THE NEW CHALLENGING FUTURE OF "EMERGENCY" CLIMATE RESEARCH

In the 'Future of International Cooperation in the Earth Sciences and Services'

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Climate change research entered a new and different regime with the publication of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (Solomon *et al*., 2007, Parry *et al.,* 2007, Metz *et al*., 2007). There is no longer any question about 'whether' human activities are changing the climate. Instead research must tackle the urgent questions of: 'how fast?'; 'with what impacts?'; and 'what responses are needed?' Climate change researchers can no longer solely improve models/observations, despite the need for such improvements. We must face that fact that answers are now being demanded faster than, and at higher resolutions than, climate change practitioners can currently deliver. One consequence of this situation might be that international cooperation in climate-related research be re-directed to "emergency" climate change unknowns and that the climate change research community become more obviously transparent as we describe what can (and cannot) be delivered and how (if ever) current inadequacies can be resolved.

Action is undoubtedly and urgently required to adapt to inevitable changes and mitigate further 'dangerous climate change' (UNFCCC Article 2). The way in which science interacts with policy and, more broadly, with society is not a new dilemma (e.g. Crewe, 1967, reprinted 2007). In my opinion, the challenge is to separate but make coexist the traditional 'objective' climate science and a new type of 'emergency' research. Today, I shall introduce the latter, which is needed now because, as was stated in 1984 and is still (& even more so) true today: "important economic and social decisions required to be made today … on the assumption that past climatic data are a reliable guide to future.. (is) no longer good" (Villach, 1984).

There are widely agreed priorities for climate change emergency research including:

- Make climate predictions out to 30 years (we've only created projections to date);
- Regionalise these predictions of future climate to advise mitigation by determining threatening thresholds and adaptation by identifying changed climate stress; and
- Validate these regionalised predictions – including with high quality observations.

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1. OPERATIONALIZE CLIMATE PREDICTION

1.1 Transparency: the real climate challenge is to mesh science with society's needs

We are, in my opinion, on the brink of genuine climate predictability. In many ways, climate forecast capability in 2008 resembles the nascent medium-term weather skill in the late 1970s. Then, far-sighted nations created dedicated forecast centres, notably the European Centre for Medium Range Weather Forecasting (ECMWF) to grasp this new skill. Furthermore, the undoubted demand for genuine climate prediction needs to be harmonised with societal needs. Figure 1 represents an attempt to synthesize emergency climate change science imperatives with policy demands by focussing on 'hot spots' around the world where regionalised climate change predictions are urgently demanded.

Today, climate research faces orthogonal demands to: remain a purely 'objective' activity (e.g. IPCC mandate to be policy relevant but not policy prescriptive) and, alternatively, to redesign and direct urgent climate change action (e.g. UN Foundation report, 2007) such as development of new technologies appropriate to a low (or zero) carbon economy; the creative use of markets to help reduce greenhouse gas burden; and even extending to widespread behavioural change. Quoting three well-regarded climate scientists on this science-society issue illustrates the spectrum of views.

- "When risks cannot be well quantified, it is the job of policy to make decisions…. Scientists must make it clear where our job stops and the job of policy begins" (S. Solomon, 2007, public communication, Royal Society, March 2007)
- "Bottom line is how best to deal with risk and provide credible and defensible information to support this activity" (B. Hewitson, 2007, public communication, Royal Society, March 2007)
- "The ultimate policy-maker is the public. Unless the public is provided with unfiltered scientific information that accurately reflects the views of the scientific community, policymaking is likely to suffer." (J. Hansen, 2005, public communication, American Geophysical Union, December 2005)

If it is accepted that science has a responsibility to engage actively with society (e.g. Crewe, 1967) and therefore to undertake and communicate the results of needed research, then three fundamental aspects of the nature of research (to calculate, advocate and

