PREPARED STATEMENT OF GARY W. YOHE

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Mr. Chairman, Senator Allard, and Members of the Subcommittee on Securities, Insurance and Investment of the Senate Committee on Banking, Housing and Urban Affairs. Thank you for your invitation to present testimony on a range of topics related to my work as an economist and as a senior member of the Intergovernmental Panel on Climate Change (IPCC). You have, specifically, asked that I discuss (1) how economics can inform national and global responses to the risks and opportunities of climate change, (2) how those risks might be connected with the health of financial markets, (3) how the *Stern Review on the Economics of Climate Change* and my work for the IPCC can inform your deliberations.

My testimony will be anchored on a fundamental conclusion that has emerged to broad consensus from both the Fourth Assessment Report of the IPCC (2007) and the *Stern Review* - economics can play a significant role in understanding how we should respond to the risks of climate change. My take on it all is, though, that this role will lead to productive deliberations only if practitioners accept the shortcomings of a cost-benefit approach to the problem of what to do about climate change *and* recognize the strengths of a risk management approach to the same set of issues. Only then can the analyses climate change and the resulting policy discussions accommodate fully the multiple metrics with which climate risks and opportunities must be calibrated

I recognize, of course, that the Subcommittee on Securities, Insurance and Investment is primarily concerned about vulnerabilities and opportunities that can be enumerated in dollars and cents. I hope that you will see, however, that risks calibrated in other metrics (like millions of people at risk of hunger or water stress or coastal flooding) also matter to financial markets. I think that it is obvious that exposure to climate policy matters to investors and that setting standardized rules for carbon accounting will be a critical concern as we move forward. Surely risks expressed in terms of the frequency and intensity of extreme weather events matter to a subcommittee with the word insurance in its name. In short, I hope to connect some important dots so that even climate skeptics will take the issues before you seriously.

Before I proceed, it is imperative that you recognize that the IPCC, because it cannot be policy prescriptive, makes no policy recommendations. It does, though, describe thoroughly the increasing evidence that climate is changing faster than we thought just five years ago in support of a conclusion that risks and opportunities are coming at us faster than previously thought. Increased resolution in our understandings of impacts and vulnerabilities that are apparent throughout the Fourth Assessment Report show that vulnerability to climate change is perhaps even more widely diverse than previously thought, that differences in the capacities to adapt and to mitigate vary even more widely across nations and communities within nations (even within the most developed nations), and that unabated climate change will likely impede progress toward achieving Millennium Development Goals by mid-century.

The *Stern Review* was, in contrast, designed explicitly to be policy prescriptive and to make an economic case for immediate action to reduce the emission of greenhouse gases. It anchored its analysis on the same literature as the IPCC, but it did not stop there. It ultimately calls for immediate action designed to limit concentrations of greenhouse gases to no more than 550 parts per million in carbon dioxide equivalents, and it supports this call with a dazzling array of statistics which have, themselves, become a source of debate. I have repeatedly asked, however, that the discussions of *Stern* not focus on those statistics at the expense of missing the major message – climate policy is required, and the least expensive way to proceed toward any policy target is to begin now.

1. **The major messages of the *Stern Review's* assessment of the current science are sound. Indeed, they are completely consistent with the conclusions presented by the three Working Groups of the IPCC in their contributions to the Fourth Assessment Report. They are consistent, in other words, with the conclusions about the underlying science that were unanimously accepted by representatives of the signatory nations of the United Nations Framework Convention on Climate Change who attended the IPCC plenary meetings in Paris, Brussels, and Bangkok. They include:**

    a. **Climate is changing faster than was anticipated only 5 years ago (in the Third Assessment Report of the IPCC).**
    b. **Significant climate impacts have been calibrated in terms of multiple metrics (some are economic, but many are not), and thresholds of associated climate risk have been identified in terms of changes in global mean temperature.**
    c. **Many of the temperature thresholds for critical impacts are now thought to be lower than anticipated only 5 years ago. It follows that we are approaching them more quickly than we thought, and so we will reach them sooner than we thought.**
    d. **Achieving any concentration threshold cannot guarantee achieving a specific temperature threshold; but achieving a concentration target can reduce the likelihood of crossing those thresholds at any point in time.**

e. Achieving any concentration threshold may, however, only delay the inevitable unless the rate of change in temperature is diminished by persistent policy intervention over the entire century and perhaps beyond.

Figure 2 in the Executive Summary of the *Stern Review* offers a concise portrait of the essential results of the most recent science. I attach a version here as Figure 1. Notice that temperature thresholds are identified for truly dangerous impacts in many dimensions in the lower portion of the figure. The imprecise links between temperature targets and concentration targets are meanwhile illustrated in the upper portion of Figure 1. They summarize current understanding to show, for example, that holding concentrations

- below 750 ppm means a greater than 95% chance of exceeding 2 degrees (Centigrade) of warming above current levels and a 70% chance of exceeding 3 degrees of additional warming,
- below 650 ppm means a 95% chance of exceeding 2 degrees and a 60% chance of exceeding 3 degrees,
- below 550 ppm means around a 70%-80% chance of exceeding 2 degrees and a 50% chance of exceeding 3 degrees,
- below 450 ppm means a 50% chance of exceeding 2 degrees and a 25% chance of exceeding 3 degrees, and
- below 400 ppm means roughly a 30% chance of exceeding 2 degrees and still a 5% chance of exceeding 3 degrees.

