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Global Distributions of Vulnerability to Climate Change

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Abstract

In this brief paper we respond to the apparent contradiction in two conclusions of the Third Assessment Report (the TAR) of the Intergovernmental Panel on Climate Change (IPCC, 2001*a*). In one conclusion the IPCC states that developing countries will be most vulnerable to climate change; in another, the TAR reports that we are unable to predict adaptive responses to site-specific exposures to climate impacts. Here we explore how variation in adaptive capacity and climate impacts can be seen to influence the global distribution of vulnerability. We find that all countries will be vulnerable to climate change, even if their adaptive capacities are enhanced. Developing nations are most vulnerable to modest climate change, and reducing greenhouse-gas emissions would diminish their vulnerabilities significantly. Developed countries would benefit most

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from mitigation for moderate climate change. Extreme climate change overwhelms the abilities of all countries to adapt.

Keywords: vulnerability, adaptive capacity, mitigation, global distribution

1 Introduction

Signatories of the United Nations Framework Convention on Climate Change (UNFCCC) have committed themselves to addressing the "specific needs and special circumstances of developing country parties, especially those that are particularly vulnerable to the adverse effects of climate change" (Article 3; `http://unfccc.int`). The Intergovernmental Panel on Climate Change (IPCC) has since concluded with high confidence that "developing countries will be more vulnerable to climate change than developed countries" (IPCC, 2001*a*, p. 916). The Third Assessment Report, however, also concludes with high confidence that "current knowledge of adaptation and adaptive capacity is insufficient for reliable prediction of adaptations (pg. 880)" because "the capacity to adapt varies considerably among regions, countries and socioeconomic groups and will vary over time (pg. 879)".

Here we respond to the apparent contradiction in these statements by exploring how variation in adaptive capacity and climate impacts combine to influence the global distribution of vulnerability. In Section 2 we describe our simple indexing method and the means employed to display exposure to climate change. Our results are then presented in Section 3. We understand that our results perhaps generate more questions than answers. Some of these questions are presented in the discussion of Section 4.

2 Methods

We adopt the IPCC (2001*a*) convention offered in Chapter 18 that vulnerability depends on exposure, sensitivity, and adaptive capacity. Moreover, we recognize that the relative strength of adaptive capacity is derived from a relatively short list of fundamental determinants as described in Yohe & Tol (2002). Accordingly we portray specific measures of exposure and adaptive capacity geographically in global portraits. We use changes over time t in annual-mean temperature at the national level for country i, $\Delta T_i(t)$, to reflect exposure to climate change. These changes were computed first along the Special Report on Emissions Scenarios (SRES) A2 emissions scenario from a small ensemble of general circulation model simulations; see IPCC (2000) for a complete description of the story-line from which the A2 scenario was constructed and Schlesinger & Williams (1997) for the details of the COSMIC program from which the ensembles were derived. For the sake of comparison, the baseline A2 results were compared with exposure drawn from a least-cost Wigley-Richels-Edmonds (WRE) emissions trajectory that deviates from A2 to limit effectively atmospheric concentrations of greenhouse gases to 550 ppm; Wigley et al. (1996) provide the background for this alternative future. We use an index of national adaptive capacity, $AC_i(t)$, from Brenkert & Malone (2005) that is normalized to unity for the global mean. Our measure of vulnerability, $V_i(t)$, reflects the combined roles of exposure and adaptive capacity by the simple quotient, $V_i(t) = \Delta T_i(t)/AC_i(t)$. Clearly, this index of vulnerability allows exposure to larger changes in temperature to reflect higher vulnerability that could be diminished by enhanced adaptive capacity.