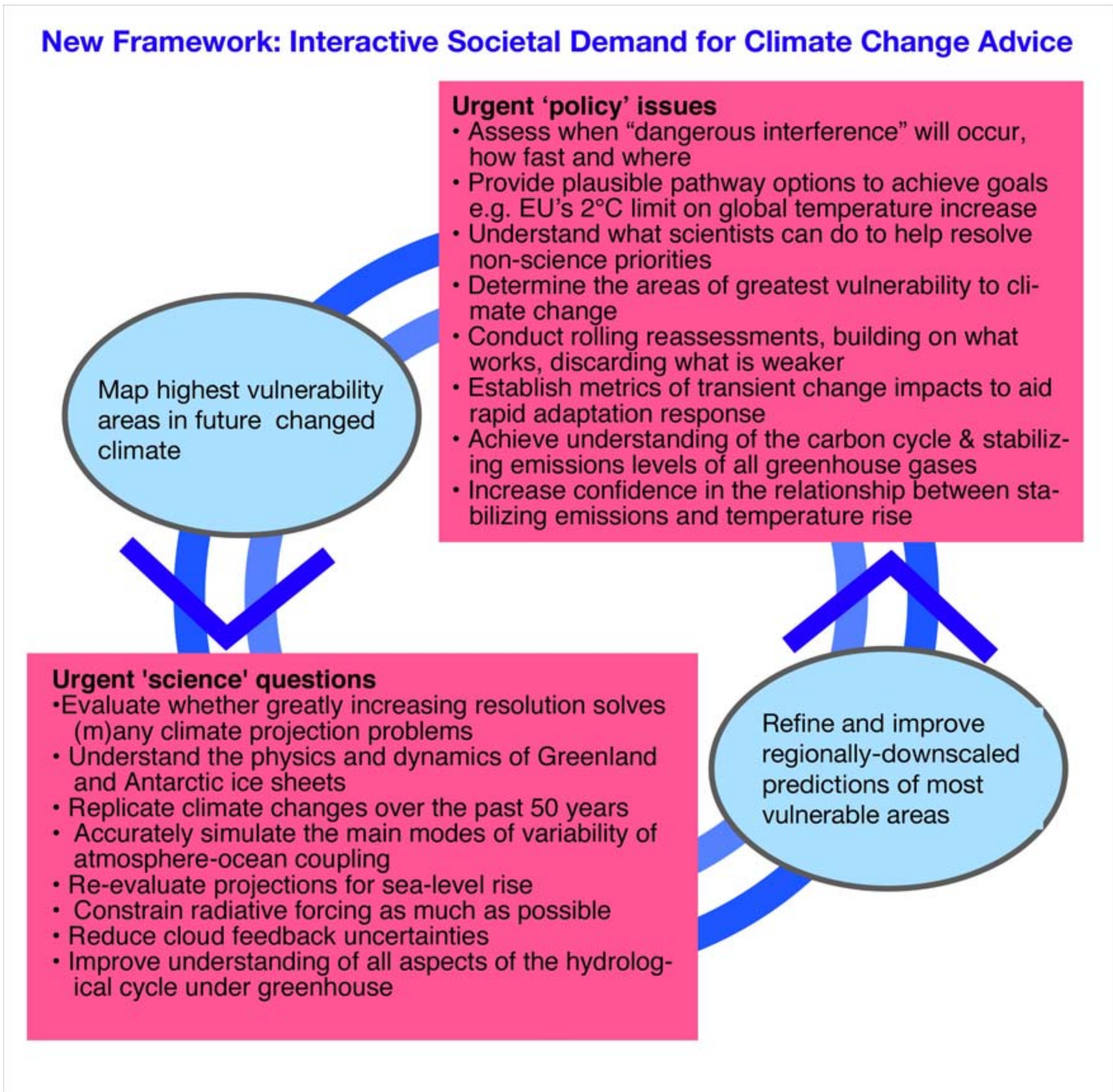

Figure 1: New framework for internationally coordinated research and observations directed towards socially-relevant climate change issues. The cycle is continuing: improved mapping of most threatened regions, prompting relevant science priorities, which, in turn, underpins better regionalising of future climate predictions and feeds into societally-demanded questions (modified from the GCOS-WCRP-IGBP Learning from IPCC workshop report, http://wcrp.wmo.int)

participate) take on different characteristics in the current situation of "unequivocal" climate change (Alley *et al.*, 2007, Solomon *et al*., 2007).

