Climate Change Research: Evaluation and Policy Implications
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Climate Change Scenarios for Great Britain and Europe

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1. INTRODUCTION

The objective of the work described here was to develop future climate change scenarios for Great Britain and for Europe related to global emissions of greenhouse gases. These scenarios were to be used by a variety of ecosystem and hydrological modellers in a research project titled 'Landscape Dynamics and Climate Change', a project sponsored by the UK Natural Environment Research Council (NERC) under their TIGER (Terrestrial Initiative in Global Environmental Research) programme. The work on the scenarios is now complete and the project as a whole will report its findings during 1995. This paper describes three stages to the scenario construction: the construction of gridded baseline climatologies for 1961-90 using station observations; the construction of the patterns of future climate change using results from General Circulation Model (GCM) experiments; and linking the previous two steps to generate estimates of future climate for specified decades in the future. At all stages work progressed at two spatial resolutions - a 10km resolution for Great Britain and a 0.5° latitude/longitude resolution for Europe.

2. THE 1961-90 CLIMATOLOGIES

Since GCMs are generally not regarded as accurate enough to provide useful descriptions of current climate at local or regional scales, one of the essential components of any future climate scenario is an adequate description of the current climatology of the region of interest based on observed data. Mean monthly climatologies were therefore constructed for the two TIGER domains (Great Britain and Europe) for the following surface climate variables: mean, minimum and maximum temperature, precipitation and raindays, sunshine hours, vapour pressure, wind speed and ground frost days. These climatologies used station data for the period 1961-90 collected from National Meteorological Agencies (NMAs) across the region. The distributions of European stations for which 1961-90 data were obtained are shown in Figure 1 for temperature.

The interpolation of the station data to the respective grids used partial thin-plate splines as developed by Mike Hutchinson from the Australian National University. Since elevation was one of the predictor variables, three climate surfaces were produced for each variable reflecting the 'minimum', mean and 'maximum' elevation within each 10km or 0.5° cell. Month-by-month anomalies on these grids for the period 1961 to 1990 were also calculated for the variables mean temperature and precipitation.

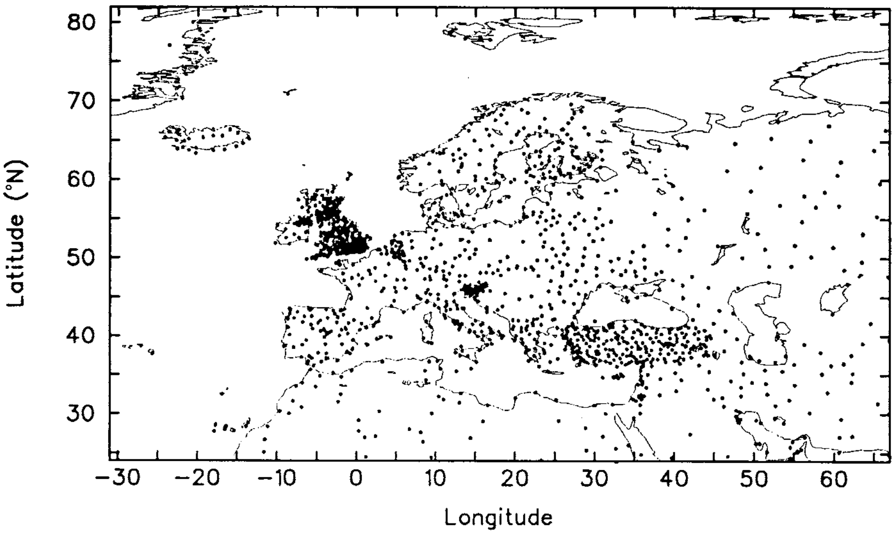

Figure 1: Distribution of sites across Europe for which 1961-90 monthly normals were obtained for temperature.

The accuracy of the various interpolated surfaces was assessed using validation sets of independent station data (i.e., station data not used in the interpolation). Estimated mean absolute errors (MAEs) for the European surfaces ranged from under 5% for vapour pressure to about 15% for wind speed to up to 20% for precipitation in some regions. The accuracy of the interpolated surface for maximum temperature was greater (MAE ~0.4°C) than for minimum temperature (MAE ~1.0°C). Some other validation statistics for the European climatology are shown in Table 1.

Table 1
Validation statistics for the European climate surfaces for January and July. None of the validation sites (n = 100) were used in generating the climate surfaces. Frostdays for July are omitted since so few occur.

	January			July		
	Obs. mean	Mean bias	MAE	Obs. mean	Mean bias	MAE
Max. temp. (°C)	5.4	-0.1	0.6°C	24.9	0.0	.6°C
Min. temp. (°C)	-1.9	0.1	0.8°C	15.4	0.0	0.6°C
Precipitation (mm).	66.1	-1.6	21.7%	49.9	-2.4	13.0%
Sunshine (hours)	72.9	1.4	6.2%	268.2	1.8	3.8%
Vapour press. (mb)	6.1	0.1	3.4%	15.2	0.0	4.1%
Wind speed (ms^{-1})	3.4	0.0	15.7%	3.0	0.0	17.4%
Frostdays (days)	16.1	0.1	10.6%	-	-	-
Raindays (days)	16.9	-0.1	6.0%	12.0	-1.3	7.0%

3. GENERAL CIRCULATION MODEL EXPERIMENTS

General Circulation Models (GCMs) provide the most comprehensive method of investigating the response of the global climate system to various types of internal or external forcing. A considerable number of GCMs have now been used to simulate the effect of increasing atmospheric concentrations of greenhouse gases (GHGs) on global climate. GCM climate change experiments have fallen into one of two types: equilibrium and transient experiments. In equilibrium experiments, oceans are represented by a simple specified mixed layer with no deep vertical mixing. After integrating the model under a control concentration of GHGs, concentrations are usually instantaneously doubled and the model integrated until a new quasi-equilibrium climate state is reached. The difference between the control and perturbed climates then represents the equilibrium pattern of GHG-induced climate change. In transient experiments the situation is more complicated owing to the fully three-dimensional representation of the oceans. These ocean-GCMs are linked to the atmospheric-GCMs and the two models integrated in parallel allowing the ocean circulation respond to the changed fluxes between ocean and atmosphere. The perturbed experiment usually introduces a progressive increase in GHG concentrations, often a 1% per annum increase.