Putting the two parts of the figure together allows the reader to judge the sensitivity of our experiencing any specific risk to various policy objectives. It is, indeed, a spectacularly powerful portrait of the policy predicament.

2. The contribution of Working Group II to the Fourth Assessment Report of the IPCC puts people on the planet and offers more detailed descriptions of climate risks across diverse regions and sectors. Risks are calibrated in multiple metrics, and vulnerability depends on exposure and sensitivity, both of which vary from place to place in ways that are determined by development pathways.

The Fourth Assessment Report confirms the assertion from the Third Assessment Report that developing nations will be most vulnerable to climate change because of high exposure to potential impacts and low capacity to adapt. Some of the details behind this conclusion can be found most easily from Tables 20.8 and 20.9 in the contribution of Working Group II; they are replicated here as Tables 1 and 2, including the notes that locate discussions of the various risks in the background chapters. Notice, for example, that literature published since the Third Assessment Report was released in 2001 shows that

- an additional 1^{o}C of warming would increase the number of people facing water scarcity by up to 1.2 billion additional people in Asia and 250 million in Africa and would cause up to a 5% decline in wheat and maize productivity in India;
- for another degree of warming, China would experience a 12% decline in rice productivity, that up to 2 million additional people in Asia would confront significant risk of coastal flooding, and that water scarcity would affect another 1.6 billion more people in Asia and Africa; and
- for more warming, the pace of increased exposure will accelerate.

The Summary for Policymakers approved in Paris synthesizes these and a wide assortment of other results in a series of fundamental conclusions:

- vulnerability to climate risk will be amplified in areas that already confront multiple stresses (for example, from land degradation, globalization, exposure to disease, etc.);
- adaptation is unavoidable because the planet would be committed to more warming even if emissions of greenhouse gases were halted today;
- a portfolio of adaptation and emissions controls will be required if the world's people are to cope with climate risk because, of course, emissions will not end tomorrow; and
- even these combined actions may be overwhelmed by the turn of the century.

Everyone has his or her own view of what is most important among these far-reaching conclusions. You can find your own collection of risks and opportunities for various amounts of warming on Tables 1 and 2. For me, the fundamental bottom line that plenary delegates decided to take home to their governments is that ***climate change will impede progress toward meeting Millennium Development Goals (MDGs) across the world.***

This stark and succinct assessment of the future, along with the recognition that adaptation and mitigation will be necessary, is certainly troubling; but the silver lining behind the growing storm cloud is an enormous opportunity. The Fourth Assessment Report emphasizes that strengthening many of the factors that support the capacities of communities to adapt to climate risk is entirely consistent making progress toward achieving the MDGs over the next half century. Indeed, investments in eradicating extreme poverty and hunger, providing primary education, promoting gender equality, combating HIV/AIDS and other diseases, ensuring environmental sustainability, and working to develop global partnerships for development could all be essential components of an efficient part of an effective climate policy.

To my eyes, therefore, the new Fourth Assessment Report thereby offers a roadmap by which climate change can find its way onto the planning and implementation agendas of finance ministers all around the world – and into the deliberations of committees like this one. Instead of being yet another problem that complicates your lives, the coincidence of goals noted by the Report shows why coping with climate risk can be yet another good reason for them to what they have been trying to do all along – to promote sustainable development.

This pathway to the highest levels of government is also illuminated, for any country that wants to pick up the idea, when the Report calls for ***adopting a risk management perspective in assessing impacts, adaptation, and sustainable development.*** The language of risk management is a language with which finance ministers and financially focused committees are quite familiar. The IPCC now sees that risk-based portraits of impacts net of the effects of alternative adaptations can, when inserted into alternative development pathways at specific locations, offer decision-makers simultaneous insight into a multiplicity of climate risks. ***A policy portfolio designed to reduce climate risk should take advantage of two different policy tools: reducing exposure through mitigation and reducing sensitivity through adaptation.***

3. Translating this range of climate risks into economic terms continues to be a challenge. Many of them defy calibration in terms of dollars and cents. Many of them have not been thoroughly analyzed. Summary statistics are fraught with uncertainty, and are critically dependent on value judgments imposed by decision-makers, themselves.

Economists have been trying for some time to assign currency values to the impacts of climate change identified in Figure 1 and Tables 1 and 2 by tracking their potential trajectories along long-term scenarios of how the future might unfold. Not surprisingly, economists do not agree on what that future might hold. They do, however, agree on what measure to use: "the social cost of carbon" defined as the damage caused over time by releasing an addition unit of ton of carbon in the atmosphere discounted back to the year of its emission. That is to say, the social cost of carbon represents the "marginal cost" of emissions; alternatively, it represents the "marginal benefit" of unit of carbon emissions reduction.

More than 200 estimates of the social cost of carbon are now available. The median estimate for studies using a 3% utility discount rate (4% to 5% on the dollar) with no equity weighting is about $20 per tonne of carbon (slightly more than $5 per tonne of carbon dioxide or about $3 per barrel of oil). For estimates that discount the future much more heavily and apply equity weighting to the distribution of economic impacts, however, the median is about $100 per tonne of carbon ($27 per tonne of carbon dioxide), and 10% of the estimates exceed $200 per tonne of carbon. The Fourth Assessment Report, based on a smaller sample, puts the average estimate around $43 per tonne of carbon (about $12 per tonne of carbon dioxide), but notes that 12% or the estimates are actually negative. The *Stern Review* (with its very low discount rate, equity weighting, and reflections of potential catastrophic loss) reports an estimate in excess of $300 per tonne of carbon (around $85 per tonne of carbon dioxide).