1.2 Ethics: facing the serious inadequacies in climate change knowledge that only research can resolve

In December 2006, the Parties to the UNFCCC agreed on the Nairobi Work Programme: Impacts, Vulnerability and Adaptation to Climate Change. This programme demands regional to local climate predictions. However, contributors to a 2007 survey conducted by the World Climate Research Programme (WCRP) and Global Climate Observing System (GCOS) stressed that, despite this demand, the rush to emphasize regional climate does not have a scientifically sound basis. Specifically, the following comments were stressed as being of high priority in formulating societal response to climate change:

- *Regional climate is not a well defined problem. Until and unless major climate oscillations (ENSO, PDO, NAO, AMO etc.) can be predicted to the extent that they are predictable, it may never be. If that is the case, then climate science must say so i.e. it is not just the forecast but the confidence and uncertainty that are key for society;*
- *Adding complexity to models, when some basic elements are not working right (e.g. the*

hydrological cycle), is not sound science. A hierarchy of models can help in this regard; and

- *Prioritize the models so that weaker ones included in IPCC reports for nationalistic reasons do not confuse/dilute knowable signals.*

In other words, internationally co-ordinated climate change science is in grave danger of delivering a deceptive view of what we know and even, perhaps, what we can know.

In the area of explaining results, especially the difference between prediction (just becoming possible for maybe 20-30 years) and projection (depending on scenarios and initialization) and the impact of future changes, climate science needs to be more transparent in order to deliver useful warnings. On this (short- for climate) time frame, climate predictions are not sensitive to emissions scenarios and hence this aspect can be largely removed from consideration. Yet forecasts on this time frame could be exceedingly valuable. To deliver climate change predictions on this 10-30 year time scale, with estimates of uncertainty from ensembles, it is essential to have the patterns of global sea-surface temperatures. If these are not observed, then they must be simulated and it is clearly not possible to make such predictions without initialisation of oceans and other aspects of the climate system. The extent to which this leads to predictability is not yet clear, but the underlying hypothesis is that there is significant predictability that can be exploited for improved adaptation and planning by decision makers. Early tests of this approach (Smith *et al.,* 2007) show promise and benefit of initializing models, but the benefit thus far stems mainly from a better understanding of ENSO.

That hydrologic extremes (e.g. droughts and floods) will occur must be augmented by 'security threat' characteristics indicating coastal deaths, migration from flooded areas and from regions bereft of water supplied previously from glaciers (cf. Anthes *et al.*, 2007). From today, the urgency of impending change demands that the climate science must be well done, but not only in its traditional role e.g. improving clouds and convection in climate models but in a way that quantifies better high risk, low probability outcomes e.g. thresholds for melting of the West Antarctic Ice Sheet & Greenland ice sheet; for a possible, profound Amazon die back; North Atlantic meridional overturning slowdown (or stopping); and for more and/or more intense tropical cyclones (e.g. Holland and Webster, 2007).

2. VALIDATE LARGER AND REGIONALISED PREDICTIONS

2.1 Interspecies breeding: policy issues that climate change research must tackle urgently

Senior and respected political and economic commentators such as Al Gore (recipient of the 2007 Nobel Peace Prize jointly with the IPCC) and Sir Nicholas Stern (Stern, 2006) have argued that scientific participation in societal debate is necessary to combat the looming climate security threat. I believe that climate change scientists can and should argue for the use of ethical discount rates; for good business goal setting; for better international governance enhancing carbon trading and even pricing virtual water trading. Although many climate practitioners are afraid of seeming to prostitute their science in societal issues, this fear is not universal. A concept paper prepared for the "Learning from the IPCC AR4" workshop hosted jointly by WCRP, International Geosphere Biosphere Programme (IGBP) and GCOS (Bojinski and Doherty, 2007) highlighted some topics as being of extreme urgency for climate change:

- *Monitoring the trajectory of climate change to assess whether we are heading into a danger-zone, how fast and where and continuously revisiting with governments and stakeholders their priority needs;*
- *Examining policy-driven questions to learn what scientists need to do to help resolve such non-science priorities: for example, assisting in determining what adaptation measures are needed beyond current coping capacity;*
- *Establishing metrics of transient change impacts to detect and monitor via rolling reassessment the most likely (use best predicted and discard what is weaker) changes of importance for rapid adaptation response;*
- *Increasing confidence in the relationship between stabilizing emissions and temperature rise: for example by providing pathway options to achieve limits such as the 2^{o}C limit goal of the European Union.*

In other words, internationally co-ordinated climate change science needs to deliver a new view of what society needs to know.

