples I have offered suggest that even in the study of a global process such as climate change the scope should be expanded to include local phenomena, such as local changes in sea level or initial conditions for coastal developments. In other words context matters a great deal in how climate change impacts will emerge and how well we can cope with these. There is broad agreement that multiple stresses acting on the system simultaneously are where we should be focussing our attention. We are now in a better position to realize that interactions between different stresses and the remedies we adopt in dealing with these are how we change the profile of our vulnerability [25, 26].

I worry that the narrower scope of initiatives such as the Intergovernmental Panel on Climate Change have led to too much focus on climate issues and insufficient attention to other processes of environmental and social change. I also believe that there has been a misallocation of human capital to the study climate related issues while these other issues loom larger and more immediate. Therefore, I fear that the narrower focus on climate change, adopted by so many of us, has needlessly limited the generation and delivery of appropriate scientific information to the decision-makers responsible for shepherding local, regional and national development plans.

The focus on crafting a global accord on climate change has led to a political impasse that, if ever made substantive, is unlikely to deliver a solution that will be embraced by the industrialized and non-industrialized nations alike. Meanwhile, we could have tried to craft an accord on a global effort to deliver potable water, or sanitation. We could have launched a program on mapping global natural hazards and put into place institutions that can limit our vulnerability to these. Unfortunately, by continuing to focus on Kyoto, these and other opportunities to implement good policies whether or not climate changes are being lost every day.

The insight I hope to illustrate with the examples above is the importance of understanding and representing interacting processes at appropriate scale(s). All too often, the different sides of an equation (or system in dynamic tension) are represented as being at the same scale. The social sciences are an aggregation of scholarly studies at different scales from the cognitive psychologists who focus on the individual, to organizational behaviorists who study groups of people aiming to achieve a specific goal, to social and political scientists who study our interactions at higher levels of aggregation. What makes the social sciences so very difficult is that under the appropriate conditions, observed phenomena are under the influence of forces at many different scales. Unlike the natural sciences (specifically Physics) where at a given scale, one force of nature dominates interactions, in social interactions cognitive processes of the individual are affected by the culture of the society and the society's culture can be shaped under the influence of an individual's thought processes. This is not simply true for public policy, it reaches deep into our psyche and permeates how we conduct research in both what we choose to study and how we interpret available empirical evidence [27]. In a sense this can be viewed as coming back full circle. After ten years of research, I am still asking, *what is good climate policy*? and *what is good policy if climate changes*? But at least I have some idea that the problem needs to be tackled using multi-scale analyses that reflect human cognitive and organizational issues as well as the scales at which natural processes operate.

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