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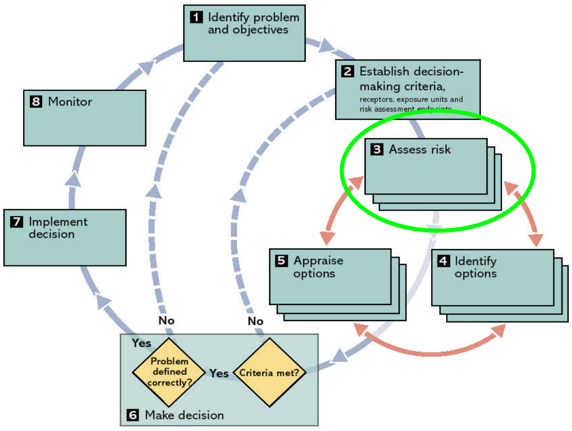
The Isle of Man Climate Change Scoping Study

Technical Paper 4

Future climate change scenarios



Report for
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Our reference IOM 001

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CLIMATE CHANGE:

Indicators, Scenarios and Impacts for the Isle of Man

A scoping report prepared for the Isle of Man
on behalf of
acclimatise.

Prepared by

ICARUS
Irish Climate Analysis and Research Units

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1 Introduction

Large scale dynamical models of the climate system or global climate models (GCMs) suggest that mean global temperatures could rise significantly as a consequence of increasing anthropogenic emissions of greenhouse gases. Estimates from a selection of GCM models suggest that end of century increases in global temperatures could be in the range of between 1.4-5.8°C, depending on which emissions scenario is considered likely (Figure 1.1, Figure 1.2, Box 1.1) (IPCC, 2001). An increase in global temperatures of this magnitude is likely to have a significant impact on climate processes operating at various scales, from global and hemispherical scale processes to the regional and local scale surface environmental variables.

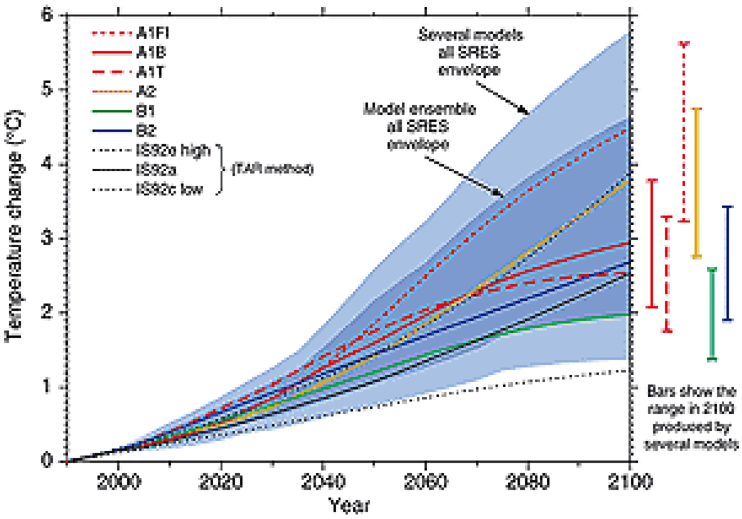

Figure 1.1 Temperature change by 2100 depending on emissions scenario (IPCC, 2001)

Confidence in the simulations of these models is largely based on the assumptions and parameterisations used to develop them but also on the ability of these models to reproduce the observed climate (Karl *et al.*, 1990). In recent years increasing sophistication of these models has resulted from an improved understanding of the underlying climate process and ability to incorporate these advances into these numerical models. Complexity of the climate system is also accounted for with the incorporation of horizontal and vertical exchanges of heat, moisture and momentum extending into the atmosphere and ocean.

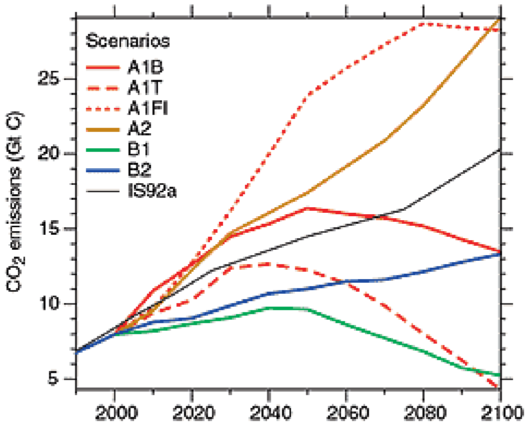

Figure 1.2 Carbon Dioxide (CO_2) emissions, 1990-2100, for seven marker emissions scenarios.