Forty years ago, Albert Crewe (1967 & 2007) argued that science must take a proactive stance in its interactions with wider society. He said then that: "It is up to the scientific community to point out where they can help." "Government cannot be expected to seek our advice and help because they are much more accustomed to solving problems by new legislation." He concluded that, "Perhaps better solutions exist… (but) until we can make ourselves heard…. these problems are in danger of being grossly underestimated". I agree strongly with Crewe's proposition made then in relation to regional air pollution but now clearly applicable to global warming including, ironically, regional aerosol interaction with global greenhouse gas increases.

Climate science around the world costs about US $5 billion every year. I consider that around this total could fund the 'climate threat' research advocated by participants in the October 2007 "Learning from the IPCC AR4" workshop. A window of opportunity exists now for perhaps ten years, but probably no longer, during which well focussed and well conducted 'emergency' climate research might help us manage better (Stern, 2006). There are therefore two options:

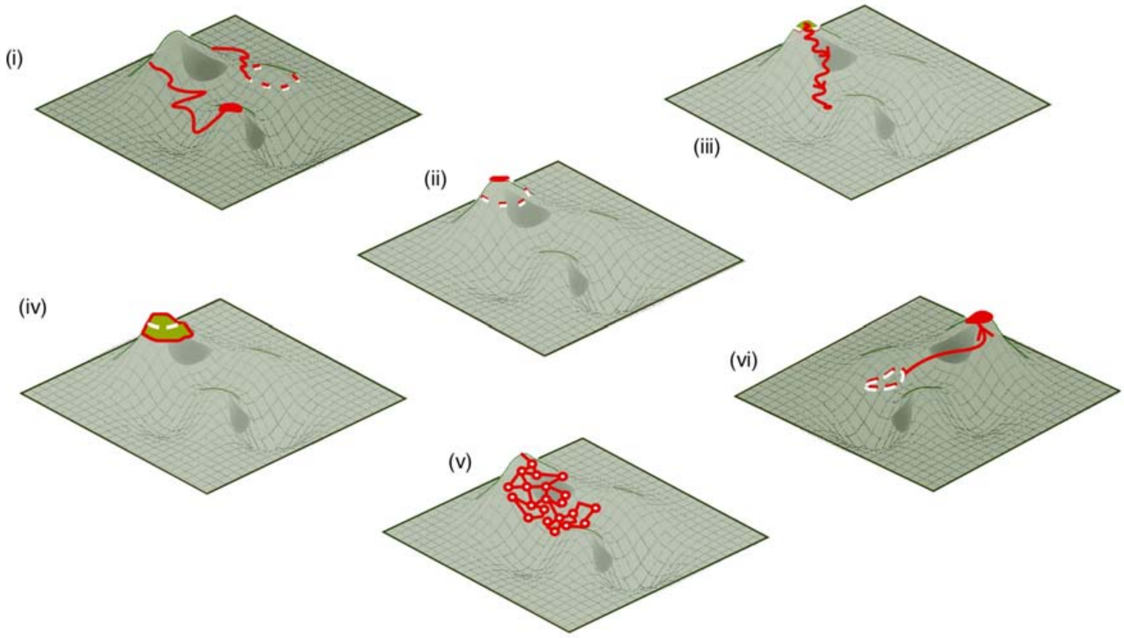

Figure 2 Landscape cartoon showing peaks of skills achievement schematically with various examples of climate model skill evolution (from white dashed to solid red and/or in arrow direction) under a variety of funding and management situations (modified from Greene, 2006): (i) drift may achieve a higher skill level unmanaged; (ii) strong management and reporting pushes to local skill peak but sticks there; (iii) with plenty of funds and poor/conservative management skill evolution can drift down the skill slope; (iv) a high mutation rate (e.g. many model parameters) and plenty of funds actually restricts skill to one hill and may not ever reach its peak; (v) multiple, independent climate models sharing success can traverse saddle points and jointly achieve higher skill peaks; and (vi) an external change such as global warming (here a forced upward tilt of the landscape) appears to give higher skill to virtually any model.