3 Results

Figure 1 and Figure 3 show the global distribution of $V_i(t)$ in 2050 and 2100 under the assumption that the climate sensitivity is 5.5°C. Panel A depicts vulnerabilities along a representation of the A2 scenario for a static index of current national adaptive capacities taken directly from Brenkert & Malone (2005). Panel B allows national adaptive capacities to improve over time, reaching the larger of either a 25% increase from current levels or the current global mean. It is important to note that we are not trying to link the evolution of future adaptive capacity to the A2 storyline. We are, instead, conducting a thought experiment of arbitrary design, since convincing projections of future adaptive capacity are not yet available. Panel C returns to the case of static adaptive capacity, but national temperatures are now derived from the WRE mitigation scenario that constrains effective global concentrations of greenhouse gases to 550 ppm. Panel D finally combines enhanced adaptive capacities described above with mitigation that achieves the 550 ppm concentration cap.

The maps assign one of four colors to each of the 110 countries in our sample within which over 85% of the world's population currently resides. Pale green countries have $V_i(t) < 1$; we conclude that they face little or no vulnerability to climate change. Countries framed in bright yellow have indices between 1 and 2 suggesting moderate vulnerability. The indices of orange countries lie between 2 and 3; they will confront significant vulnerability. Finally, countries with $V_i(t) > 3$ are colored red; they can expect extreme vulnerability because their exposure to climate change will likely overwhelm their capacity to adapt. Countries colored light grey were not included in the sample.

Our assignment and interpretation of the colors displayed for each country on the map were both motivated by the IPCC (2001*a*) assessment of climate risks denominated in terms of "Aggregate Impacts" and illustrated in Figure TS-12 drawn from Chapter 19 in IPCC (2001*a*). In their assessment of risk (i.e. their subjective assessment of vulnerability to climate impacts including some limited consideration of possible adaptation), "white means no or virtually neutral impact or risk, yellow means somewhat negative impacts or low risk, and red means more negative impacts or higher risks (pg. 71)." For their concern over "Aggregate Impacts", white turns pale yellow after another 1°C of warming. Yellow turns orange with about 2°C of warming. The scale reaches levels of maximum concern about climate risk, and so turns red, after about 3°C of extra warming. Accordingly, our thresholds between colors are the same as those in Figure TS-12 for the "Aggregate Impacts" line of evidence as reported