Despite the high degree of sophistication of GCMs, their output is generally too coarse to be useful for regional or local scale impacts analysis, as important processes which occur at sub grid scale are not at present resolved by these models (Wilby *et al.,* 1999). Changes in both temporal and spatial variability (Figure 1.3), which may be just as important as the magnitude of change, are also masked at the sub grid scale (Wigley *et al.*, 1990), as it is unlikely that all locations will warm by the same amount and at the same rate. Global variations in the amount and rate of warming will also affect the distribution and rates of change of other meteorological variables, such as precipitation. Therefore a disparity of scales exists between the global scenarios, as output by GCMs, and changes that could occur at the regional or local level due to these large-scale changes. In order to overcome some of these scale differences, a number of techniques have been developed in which large-scale GCM output can be translated or 'downscaled' into information about changes in the climate that can then be used for local scale impact analysis.

The application of regional climate models (RCMs), which are dynamical in nature, to the downscaling problem have become more widespread in recent years due to the increase in available computational resources. RCMs are fundamentally similar to GCMs in that they utilise physical parameterisations that are either consistent to their respective resolutions or each other (Yarnal *et al.*, 2001). Their added value is derived from the fact that they operate on a much smaller domain and as such offer a much higher resolution than that of the parent GCM within which they are nested. The optimum resolution at which nested RCMs operate is in the tens of kilometres, which may still be too coarse for some impacts analysis needs.

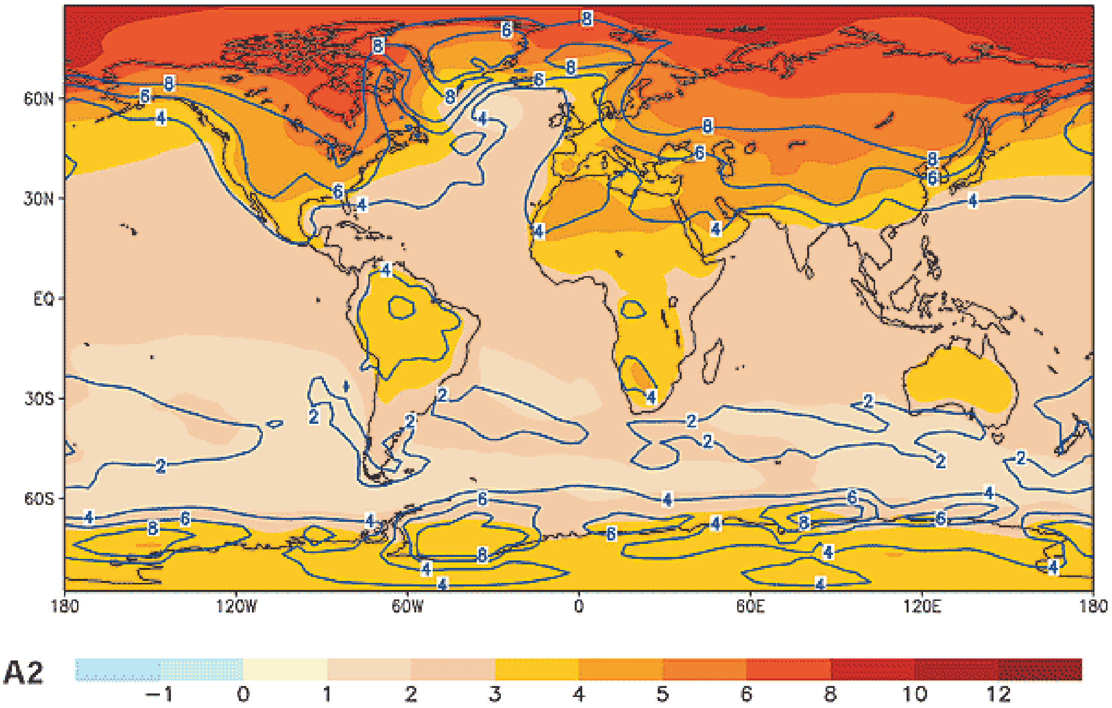

Figure 1.3 Mean annual change in temperature (colour shading) and its range (isolines) (Unit: °C) for the SRES scenario A2, for the period 2071 to 2100 relative to the period 1961 to 1990.