either funding sources (predominantly in the developed nations) could offer to double climate research funds for a decade or society and scientists could give up traditional research in order to focus solely on social and economic greenhouse warming emergency needs. Doubling the current US$5 billion for the 10 years from 2008 to 2018 to develop climate emergency solutions is ***not*** a large funding increase. It is only a 50th of global government subsidies for fossil fuels; approximately a 30th of today's US aircraft sales; and roughly equal to the R&D investment made by a typical European telecommunication firm each year. One single organisation, *Citi*, announced a $5 billion investment p.a. over the decade 2007-2016. However, such a step rise in research funding has not been seen since the Second World War. Indeed, the analogy is excellent as this investment is needed to fight a similar world security threat.

While mentioning step changes, it is also essential to change - both personal and business behaviour. As one example it has been suggested by many non-governmental organizations (NGOs) that market action could be used to fix "carbon poverty". The new economic activity of carbon poverty reduction offers a means for developed nations to invest ~$50 billion p.a. However, wise investment depends critically on knowledge about future regional and even local climate regimes if, for example, protected existing or newly replanted tropical forests are to flourish in the future (cf. Irannejad and Henderson-Sellers, 2007). Unfortunately, there is at present very little skill in regional climate prediction: "*the rush to emphasize regional climate does not have a scientifically sound basis.*"

2.2 Globalisation: Institutional and infrastructure overhaul to advance climate change research

A 'revolution' in climate modelling is overdue (cf. McGuffie and Henderson-Sellers, 2004). Greene (2006) argues that climate prediction has languished near or at the top of local 'highs' in predictive skill for some years and that, while there are possible routes to improving the current models, few if any groups seem poised to pursue these. Contributions in the survey conducted by WCRP, IGBP and GCOS as part of the October 2007 "Learning from IPCC" workshop identified structural re-organization as being of high priority. Participants specifically proposed:

- *Direct our science towards "solutions" (the problem is well understood);*
- *Merge IGBP and WCRP and revitalize the international framework for climate science (including the IPCC);*
- *Solve the "human-ware" depletion crisis: younger scientists be urged, funded and motivated to delve into the climate change challenge; and*

- *Simplify the international facilitatory structure, reducing unnecessary overlap and complexity as way too much time is spent on liaising between 'partners' and participants (e.g. in GEO).*

The first of these quotes, in particular, underlines that science itself sees what it must achieve in order that social and economic systems benefit.

Combining these organizational issues with the ethical, transparency and policy-science priorities identified by climate scientists themselves clearly defines the urgent needs of rapid evolution of climate prediction. Greene (2006) uses Sewall Wright's (1932) depiction of evolutionary theory to illustrate the current state of climatic prediction. In common with evolution of organisms, his schematics illustrate climate change prediction tools (numerical models combined with application demands and policy directives) challenged by a higher skill hill but hampered by institutional, funding and capability handicaps (Figure 2). If climate change science is to create less uncertain regional climate forecasts and clearly quantify thresholds for climate shocks, prediction tools must evolve in less than a decade.

Greene's cartoons illustrate the ways in which funding and management both encourage and restrain evolution to higher skill hills. The evolutionary situation is that in time and by luck any prediction tool can drift to a higher optimum, but without any deliberate strategy; this will generally take a very long time (Figure 2(i)). Typically, as with the evolution of organisms, climate model skill expansion is cautious, for each novelty selection pressure may sidestep or retreat. High fitness is usually maintained by strong central direction and the restriction of new model parameters. Severe selection pressure can be caused by demands for careful accounting and benefit demonstration for received resources (Figure 2(ii)). In this case, Greene argues that selection pressure would have to relax in order for climate change skill to progress to a higher optimum, but the restriction on random mutation is seen as having value.