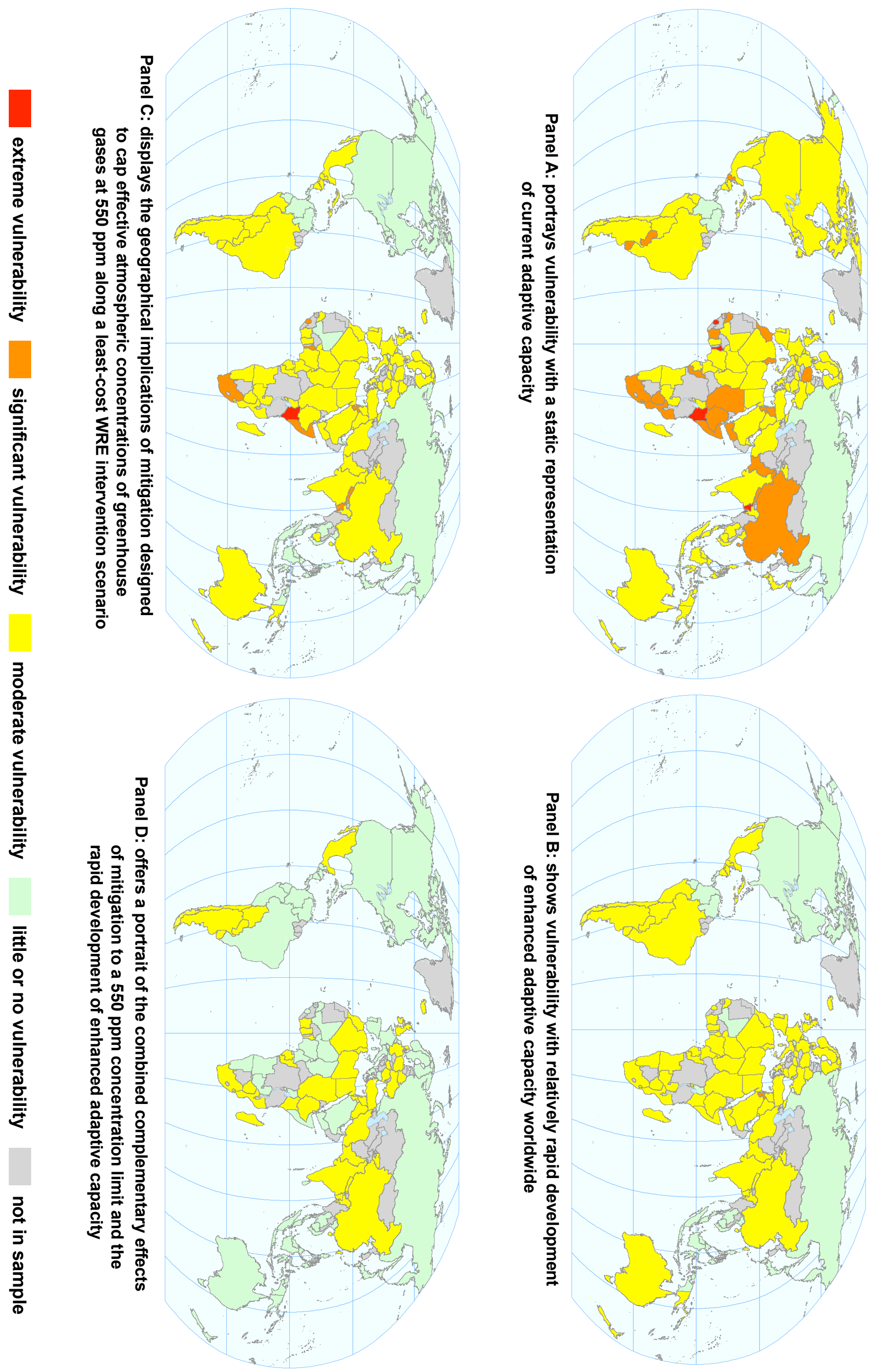
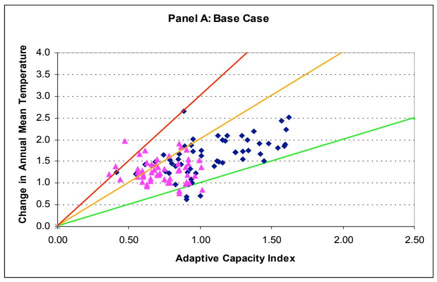
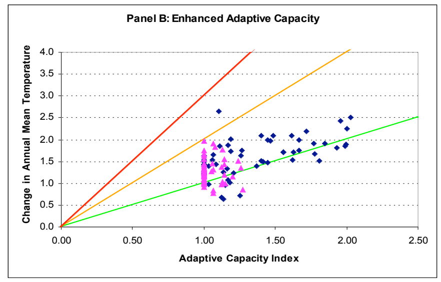


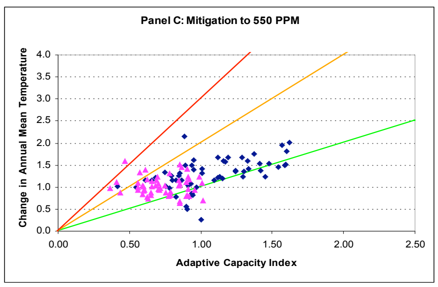
Figure 1: Geographical distribution of vulnerability in 2050 along an A2 emissions scenario with a climate sensitivity of 5.5°C.