In our work we have used results from three GCM experiments: two equilibrium and one transient. The equilibrium experiments were those performed in 1989 at the Hadley Centre (UKHI) and the Canadian Climate Centre (CCC) using relatively high-resolution atmospheric GCMs. The transient experiment (UKTR) was performed at the Hadley Centre in 1991/92 using their coupled ocean-atmosphere GCM. The mean monthly fields from these three GCM experiments were extracted for the same range of climate variables as existed in the baseline climatology and the changes between the control and perturbed integrations calculated. The change fields were interpolated down to the same resolutions as the baseline climatology using a simple Gaussian space filter.

4. CREATING CLIMATE CHANGE SCENARIOS

For a climate change scenario to be used most effectively in an impacts analysis, it needs to be identified with a particular set of assumptions about the future GHG emissions path which might cause it. It is also necessary to assign a future year or decade by which the scenario might be realised. For a variety of reasons, using direct results from GCM experiments does not allow either of these conditions to be met. We therefore used a further type of climate model, a simple one-dimensional upwelling-diffusion model, to assist in this task. The model used is called MAGICC (Model for the Assessment of Greenhouse gas-Induced Climate Change) and was developed by Tom Wigley, Sarah Raper and Mike Salmon of the Climatic Research Unit. MAGICC determines the global-mean temperature and sea-level change implications of specified emissions scenarios for the various trace gases that may affect the Earth's climate. There are a number of model parameters which can be adjusted by the user, the most important one being the climate sensitivity which can take on a value between 1.5° and 4.5°C for a doubling of CO_2.

Using the set of six GHG emissions scenarios published by the Intergovernmental Panel on Climate Change (IPCC) in 1992, estimates of future global warming were calculated using MAGICC (note here that we are ignoring the cooling effect of sulphate aerosols on global temperature since the forcing due to such aerosols was not included in the GCM experiments from which we derive our patterns of change). These estimates for three of the IPCC emissions scenarios (IS92a, IS92c and IS92e) are shown in Figure 2 as projections between 1990 and 2100 with respect to 1990. The effect of three different climate sensitivities on these estimates is also shown. The IS92a scenario, with a 'central' climate sensitivity of 2.5°C, yields a global warming of just under 2.5°C by 2100. Table 2 presents these calculations in a different way - as the estimated date by which 1°C of global warming, with respect to 1990, will have been reached. For the IS92a scenario this date may vary between 2023 and 2055 depending on the climate sensitivity.

Using the results from MAGICC, together with the standardised GCM change fields described above, and then projecting these changes onto the 1961-90 baseline climatology, a variety of future climates can be generated. These scenarios relate to a range of future dates and are based on different assumptions about both the GHG emissions path the world will follow and the sensitivity of the climate system to GHG forcing.

Table 2
Estimated dates by which 1°C of global warming would be reached, with respect to 1990, under different GHG emissions scenarios and assuming different climate sensitivities (results from MAGICC). Effect of sulphate aerosols are ignored.

	1992 IPCC Greenhouse Gas Emissions Scenarios					
Climate sensitivity	IS92a	IS92b	IS92c	IS92d	IS92e	IS92f
1.5°C	2055	2057	After 2100	2084	2048	2047
2.5°C	2036	2037	2049	2047	2035	2032
3.5°C	2027	2028	2034	2033	2025	2025
4.5°C	2023	2024	2028	2027	2021	2021

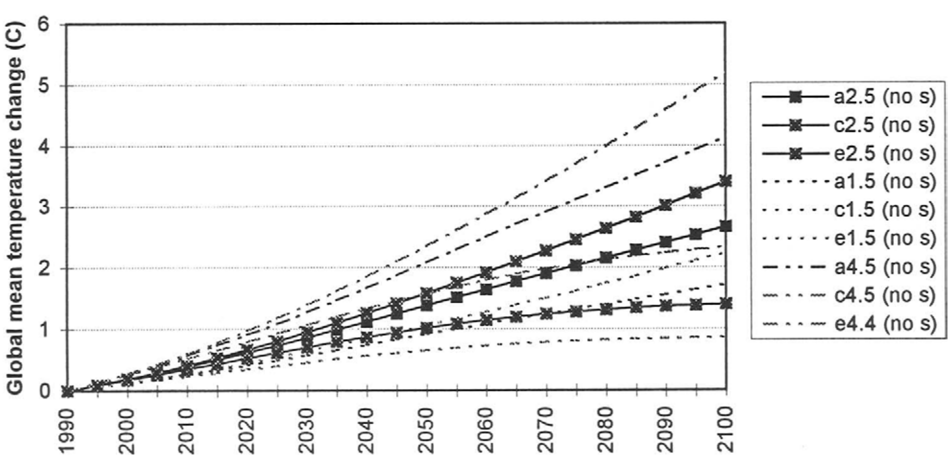

Figure 2: Global-mean warming projections from 1990 to 2100 for the IPCC emissions scenarios IS92a, IS92c and IS92e assuming three different climate sensitivities: 1.5°, 2.5° and 4.5°C. Results are from the MAGICC model. Sulphate aerosol effect ignored.