I have been told that presenting such a range in a political environment would allow people who do not think that climate is a problem to focus on the lower part of range and people who think that climate is a large problem to focus on the upper part of the range. Productive conversations between the two sides, I have also been told, would seldom be a product of such readings. For this, and a few other reasons, I now preach caution to all. To appropriately understand the content of the range of estimates, we must work to understand what is going on behind the scenes. Why is the range so large? What combinations of underlying factors produce low or even negative estimates of social cost, and what other combinations support estimates on the high end of the scale? Answers to these questions can be enormously revealing.

The choice of discount rate and the incorporation of equity weights are extremely important, and both lie within the purview of decision-makers. High discount rates sustain low estimates because future damages become insignificant (and even negative costs derived from near term opportunities that are not overcome by long-term risks). Conversely, low discount rates produce high estimates because future damages are important. Meanwhile, strong equity weighting across the globe support high estimates because poor developing countries are most vulnerable. Conversely, weak or no equity weighting can produce low estimates because poor developing countries do not factor heavily in the overall calculation.

It turns out, however, that several scientific parameters that decision-makers cannot choose are even more important in explaining the range. Indeed, climate sensitivity (i.e., the increase in global mean temperature that would result from a doubling of greenhouse gas concentrations from pre-industrial levels) is the largest source of variation. It is possible to derive high estimates for the social cost of carbon even if you assume low discount rates and almost no equity weighting; all that is required is the recognition that "Mother Nature" may have put the climate sensitivity lies at the high end of the latest range of estimates. Andronova and Schlesinger (2001), for example, find that the historical record could easily be explained with climate sensitivities as high as 8 or 9 degrees Centigrade (even though the TAR reported an upper bound of 5.5 degrees).

There is, in short, no way around a fundamental truth - this and other sources of profound uncertainty in our understanding of the climate system and how it will evolve over time are intrinsic parts of the arena within which climate policy will be discussed. It is pointless to wait for the uncertainty to be resolved.

4. **The *Stern Review's* estimates of economic damages have been controversial in part because they are difficult to understand and in part because they are highly dependent on underlying assumptions about discounting, aversion to risk, aversion to inequality, and the valuation of non-economic metrics of impact and significant risk (abrupt change and extreme events, for example).**

The controversies surrounding the damage estimates have spawned a spate of detailed discussions of the technicalities involved in applying economic analysis to a complex problem like climate change. Many economists have concluded that the *Review* is right for the wrong reason in its call for immediate climate policy. Details of my own views can be found in my testimony before the Senate Committee on Energy and Natural Resources last February (attached here as an appendix).

5. What is the right reason? It follows from the Fourth Assessment Report and the underlying documentation of the *Stern Review* that some sort of policy intervention, based on the economics of hedging against climate risks *and* the economic cost of policy adjustment that may have to be applied to abruptly, will be required to avoid "dangerous anthropogenic interference with the climate system".

It is important to note that it is impossible to write climate policy in 2007 that will be valid for the entire century. Coping with thresholds and uncertainty over the long term will require adopting an adaptive risk management approach where series of medium-term policy decisions will be informed by the evolution of long-term objectives. Designing such a program will be difficult, because it will need to give clear signals of intention over the medium-term even as it maintains flexibility so that it can respond to

- changes in scientific understanding,
- changes in social valuations of impacts, and
- changes in our expectations of how the policies are working.

In every case, however, this flexibility must somehow be immune to political and/or economic manipulation, and so designing such a mechanism will require a considerable amount of political leadership.[1]

As soon as you recognize that some sort of policy will be required (and that recognition follows directly from Figure 1 and/or Tables 1 and 2), simple economics says that taking the least cost approach means starting now. This conclusion is true in large measure because atmospheric concentrations of greenhouse gases depend on cumulative emissions over time, so achieving a targeted concentration target (and thus a corresponding range of possible temperature increases and associated climate risks) is fundamentally an exhaustible resource problem. The long-standing Hotelling result that I teach my students in their first course on environmental and resource economics therefore applies (at least to a first approximation): to maximize the discounted value of welfare derived from an exhaustible resource (that is, to minimize

[1] It strikes me, as an aside, that the Federal Reserve System of the United States (the FED) is an example of an institution designed to accomplish all of these tasks. While surely in a different context, the FED confronts the same sorts of short-term versus long-term tensions with the same sorts of price or quantity policy tools and protected from political manipulation by carefully designed insulation.

the discounted costs of limiting cumulative emissions over the long-term), simply calculate the appropriate initial "scarcity rent" (in this case, an initial price for carbon for 2007) and let it increase over time at the rate of interest.[2]

Adjustments over time in the policy target (borne of uncertainty about the climate system specifically and the future more generally) confound the issue, to be sure, but I have shown in Yohe, et al. (2004) that some hedging based on the Hotelling minimum cost result minimizes expected costs even if there is a chance that we will discover sometime in the future that the climate problem fixes itself and climate policy initiated now was unnecessary. Why? Not because it generated some energy independence for the United States, even though that would be a good idea. Rather, because the expected costs of adjusting to more pessimistic climate news sometime in the future if we delay taking action are higher than the expected costs of doing too much too soon (even with discounting at the market rate of interest).