Empirical statistical downscaling has become a viable alternative to that of RCMs where high spatial and temporal resolution climate scenarios are required. It requires substantially less computational resources and produces results that are comparable to that output from RCMs. The methodologies employed in statistical downscaling are largely in common with those of synoptic climatology, however, the goal of downscaling is to adequately describe the relationship between atmospheric circulation and the surface environment, with attention being focused more on model parsimony and accuracy, rather than understanding the relationship between them (Yarnal *et al.,* 2001). As a consequence of their relative ease of implementation and comparability of output to RCMs, the use of statistical downscaling methodologies to produce climate scenarios from GCMs is now the favoured technique for many researchers.

Box 1.1: The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)

A1. The A1 storyline and scenario family is indicative of high levels of greenhouse gases and describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2. The A2 storyline and scenario family is indicative of medium-high levels of greenhouse gases and describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family is indicative of low levels of greenhouse gases and describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family is indicative of medium-low levels of greenhouse gases and describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

(Source: IPCC, 2001)

Results from both RCMs and statistical downscaling techniques are, however, largely dependant on the parent GCM used as input to these models. Therefore uncertainties in the GCM are translated though both methodologies. Ideally, in order to account for some of these uncertainties, a number of GCMs should be employed, which account for uncertainties that arise with regards to climate sensitivity and model uncertainty. However, due to the computational requirements of RCMs, production of ensembles or averages of a range of GCM forced output, are not presently feasible. While employing a number of GCMs to force statistical downscaling techniques is possible, few studies to date have done so, due to differing model resolutions of the various GCMs.

2 Climate scenarios: UK and Ireland (UKCIP and ICARUS)

Both RCMs and statistical downscaling methodologies have found fairly widespread application in the UK and Ireland. The Hadley Centre employed an RCM, HadRM3, to produce a future scenario of climate based on the A2 or Medium-High emissions scenario for the 2071 to 2100. The boundary conditions for the RCM were provided from the global atmospheric model, HadAM3H (~120 km). This nesting approach results in high-resolution regional scenarios (~50km), with significantly improved spatial detail for a domain over the UK and Ireland. Due to the cost of running the nested RCM, only four climate model experiments were undertaken, three for the Medium-High (A2) emissions scenario and one for the Medium-Low (B2) scenario. Climate scenarios for all other emissions scenarios and time slices were then pattern scaled based on the respective global average temperature change for each of the remaining scenarios.

Results from the HadRM3 suggest annual warming rates of 0.1 to 0.3°C per decade for the Low Emissions scenario, to 0.3 to 0.5°C per decade for the High Emissions scenario (Hulme at el., 2002), rates which are consistent with global average temperature increases. This results in an increase in annual temperatures of between 1 to 5°C by the end of the present century, with greatest warming experienced in the southeast of England particularly during the summer as a consequence of its proximity to the continent. Rates of warming were found to be greater during summer and autumn than during winter and spring.

Increases in winter precipitation were found for all scenarios and periods, ranging from increases by the 2080s of 5-15% for the Low Emissions scenarios to more than 30% for the High Emissions scenario (Hulme et al., 2002). Summer decreases ranging from 20% for the Low Emissions scenario to more than 40% for the High Emissions scenario were projected to occur across the whole country. While only a slight change was projected to occur in the annual totals, a significantly increased seasonality, with wetter winters and drier summers, is likely to occur in precipitation.

Changes in interannual variability were also projected to occur in temperature and precipitation. Winter and spring temperatures decrease in variability, while summer and autumn become more variable. For precipitation, again there is a marked seasonal component with increased variability during winter, while reduced variability during the summer months are projected to occur.