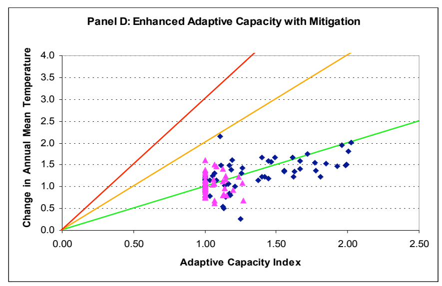
Panel A



Panel B



Panel C



Panel D

Figure 2: Graphical Representation of Global Diversity in Adaptive Capacity and Increases in Annual-Mean Temperature. Ordered pairs of the components of the vulnerability index for 2050 assuming a climate sensitivity equal to 5.5°C. Blue diamonds correspond to developed countries in the sample; purple triangles indicate developing countries. Little vulnerability is threatened for combinations below the green line. Modest vulnerability is suggested between the green and orange lines. Significant vulnerability is expected between the orange and red lines. Adaptive capacity is overwhelmed by climate change for combinations above the red line.

in IPCC (2001*b*).

The link between the IPCC (2001*b*) assessment and color calibration of climate risk and our representation of the geographic distribution of vulnerability becomes clear when we consider a hypothetical country with an adaptive capacity index of unity, that is, equal to the current global average. Such a country would be assigned one of four colors on our maps according to the color thresholds of Figure TS-12. A temperature increase less than 1°C would mean the pale green of little vulnerability. An increase in the national-mean temperature between 1°C and 2°C would call for the yellow designation of moderate vulnerability. Between 2°C and 3°C would be indicated by orange; and increases of more than 3°C would glare the sharp red of extreme vulnerability. Countries with adaptive capacities below the global average would be more sensitive to exposure to their temperatures increase, hence they would be 'red-shifted' on the color scale. Countries with higher-than-average capacities to adapt would be 'green-shifted' on the color scale.

The specific combinations of time and color calibration reflected in Figure 1 and Figure 3 were chosen because they were most illustrative of results drawn from a larger collection of maps that has been archived at Yohe et al. (2006). The patterns of colors depicted in the top two panels of Figure 1 indicate how developed and developing countries alike could be vulnerable to climate change before 2050 if climate sensitivity turns out to be high. Even rapid advances in enhancing adaptive capacity would have trouble keeping pace with exposure to climate impacts. The bottom two panels of Figure 1 bring mitigation into the mix. The colors show that global mitigation efforts that would ultimately cap concentrations of greenhouse gases at 550 ppm would benefit developing countries, in terms of reducing vulnerability, more than developed countries through 2050, especially if they were accompanied by rapid enhancement of adaptive capacity across the globe. Mitigation would, though, provide benefit to the developed world, as well.

Figure 2 offers an alternative, graphical portrait of the results portrayed in the four panels of Figure 1. The points indicate combinations of the adaptive capacity indices and increase in annual-mean temperature for each of the countries in the sample, and the lines indicate the thresholds that defined the color calibrations in the maps. Reading from Panel A to B demonstrates the effect on the geographical distribution relative to these thresholds of simply enhancing adaptive capacity—all countries shift to the right. Reading from A to C shows the effect on the geographical distribution of implementing mitigation to the 550 ppm limit—all countries shift down. Finally, reading from A to D depicts the effect of undertaking both—all countries shift right and down. Clearly, intervention can be effective through 2050.

These observations are confirmed in the first two columns of Table 1. Mitigation alone works about as well as enhanced adaptive capacity in reducing the vulnerabilities of developed and most developing countries into the moderate range, but mitigation combined with enhanced adaptive capacity nearly equalizes the statistical distribution of vulnerability and brings all nations in the sample into the lowest two categories.

Figure 3 and the last two columns of Table 1 show results for the same combination of cases along the same emissions and climate scenarios in 2100. By then, unfettered climate change overwhelms even enhanced adaptive capacity nearly everywhere. Mitigation alone helps a larger percentage of developed countries. Combined with enhanced adaptive capacity at the more leisurely pace permitted by the 2100 timeframe, the global distributions of vulnerability indices for developed and developing countries again converge. This means that a larger percentage of developing countries would be helped, at least in the sense of escaping maximal vulnerability. Notice, though, that no country would experience the calm of little-to-no vulnerability, and less than 1 country in 6 would experience moderate vulnerability net of the effects of exploiting enhanced adaptive capacity in a world that had capped greenhouse gas concentrations at the familiar 550 ppm target.