To be more specific, the Hotelling result means that it is enough to specify an initial price of carbon (or perhaps setting targeted permit price for a cap and trade system). This price should be designed to get the attention of American business and to show political leadership in the face of a serious problem. It need not, however, be set so high that it would cause undo economic harm in the short-run. Allowing the carbon price to increase at the rate of interest year after year (following Hotelling) and acknowledging that adjustments for new knowledge about performance and risk will have to be accommodated over time will give the policy traction.

I personally favor a tax because permit markets can be volatile, and because responding to this volatility by building in a "safety value" on the price of permits sets up a loophole in the policy that could easily be manipulated. Indeed, it undermines the power of the policy. A tax, increasing at the rate of interest, would produce a persistent and predictable increase in the cost of using carbon that would inspire cost-reducing innovation and fuel switching in the transportation, building, and energy supply sectors of our economy.[3]

The revenue of a carbon tax (or the auction of tradable permits, for that matter) could be used to subsidize research and development of alternative energy. At the moment, we have the technology for modest reduction of greenhouse gases at little cost. Deeper cuts in the future would be expensive unless there is substantial technological progress. Developing large-scale, safe, clean and cheap energy is essential for solving the climate problem, and would also help the American economy become less dependent on imported fuels; and to help it prepare for the depletion of conventional oil and gas. American companies have the potential to lead what the Europeans call the next industrial revolution.

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[2] Note that the emission reduction trajectory in the Stern Review violates this basic principle.

[3] The tax should increase, in real terms, at the real rate of interest. If expressed in nominal terms downstream, then it should increase at the nominal rate of interest.

Be assured that providing incentives for American business to prepare for a carbon scarce future will put them in a good position when it comes time to compete in world markets, especially if their competitors in China and India do not follow suit. This is why 10 major corporations are on record in support of a U.S. (federal) climate policy that has some teeth and is predictable. There is money to be made, but only if uncertainty about climate policy is reduced.

6. Setting the initial tax can be an exercise in determining the appropriate short-term incentives for carbon-saving investments and energy conservation rather than an exercise in "solving the climate problem".

Since no policy created in 2007 will "solve the climate problem", it is possible and even desirable for the Senate to step out from under that burden to confront a more manageable problem (while still making progress towards an ultimate solution to the climate problem). You are not trying to "Solve the climate problem." You are trying to "Acknowledge and confront the climate problem in 2007 with the best information available." More specifically, your problem is "What do we do now?"

The answer is to design something for the near-term that will discourage long-term investments in energy, transportation, and construction that would lock in high carbon intensities for decades to come. Moving decisions in that direction would be consistent with long-term programs designed to "solve" the climate problem (however our understanding of it evolves) and with the minimization of long-term economic costs of the policies.

The ramifications of concluding that adaptation alone will not be able to accommodate unabated climate change should also be understood. For some developing countries, and particularly for the least developed countries whose emissions are small, the need for mitigation may not be an immediate problem. For other countries like China, India, and Brazil where substantial industrial development has already taken place, current and anticipated future emissions of greenhouse gas emissions are more significant. These countries have historically been reluctant to commit to emissions standards, and that was an understandable position in a world where the largest contributor to atmospheric contributions sits on the sidelines. In a future where significant mitigation policies will be in place, however, ignoring future of vigorous climate policy will lead to development plans that are unsustainable – indeed, as unsustainable as development plans designed without taking climate risks into account.

Appendix – Testimony on the *Stern Review*
February 13, 2007
Senate Committee on Committee on Energy and Natural Resources

The damage estimates are difficult to understand because they are expressed in terms of a "certainty equivalent and equity equivalent annuity" metric that converts expected discounted welfare values computed across thousands of possible futures into a single number.

The analysis underlying the computation of this metric is sound, if not brilliant; see Mirrlees and Stern (1972) for the details of its development. Its application to the climate problem is path-breaking, but it is vulnerable to the sort of misinterpretation that will make people roll their eyes and wonder if any of us know what we are talking about. The authors of the *Review* are careful to say that "total cost over the next two centuries…..*are equivalent* to an average reduction in global per capita consumption of at least 5%, now and forever" (my emphasis). When the results are reported in the popular press, however, the conditional phrase about equivalence is usually deleted, and that is a problem. Readers can react by saying - "It's now, and I don't see my 5.3% reduction in consumption. Where is it? It's still now! Still not here!"

Notwithstanding this presentation problem, it is important to note that the damage estimates include not only the economic ramifications of climate impacts as they play out over time, but also a "risk premium" tied to the current level of uncertainty about the future as displayed in the simulation model. It is here that aversion to risk and aversion to inequality have an effect on the estimates. Weitzman (2007) argues that the *Stern* estimates undervalue these contributions because the tails of the distributions of our understanding of the climate impacts are so "thick"; in other words, the representations of uncertainty upon which the underlying simulations are conducted do not adequately consider the likelihood of extreme consequences.

The damage estimates have been criticized because they are based on a very low discount rate – a rate that virtually guarantees high values.