In an assessment of climate change for Ireland, Sweeney and Fealy (2003) employed the alternative approach of statistical downscaling to produce climate scenarios, based on the HadCM3 GCM. High-resolution spatial detail was inferred from the large number of stations employed in the analysis which incorporated ~550 stations measuring precipitation and ~70 stations measuring temperature. Results from this research project increases in winter temperatures of 1.5°C by mid-century, with summer increases of 2.0°C. Greatest warming was found to be occurring in inland regions away from the coast during the summer months. The spatial extent of this ‘continental’ effect during the summer months is further enhanced by the end of the century with temperature increases of 2.5°C being experienced from the west to east coast and over all the central midlands. Winter increases of similar magnitude are projected by the 2070s (2061-2090). Mean projected temperatures for Ireland exhibit a warming rate of ~0.25°C per decade, again in line with observations (Sweeney, et al., 2002) and projected global temperature increases.

The greatest changes occur in projected seasonal precipitation for Ireland and have a marked spatial gradient. Winter increases in precipitation are projected to be 11%, with up to 20% for regions in the north west of the country. While decreases during the summer months of the order of 25%, with decreases of over 40% projected for the south east of the country by the 2070s. The major difference between the 2050s and 2070s is the spatial extent to which the changes occur between these periods.

However, precipitation scenarios are inherently less reliable than those of temperature due to the large stochastic and local component, which affects precipitation mechanisms. As a consequence, the large scale deterministic forcing for precipitation is much less than that of temperature. As temperature is also a largely homogeneous variable over space and therefore more confidence can be placed in the temporal and spatial changes which occur in this variable.

3 Climate scenarios: Isle of Man (BIC)

Due to the resolution of the HadRM3, the Isle of Man and other islands around the British Isles were not capable of being resolved in the original UKCIP02 Scientific Report. However, under the auspices of the British-Irish Council, a high resolution RCM (HadRM3H) that was capable of resolving the island was run. The HadRM3H (~25km) was run with boundary conditions from a high-resolution global atmospheric model, HadAM3H, for two periods, 1961-1990 and 2071-2100, to produce climate projections for the Medium-High emissions scenario. Similar to the UKCIP methodology, the remaining emissions scenarios and time periods were then pattern scaled according to the global mean temperature temperatures for the respective time periods and emissions scenarios

	DJF	MAM	JJA	SON	ANN
Mean temperature (°C)	+1.7	+2.2	+2.7	+2.8	+2.4
Max. temperature (°C)	+1.8		+3.0		
Min. temperature (°C)	+1.8		+2.4		
Precipitation (%)	20	12	-36	-8	-1
Snow (%)	-75				
Cloud cover (%)	-3	-4	-9	-8	-6
Relative humidity (%)	-0.8	-1.8	-4.4	-1.6	-2.1
Soil moisture (%)	2	2	-12	-7	-4

Table 1.1 Changes in seasonal and annual values for a selection of variables for the Isle of Man by the 2080s for the Medium-High emissions scenario.

Table 1.1 presents the results from the HadRM3H RCM for the 2080s for the Medium-High emissions scenario. Seasonal changes in temperature are broadly consistent with the findings from both the UKCIP and Irish analysis. The changes in precipitation are also in line with previous results. Again, only a small change in annual precipitation is projected, but with large seasonal changes, reflecting a more marked seasonal contrast in receipts. These projected changes in the seasonality of precipitation are likely to have a significant impact on water supply and storage, during summer and winter respectively. An increased potential for flooding during the winter months is also more likely with the projected changes.

In order to account for uncertainties arising from the modelling process, Jenkins et al. (2003) provide uncertainty margins, derived from taking the highest and lowest grid square averages for the Isle of Man from a range of GCMs. These uncertainty margins are shown in Table 1.2. Model output from different GCMs can vary for a number of reasons, such as, unknown future concentrations of greenhouse gases. As a consequence, regional climate projections can contain a considerable degree of uncertainty due which results from translating future socio-economic storylines into greenhouse gas emissions and subsequent climate change scenarios. In order to account for some of the uncertainties that can occur, results from a number of GCMs are utilised to produce ranges of future projections, all of which can be considered to be equally likely.