Prediction tools managed under scientific conservatism tend to have lots of money and coordination without respect to fitness (Figure 2(iii)). Here, regression to the mean and ultimately extinction is a slippery slide downhill. The combination of high mutation rate (e.g. lots of new model parameters) and relaxed selection (plenty of funding) tends, paradoxically, to decrease fitness over time (Figure 2(iv)). Greene claims that such a strategy cannot lead to a higher optimum leaving the model remaining stuck on or near the current prediction skill peak.

The last pair of evolutionary paths are the most interesting. A plethora of independent groups, with rapid experimentation and quick transfer of success from one group to another through a network of nodes results in a rapid traverse by the community across a saddle point to a higher climate prediction skill optimum is shown in Figure 2(v). There is, of course, a catch. If the network of nodes is to bridge a trough to reach a higher optimum, it cannot consist of parameter clubs as is the case for today's climate modelling centres in Greene's view. The entire genetic complement (all the active parameters) must be in each node, and the sharing would be best if internationally open and transparent. The last situation, an external agent in the prediction skill evolution, termed 'the Gods intervene', depicts a situation like the present day in which the reality of global warming and the fact that its effects on the climate are so apparent, even bad models appear to improve in skill (Figure 2(vi)). This situation deforms the fitness (or prediction skill) landscape in a way that moves all models to higher fitness although they are not in truth any better (cf. IPCC AR4).

3. REGIONALISE PREDICTIONS OF FUTURE CLIMATE

3.1 Prioritise for mitigation: Immediate climate change 'emergency' research actions

On the level of each individual the disparity between the enormity of climate change and the apparent smallness of individual actions has to be admitted and tackled directly. Ereaut and Segnit (2006), in their treatise "Warm Words", explain how behavioural change can be positively pursued. For example, it is most valuable to target 'feels like what my people do' behaviours. Successful behavioural change strategies exploit esteem-driven actions achieved through what people do; not through what they do not do. Scientists need to recognise that people "trust other people much more than us" (governments, business or other institutions). The use of non-rational approaches, like metaphor, can engage broader audiences emotionally and make desired behaviours attractive.

Some success in the creation of citizen action groups in climate change can already be seen in, for example, the positive results of the Gore movie "An Inconvenient Truth' (2006). 'Al's Army' of climate volunteers is now well over 1000 citizens. All of these people, mostly in US, UK and Australia, have undertaken a 2-day training with Gore and his staff enabling them to use his 330+ slide show seen in the movie to share understanding and enable community action planning. Serious and senior climate scientists such as Richard Alley and Michael McCracken are participating in these trainings thus demonstrating transition from solely objective science to very valuable advocacy. The award of the 2007 Nobel Peace Prize jointly to the IPCC and Al Gore is recognition of the importance of climate change communication and even persuasion.

The participants in the WCRP-GCOS-IGBP Workshop on priority setting following the Intergovernmental Panel on Climate Change (IPCC) AR4 stressed the urgency of climate model improvement in a variety of forms:

- *Thorough understanding of the physics and dynamics of the Greenland and Antarctic ice* *sheets, with a view to predicting sea level rise within 20% for a specified change in climate over the ice sheets;*

- *Simulation of the main modes of variability in each of the main oceans: ENSO and PDO in Pacific, THC, MOC and AMO in Atlantic, monsoons in Indian Ocean. Replicating relative changes over the past 50 years is essential and is an initial value problem for the oceans;*
- *Establishing the likelihood of Amazon die back creating a CO_2 source (instead of sink); and*
- *Bringing the carbon cycle models to a level comparable with the physical climate change models including fully incorporating links between land use/cover change and greenhouse gas emissions and ocean chemistry and carbon.*

The Workshop proposed a new paradigm for climate change science (Figure 1) which attempts to synthesize emergency climate change science with policy demands by focussing on 'hot spots' around the world where regionalised climate change predictions are urgently sought. By means of this proposal, this representative group of climate practitioners have defined the scientific equivalent of Ereaut and Segnit's "what people like me do". Now, international collaborative systems must be re-organized so that real behavioural change occurs in climate change science and especially in climate prediction skill.