Dasgupta (2006), Maddison (2006), Nordhaus (2006), Tol (2006), Tol and Yohe (2006), Tol and Yohe (2007), Varian (2006), Yohe (2006) and Yohe and Tol (2007) all make this point. Some argue that imposing such a low discount rate on investments to mitigate climate change in a world where other investments are required to earn higher returns is a prescription for the inefficient allocation of resources over time. Others argue that public investments can earn lower than market returns if they complement private investment; see for example, Ogura and Yohe (1977). Still others, including the *Stern Review* itself, make an ethical case for minimizing the rate at which impacts that will be felt by future generations are discounted in current policy deliberations.

Regardless of how one comes down on this debate, and the choice of a discount rate is in the purview of policy-makers, it is important to recognize the sensitivity of the damage estimates to that choice. Tol and Yohe (2007) report, on the basis of a simply model calibrated to the *Stern Review* baseline scenario where damages create the equivalent of a 5.3% reduction in per capita consumption, that lowering the rate further would have very little effect on the estimate while increasing the discount rate to 3% would reduce damages to the equivalent of a 1.6% decline in equivalent per capita consumption.

It should finally be noted that Weitzman (2007) expresses concern that the economic profession at large has not yet solved the problem of exactly how to discount the distant future when intergenerational transfers of wealth must be considered. His point is simple: there is a lot of fundamental work still to be done in this regard.

The damage estimates have also been criticized because they seem to have been calibrated to the high end of current understanding of impacts, because they sometimes miss the opportunity for adaptation especially in a future where incomes will be higher, and because they add estimates of catastrophic damages to a baseline that already included estimates of the willingness to pay to avoid such calamity.

Tol (2006), Tol and Yohe (2006) and Yohe and Tol (2007) have made these points, but it is important to note that the range of uncertainty reflected in the underlying simulations is not tied entirely to these upper-end estimates. Tol and Yohe (2007) confront the "So what?" question that we begged in their earlier comments by exploring the implications of simply assuming that the developing world's capacity to adapt will grow toward the current level of the world developed countries as their economies grow. The result is a reduction in discounted damages of more than 50%. Why so large? Because the small discount rate rewards increases in future adaptive capacity as heavily as it punishes future impacts.

Mitigation costs are estimated in terms of percentage losses in GDP, and so it is difficult to compare the costs of policy with its benefits (calibrated in terms of losses in equivalent per capita consumption).

Mendelsohn (2006) has remarked that the mitigation cost estimates are too low. Others have noted that they seem to run only through 2050. Tol and Yohe (2006) wonder why the conventional 550 ppm concentration target from earlier work persists as a policy target when damage estimates are so much higher than before. Perhaps most importantly, however, the *Review* never presents the net effect of mitigation in terms of the equivalent per capita consumption metric employed to track damages. Tol and Yohe (2007) have attempted to do so for a simple model calibrated, again, to support a 5.3% loss absent any intervention. They find that achieving a 550 ppm concentration target would reduce damages to

2.2%, that a achieving a 650 ppm target would reduce damages to 3.0%, and that achieving a 400 ppm target would reduce damages to 0.8%.

References

Dasgupta, P. (2006), *Comments on the Stern Review's Economics of Climate Change*, Department of Economics, Cambridge University http://www.econ.cam.ac.uk/faculty/dasgupta/STERN.pdf

Intergovernmental Panel on Climate Change (IPCC) (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report*, in Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (eds), Cambridge University Press, Cambridge, UK.

Maddison, D.J. (2006), *Further Comments on the Stern Review*, Department of Economics, Birmingham University http://www.economics.bham.ac.uk/maddison/Stern%20Comments.pdf

Mendelsohn, R.O. (2006), "A Critique of the Stern Report", *Regulation* (Winter 2006-2007), 42-46.

Nordhaus, W.D. (2006), A Review of the Stern Review of the Economics of Climate Change", *Journal of Economic Literature* **45**: 686-702.

Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky, D. Crane, S. Cruickshank, S. Dietz, N. Edmonson, S.-L. Garbett, L. Hamid, G. Hoffman, D. Ingram, B. Jones, N. Patmore, H. Radcliffe, R. Sathiyarajah, M. Stock, C. Taylor, T. Vernon, H. Wanjie, and D. Zenghelis (2006), *Stern Review: The Economics of Climate Change*, HM Treasury, London.

Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky, D. Crane, S. Cruickshank, S. Dietz, N. Edmonson, S.-L. Garbett, L. Hamid, G. Hoffman, D. Ingram, B. Jones, N. Patmore, H. Radcliffe, R. Sathiyarajah, M. Stock, C. Taylor, T. Vernon, H. Wanjie, and D. Zenghelis (2006), *Postscript*, HM Treasury, London.

Tol, R.S.J. (2006), "The Stern Review of the Economics of Climate Change: A Comment", *Energy & Environment*, **17**, (6), 977-981.

Tol, R.S.J. and G.W. Yohe (2006), "A Review of the *Stern Review*", *World Economy* 7: 233-250, 2006.

Varian, H.R. (2006), "Recalculating the Costs of Global Climate Change", *New York Times*, December 14, http://www.nytimes.com/2006/12/14/business/14scene.html.

Weitzman, M. (2007), "A Review of the Stern Review of the Economics of Climate Change", *Journal of Economic Literature* **45**: 703-724.

Yohe, G.W. (2006), "Some thoughts on the damage estimates presented in the *Stern Review* - An editorial", *Integrated Assessment Journal* 6: 65-72.

