

A Country-by-Country Analysis of Past and Future Warming Rates¹

Timothy D. Mitchell and Mike Hulme

Tyndall Centre for Climate Change Research

School of Environmental Sciences

University of East Anglia

Norwich NR4 7TJ

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Introduction

Most studies of climate change have concentrated on global or sub-continental scales, because of issues of spatial resolution. Two recent developments at the University of East Anglia have, however, made it possible to conduct a meaningful examination of climate change at the level of individual countries. The two developments are the construction of an observed climate data set for the world on a half-degree latitude/longitude grid (New *et al.*, 2000) and the fresh impetus given to inter-model comparisons of climate predictions through the setting up of the Data Distribution Centre (DDC, 2000).

To coincide with the official opening of the Tyndall Centre for Climate Change Research on 9 November 2000 we have released this new study. We have combined the 20th century observations with the estimated 21st century changes from five state-of-the-art climate models, and examined both at the level of UN member states. We also present our results in the wider context of human responses to climate change, by combining them with measures of current carbon emissions and wealth. Thus we are able to provide information for each country for the following indicators (see Table and Graphic):

- ▶ Past Warming: the climate change each country has experienced in the recent past,
- ▶ Future Warming: the climate change each country may experience in the near future,
- ▶ Consumption: the responsibility each country bears for those changes,
- ▶ Vulnerability: an index of each country's capacity to respond to those changes.

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20th Century Temperature Change

We employed an updated version (1901-1998) of an existing data-set of monthly temperatures on a 0.5° grid (New *et al.*, 2000). We allocated each land grid-box to a single country, and for each country we calculated the mean of its constituent grid-boxes. We used a robust method of least squares regression (Emerson and Hoaglin, 1983) to calculate the trend in annual temperature over the 20th century for each country.² We expressed the trend in °C per century.

Caveats:

- ▶ 20th century climate change is reduced to a linear trend of annual temperature.

Consumption (current carbon emissions)

We employed an existing data-set of carbon emissions, developed by the Carbon Dioxide Information Analysis Center (Marland *et al.*, 2000). The emission rates are mostly for 1997, and are given in metric tons of carbon per capita for each country.

Caveats:

- ▶ only an instantaneous (1997) measurement of emissions;
- ▶ values for individual countries are expected to change in the future.

21st Century Temperature Change

We used results from five state-of-the-art global climate models from modelling centres around the world:

Country	model	reference
UK	HadCM2	Johns <i>et al.</i> (1997)
UK	HadCM3	Gordon <i>et al.</i> (2000)
Germany	ECHam4	Roeckner <i>et al.</i> (1999)
Canada	CGCM1	Flato <i>et al.</i> (2000)
Japan	CCSR-NIES	Emori <i>et al.</i> (1999)

Each model³ has been used to simulate climate change in the 21st century using a scenario for the future in which greenhouse gas concentrations increase by approximately 1% per year. The results were interpolated onto a common grid (2.5° latitude by 3.75° longitude). Since there is some evidence that averaged model behaviour provides the best comparison with observations (Lambert and Boer, 2000) we developed a measure of 21st century climate change based on the average model behaviour.

² Superior data were available for the UK, in the Central England temperature record (Jones and Hulme, 1997), which we used instead.

³ Except for HadCM2, for which we used the mean of an ensemble of four simulations.

We allocated each land grid-box to a single country, and for each country we calculated the mean of its constituent grid-boxes. For each model we calculated the annual temperature anomaly (relative to 1961-90) for a 30-year period centred on the 2080s for each country and for the globe. We eliminated any inter-model differences arising from different model climate sensitivities by expressing each country anomaly relative to the model's global anomaly. This was then added to the inter-model global-mean anomaly of 3.9°C. We express the model-related uncertainty in 21st century temperature change in terms of the inter-model mean and the inter-model range for the adjusted country anomalies described above.

Caveats:

- ▶ only one emissions scenario was used; the mean warming by the 2080s of the model simulations used here was 3.9°C, compared to a range of warming using the full set of IPCC emissions scenarios of between about 1.5° and 5.5°C.
- ▶ only a selection of models was used;
- ▶ the spatial resolution is such that some UN countries are too small to be represented (*e.g.* San Marino), and for some small countries that *are* included there are doubts about the information that may legitimately be drawn from the models;
- ▶ temperature is only one of a number of possible climatological or impact indicators.

Vulnerability

We have developed a measure of vulnerability that combines the amount of climate change to which humans may have to face with their capacity to adapt; we express this measure in GDP per capita per °C of future warming. We used GDP per capita data for 1998-99 for individual countries, expressed in terms of purchasing power parities in US \$ (World Fact Book, 2000). We divided each country's value by the inter-model mean temperature change (°C) in the 21st century that we calculated above.

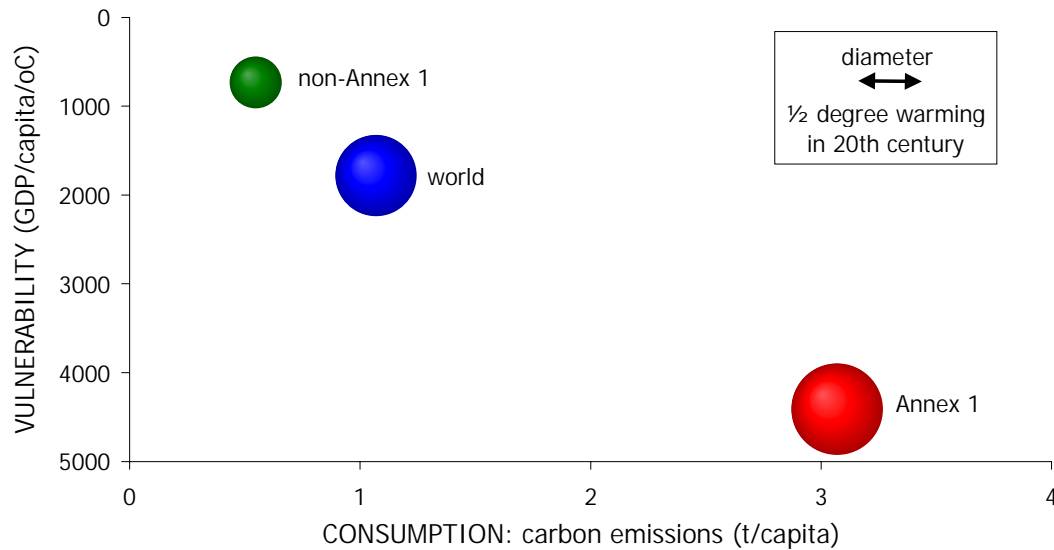
Caveats:

- ▶ although GDP per capita has been used to measure human vulnerability to climate change in some studies (*e.g.* Nicholls *et al.* 1999), there are other dimensions that cannot be captured by present GDP alone;
- ▶ those described above for 21st century temperature change.

Annexes

Finally, we combined all the work described above by calculating population-weighted means for Annex I countries, non-Annex I countries, and the world. Annex I includes countries in the OECD, and in Central and Eastern Europe. The contrast between Annex I and the rest of the world (non-Annex I) enables us to compare "rich" and "poor" countries. We combined the statistics for individual countries into Annex I and non-Annex I, weighting them by their populations. We calculated the world statistics using global-mean temperature changes for the 20th and 21st centuries, together with global-mean emissions, population, and GDP per capita. See Graphic below.

Consumption and Vulnerability



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