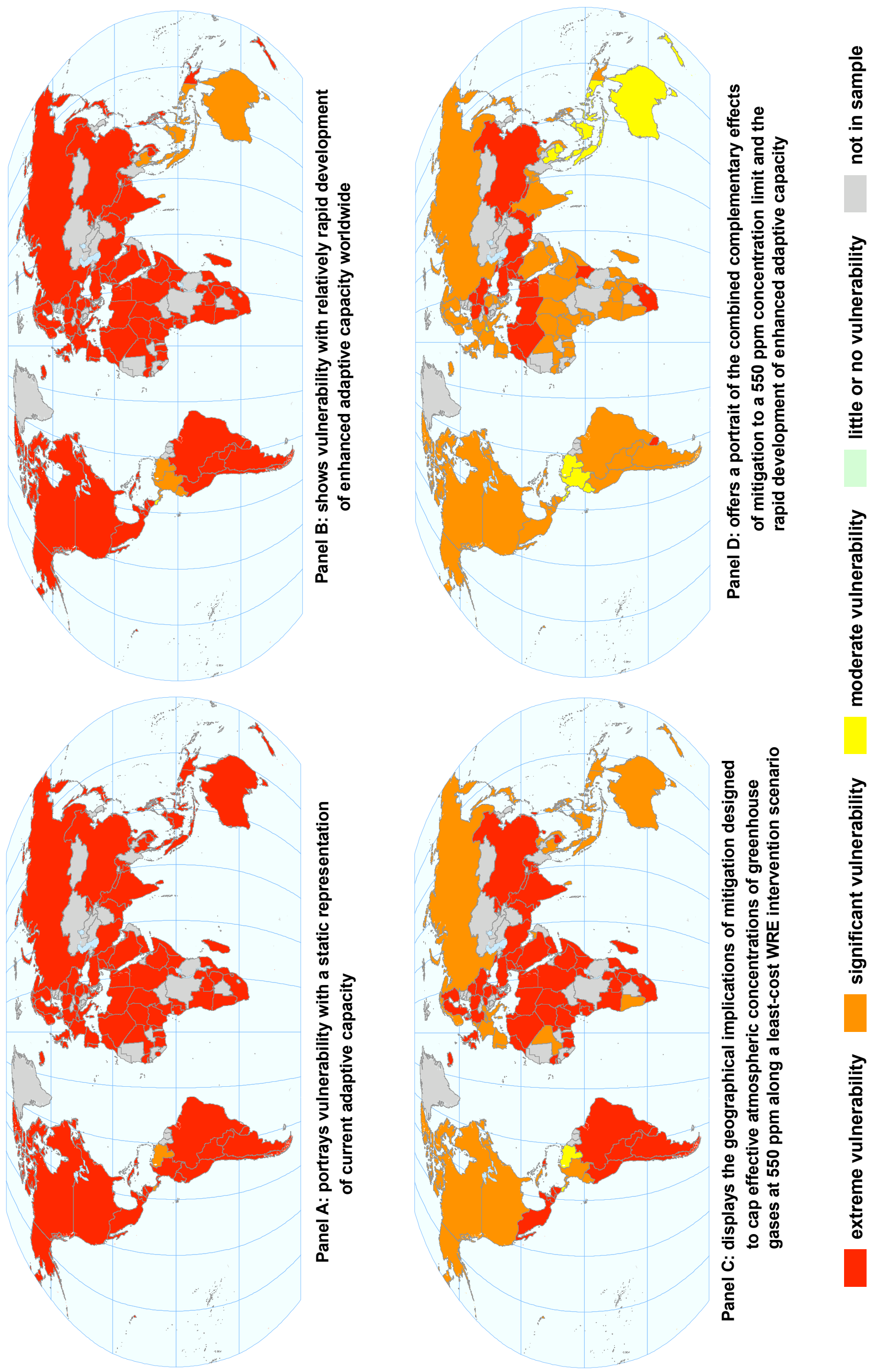


Figure 3: Geographical distribution of vulnerability in 2100 along an A2 emissions scenario with a climate sensitivity of 5.5°C.