Yohe, G.W., Schlesinger, M.E., and Andronova, N. (2004), "To Hedge or Not Against an Uncertain Climate Future", *Science* **306**: 416-417.

Yohe, G.W. and R.S.J. Tol (2007), "The Stern Review: Implications for Climate Change", *Environment*, forthcoming in March of 2007.

Figure 1: Stabilization levels and probability ranges for temperature increases. Source: Figure 2 from Stern, et al. (2006).

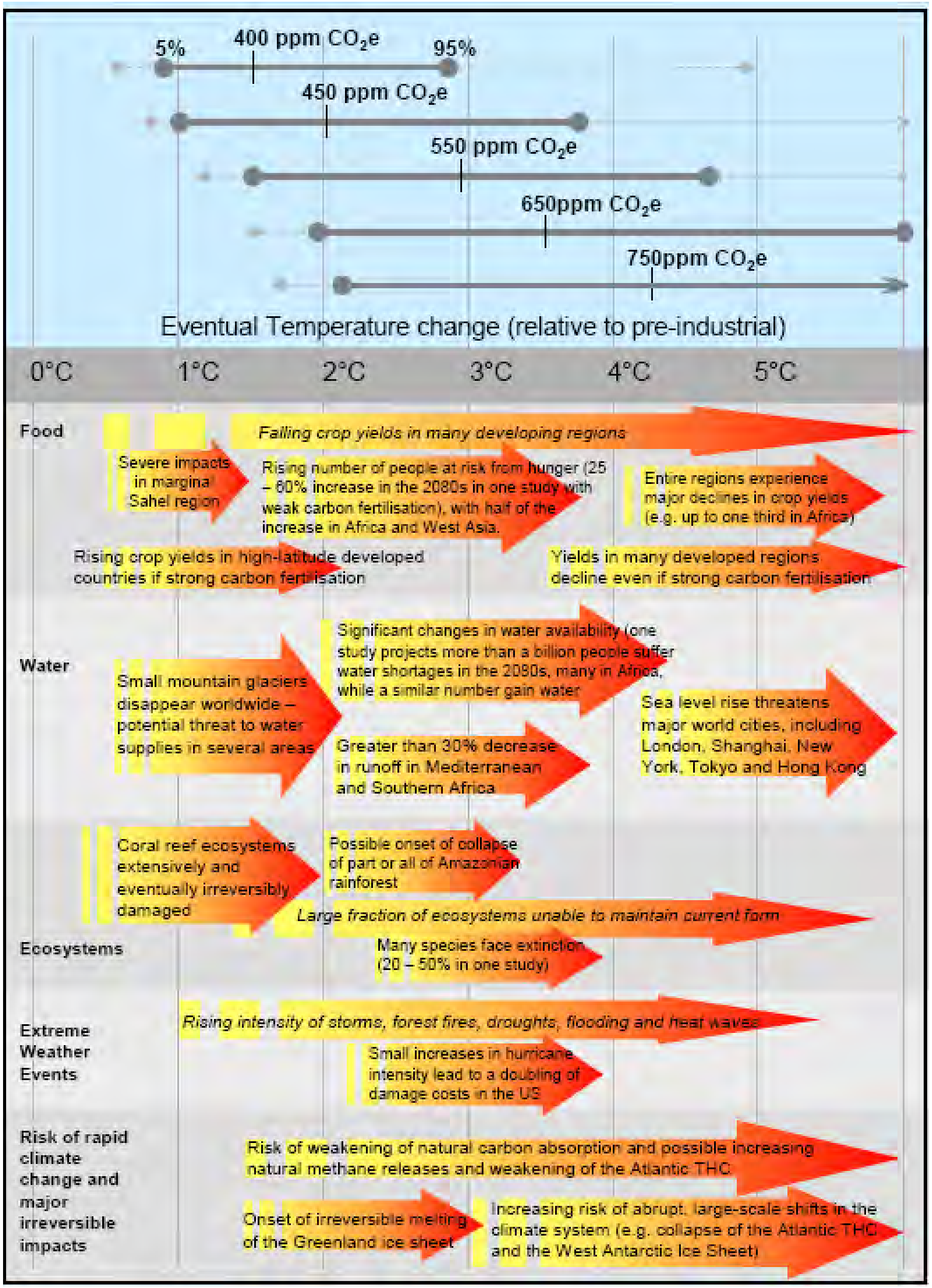

Table 1: Sectoral Risks from Climate Change; Source: IPCC (2007)