There are widely agreed priorities for climate change emergency research including: making climate predictions (we've only created projections to date); regionalising these predictions of future climate to advise both mitigation by determining threatening thresholds and adaptation by identifying (where it is possible) changed climate stress; and, of course, validating these regionalised predictions. The latter must mean making better use of the available high quality observations and lobbying for new essential observations. Our climate prediction capability is today commensurate with that of 'medium range' weather forecasting in the late 1970s/early '80s. At that time, some far-sighted European nations invested in ECMWF through which forecasting skill has advanced. We now need the equivalent for climate forecasting.

That extremes are more uncertain than non-extreme variables is well known but sometimes not well stated. Consensus policy input (such as that of the IPCC) can descend to the lowest common denominator and/or be limited by strict literature view. These and other factors mean that for, for example, sea-level rise, politicians come to have an expectation of a gradual increase of a few centimetres (but cf. Rahmstorf *et al.*, 2007). Schellnhuber and colleagues have evaluated the use of the Delphi technique to review thresholds that we are already very near or that will be passed if we fail to limit atmospheric concentration such that temperature rise is less than 2^{o}C. Their experts ranked the likelihoods as: top for Greenland disintegration; high for Amazon die-back; likely for West Antarctica ice sheet disintegration; and possible for the North Atlantic Meridional overturning ceasing or slowing very significantly. We know that the major ice sheets are melting much faster than previously expected and than predicted in AR4 (e.g. Steffen 2006; Fricker *et al.,* 2007). The time for urgent action is already upon us (Lenton and Schellnhuber, 2007).

The international co-operation I have described here is fundamentally different from what has gone before. It is not about observations (vital though those are – e.g. Trenberth *et al.,* 2006), nor is it about simulation and assessment despite the Nobel award for the IPCC. In my vision of future international cooperation in climate-related research, policy pressure for improved climate change prediction skill combines the first and last two climate prediction skill evolutionary situations in Figure 2 i.e. (i) and (vi). In such a synergistic development, a networked community, for example ClimatePrediction.net, is built upon, and funding and management direction capitalize on the climate change signal to rapidly hone future real regional and local climate change prediction capability.

3.2 Adapt or die: climate change research responding to evolutionary demands

It is clear that climate change is upon us (e.g. Alley *et al.*, 2007). Commentators now describe policy as allowing a choice between a bad or a very bad future (e.g. Stern, 2006). Climate change will remain a risk management problem for the foreseeable future but the better we can constrain distribution functions of important process variables or outcomes like climate sensitivity, risk or damages the better will be humanity's chances of adaptation. The cleverer we are in designing and directing emergency climate change research, the sooner we constrain the potential for some really "dangerous" outcomes e.g. those that cannot currently be ruled out with less than 10% chances. However, as Jim Hansen pointed out in a forthright article last year "US budget cuts wipe off the books most planned new satellite missions (some may be kept on the books, but only with a date so far in the future that no money needs to be spent now), and support for contractors, young scientists, and students disappears, with dire implications for future capabilities.
Bizarrely, this is happening just when NASA data are yielding spectacular and startling results. Two small satellites that measure the Earth's gravitational field with remarkable precision found that the mass of Greenland decreased by the equivalent of 200 cubic kilometers of ice in 2005"(Hansen, 2006).

Climate science ***must*** engage actively and do needed research: the type and level of engagement that was so ably described by Albert Crewe in 1967. US$5 billion for each of the next ten years is only one nation's (UK) health care savings as a result of exactly the air quality improvement Dr Crewe and our scientific predecessors advocated. It is less than a twentieth of the losses of another nation (USA) in a single extreme event: tropical cyclone Katrina cost approximately US$125 billion in property losses and somewhere between $200-300 billion overall. By comparison, an investment of 'only' $5 billion for each of the next 10 years is very modest. In other words, I am seeking a re-investment of international funding of the amount climate science saved developed nations last time we argued for cleaner air or the amount that could be saved in improved understanding of hurricane landfalls.

To be worthy of this significant investment, international cooperation in climate-related research must make a step change in capability. We must be re-directed to "emergency" climate change unknowns and the climate change research community must be fully honest about what it can (and cannot) deliver and how, if ever, current inadequacies can be resolved.

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