Table 1: Summary statistics for the global distribution of vulnerability in 2050 and 2100

	Global Distribution in 2050		Global distribution in 2100	
	Developed Countries	Developing Countries	Developed Countries	Developing Countries
Case A: Baseline Scenario				
Little or no vulnerability	5.3%	0.0%	0.0%	0.0%
Moderate vulnerability	78.9%	84.9%	0.0%	0.0%
Significant vulnerability	14.0%	9.4%	3.5%	0.0%
Extreme vulnerability	1.8%	5.7%	96.5%	100.0%
Panel B: Enhanced adaptive capacity only				
Little or no vulnerability	22.8%	17.0%	0.0%	0.0%
Moderate vulnerability	75.4%	83.0%	1.8%	0.0%
Significant vulnerability	1.8%	0.0%	8.8%	9.4%
Extreme vulnerability	0.0%	0.0%	89.5%	90.6%
Panel C: Concentrations limited to 550 ppm				
Little or no vulnerability	22.8%	13.2%	0.0%	0.0%
Moderate vulnerability	73.7%	75.5%	3.5%	0.0%
Significant vulnerability	3.5%	9.4%	36.8%	18.9%
Extreme vulnerability	0.0%	1.9%	59.6%	81.1%
Panel D: Concentration limit & enhanced adaptive capacity				
Little or no vulnerability	56.1%	56.6%	0.0%	0.0%
Moderate vulnerability	43.9%	43.4%	14.0%	11.3%
Significant vulnerability	0.0%	0.0%	59.6%	69.8%
Extreme vulnerability	0.0%	0.0%	17.5%	18.9%

4 Discussion

The integration of information about climate-change exposure, sensitivity, and adaptive capacity begins to provide insights into the sets of conditions under which adaptive capacity may or may not be able to provide what is needed so that societies may adapt in a timely fashion. Our results have shown that some developing countries are projected to experience impacts of climate change that stress their capacities to adapt before 2050 even at low climate sensitivity; at high climate sensitivity, some of these countries may be overwhelmed, and even developed countries will become increasingly vulnerable. With high climate sensitivity, by 2100 much of the world may need not only high adaptive capacity but also significant emissions mitigation to have been implemented in order to avoid high levels of vulnerability. Overall, these results challenge assumptions about which countries have "enough" adaptive capacity (because they are wealthy or impacts will be mild or both).

The results, while highly suggestive, are surely dependent upon our framing of a specific vulnerability index which presumes a certain, perhaps limited degree of substitutability between experiencing high exposure and generating reduced sensitivity through adaptation. They are also derived from an old-school "what if?" approach to scenarios. What if atmospheric concentrations of greenhouse gases were limited to 550 ppm? What if adaptive capacity were enhanced significantly around the world? We have not tied our thought experiments to any reason why either approach to the climate problem would be chosen; nor have we said anything about how difficult it might be to do either. Indeed, we have said nothing about the relative costs of mitigation and programs that would enhance adaptive capacity; and we certainly do not want to give the impression that a 550 ppm concentration cap should be adopted.

We have, though, demonstrated that these and other questions can be explored in a way that recognizes global diversity explicitly and that calibrates, however roughly, plausible exposure levels to accepted indicators of adaptive capacity in different places. Indeed, we think that it is important to be able to offer suggestive evidence that developing countries are most vulnerable to modest climate change but that all countries could be overwhelmed by more severe exposure. We also think that it is important to be able to suggest that developed countries could benefit most from even near-term mitigation in those not so implausible futures where climate changes rapidly and/or abruptly. Given more time and a cornucopia of analyses that do incorporate more of these details, we therefore offer hope that researchers and negotiators alike will become better informed about who is most vulnerable to climate change (both in terms of exposure and in their adaptive capacity), where they live, why they are vulnerable, and the relative efficacy of various degrees of mitigation in improving their lots in life.

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