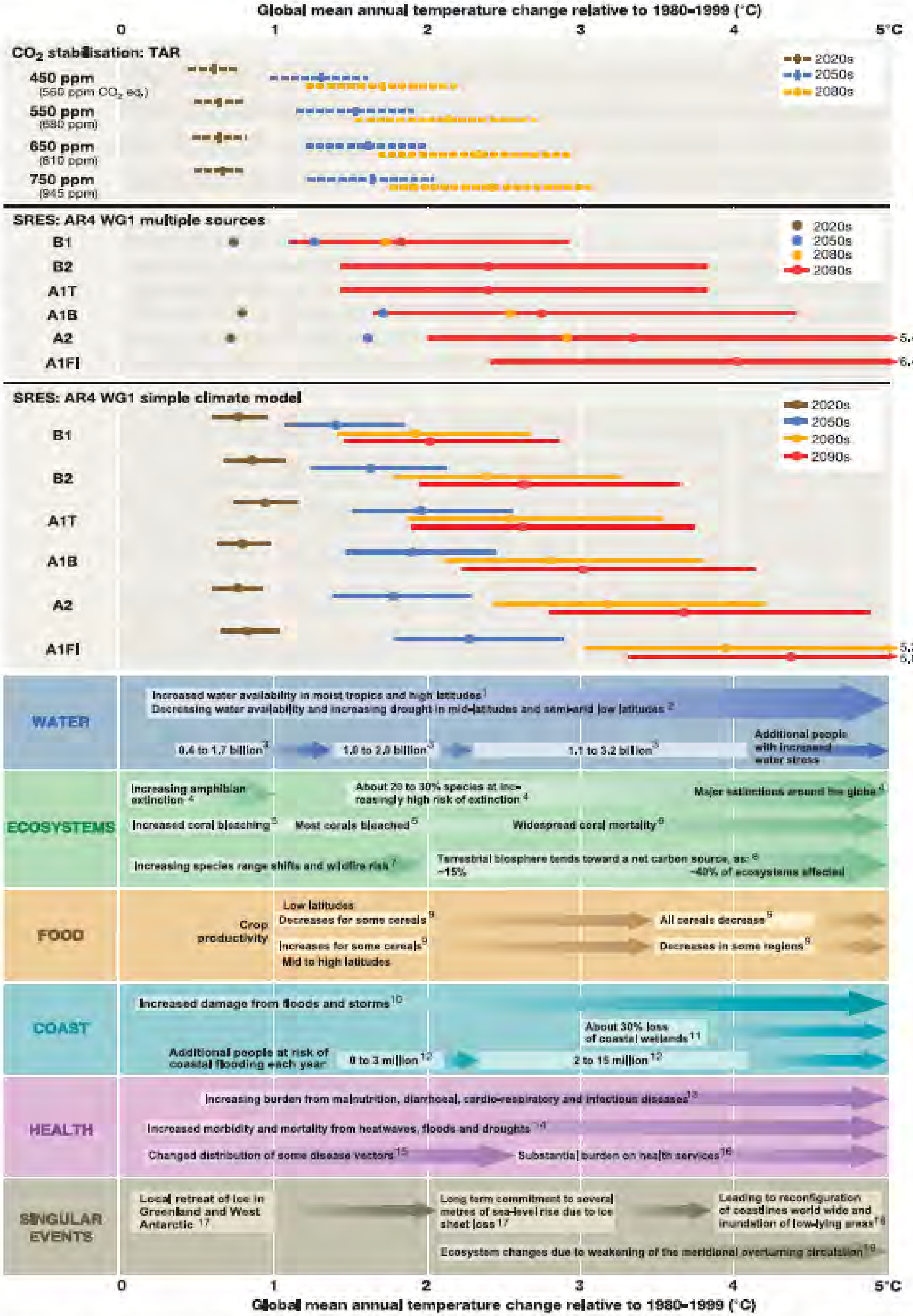

Table 20.8. *Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. This is a selection of some estimates currently available. All entries are from published studies in the chapters of the Assessment. (Continues below Table 20.9)*

Table 2: Regional Risks from Climate Change; Source: IPCC (2007)

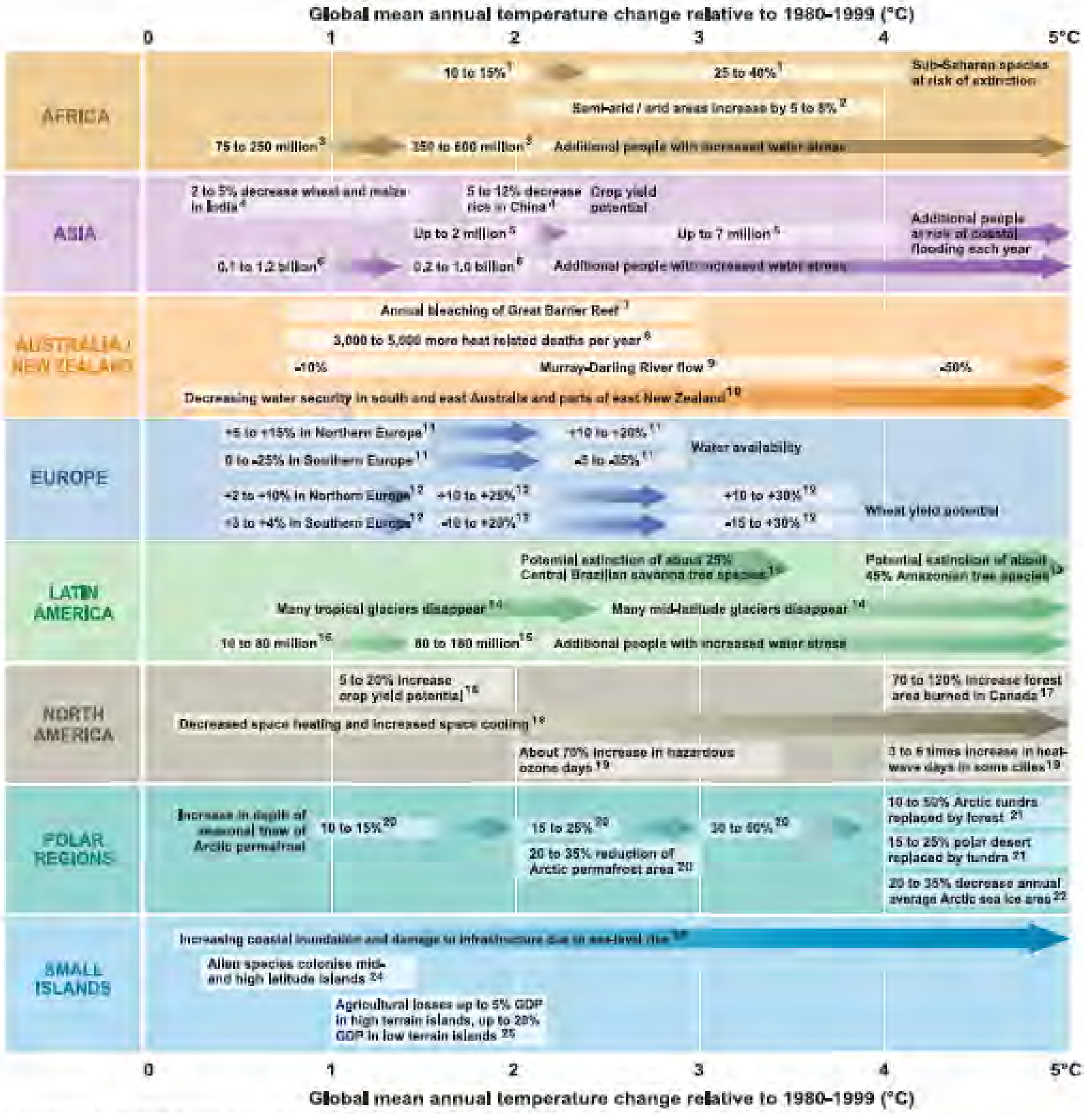

Table 20.9. *Examples of regional impacts. See caption for Table 20.8.*

Table 20.8. (cont.) *Edges of boxes and placing of text indicate the range of temperature change to which the impacts relate. Arrows between boxes indicate increasing levels of impacts between estimations. Other arrows indicate trends in impacts. All entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. For extinctions, 'major' means ~40 to ~70% of assessed species.*

The table also shows global temperature changes for selected time periods, relative to 1980-1999, projected for SRES and stabilisation scenarios. To express the temperature change relative to 1850-1899, add 0.5°C. More detail is provided in Chapter 2 [Box 2.8]. Estimates are for the 2020s, 2050s and 2080s, (the time periods used by the IPCC Data Distribution Centre and therefore in many impact studies) and for the 2090s. SRES-based projections are shown using two different approaches. Middle panel: projections from the WGI AR4 SPM based on multiple sources. Best estimates are based on AOGCMs (coloured dots). Uncertainty ranges, available only for the 2090s, are based on models, observational constraints and expert judgement. Lower panel: best estimates and uncertainty ranges based on a simple climate model (SCM), also from WGI AR4 (Chapter 10). Upper panel: best estimates and uncertainty ranges for four CO_2-stabilisation scenarios using an SCM. Results are from the TAR because comparable projections for the 21st century are not available in the AR4. However, estimates of equilibrium warming are reported in the WGI AR4 for CO_2-equivalent stabilisation[a]. Note that equilibrium temperatures would not be reached until decades or centuries after greenhouse gas stabilisation.

Table 20.8. Sources: 1, 3.4.1; **2,** 3.4.1, 3.4.3; **3,** 3.5.1; **4,** 4.4.11; **5,** 4.4.9, 4.4.11, 6.2.5, 6.4.1; **6,** 4.4.9, 4.4.11, 6.4.1; **7,** 4.2.2, 4.4.1, 4.4.4 to 4.4.6, 4.4.10; **8,** 4.4.1, 4.4.11; **9,** 5.4.2; **10,** 6.3.2, 6.4.1, 6.4.2; **11,** 6.4.1; **12,** 6.4.2; **13,** 8.4, 8.7; **14,** 8.2, 8.4, 8.7; **15,** 8.2, 8.4, 8.7; **16,** 8.6.1; **17,** 19.3.1; **18,** 19.3.1, 19.3.5; **19,** 19.3.5
Table 20.9. Sources: 1, 9.4.5; **2,** 9.4.4; **3,** 9.4.1; **4,** 10.4.1; **5,** 6.4.2; **6,** 10.4.2; **7,** 11.6; **8,** 11.4.12; **9,** 11.4.1, 11.4.12; **10,** 11.4.1, 11.4.12; **11,** 12.4.1; 12, 12.4.7; **13,** 13.4.1; **14,** 13.2.4; **15,** 13.4.3; **16,** 14.4.4; **17,** 5.4.5, 14.4.4; **18,** 14.4.8; **19,** 14.4.5; **20,** 15.3.4, **21,** 15.4.2; **22,** 15.3.3; **23,** 16.4.7; **24,** 16.4.4; **25,** 16.4.3

[a] Best estimate and likely range of equilibrium warming for seven levels of CO_2-equivalent stabilisation from WGI AR4 are: 350 ppm, 1.0°C [0.6–1.4]; 450 ppm, 2.1°C [1.4–3.1]; 550 ppm, 2.9°C [1.9–4.4]; 650 ppm, 3.6°C [2.4–5.5]; 750 ppm, 4.3°C [2.8–6.4]; 1,000 ppm, 5.5°C [3.7–8.3] and 1,200 ppm, 6.3°C [4.2–9.4].