	Winter	Summer
Mean temperature (°C)	-0.5, +1.3	-0.6, +2.5
Precipitation (%)	-19, +13	0, +36

Table 1.2 Uncertainty margins for projected changes in temperature and precipitation for the winter and summer for the 2080s under a Medium-High emissions scenario

Interannual variability is also projected to change in both temperature and precipitation, with a reduction in variability in mean winter temperatures of 10% and an increase of 20% in the variability of summer temperatures. The largest seasonal increase in the variability of precipitation is likely to occur during the summer months with a reduction of 25%, while during the winter months, an increase of 10% in the variability of precipitation is projected for the Isle of Man.

As the HadRM3H was only run for the 2071-2100 period, time series of monthly data were not available for the post-1990 period onwards. However, in order to assess future changes in runoff for the Isle of Man presented in technical report 10, time series of precipitation and potential evapotranspiration were required. In order to produce the necessary time series of data, the seasonal change factors (2071-2100 minus 1961-1990) for the four emissions scenarios for the 2080s for both precipitation and temperature were scaled employing yearly scaling factors as oppose to the average for the particular 30-year time period of interest, calculated from the HadCM3 GCM.

Estimates of potential evapotranspiration (PE) were calculated using the Thornthwaite method (1948), which utilises mean monthly temperature, in order to calculate PE. According to Thornthwaite, PE is calculated as follows-

$$PET = 1.6\, L_d \left(\frac{10T}{I} \right)^a$$

where L_d is the daytime hours in units of 12
T is the mean monthly temperature
I is the heat index, which is the sum of the monthly heat indexes ($I=\sum i$)
where the monthly heat index i is $(T_3/5)^{1.514}$
$a=0.000000675\, I^3 - 0.0000771\, I^2 + 0.01792\, I + 0.49239$

It was not possible to validate the results of calculating PE in this manner, as PE is not an observed or calculated meteorological variable on the Isle of Man. However, it is likely that it is a good approximation as monthly values of PE largely follow a sin curve reflecting seasonal changes in radiation, which is approximated by the use of mean monthly temperatures in the equation.

Figures 1.4-1.9 show the seasonal changes in precipitation and temperature for each of the four SRES marker emissions scenarios and three time periods, 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). Differences between the emissions scenarios is not that apparent in the 2020s, but by the 2080s the difference in winter precipitation ranges from 13% in the Low Emissions scenario to 25% in the High Emissions scenario. While in summer the spread is greater, ranging from reductions of 23% to 45%. Similarly with temperature changes, the greatest differences between scenarios is in the 2080s, during the autumn season, where a range of 1.8°C to 3.5°C is apparent between the lowest and highest emissions scenario. Greater warming projected during the summer and autumn and increasingly wetter winters and drier summers are consistent with the UKCIP scenarios for the UK. The differences in the scenarios reflect uncertainties in future emissions pathways, which increase over time depending on which emissions storyline is more realistic.

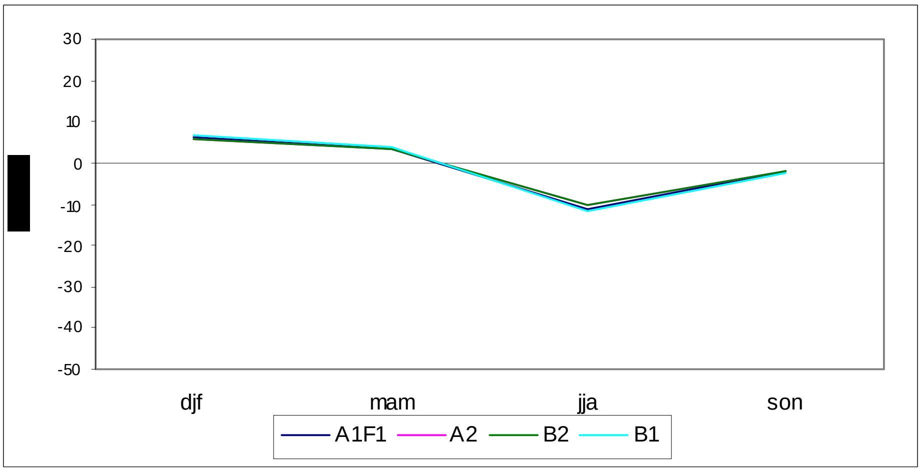

Figure1.4 % change in precipitation, 2020s for all emissions scenarios.

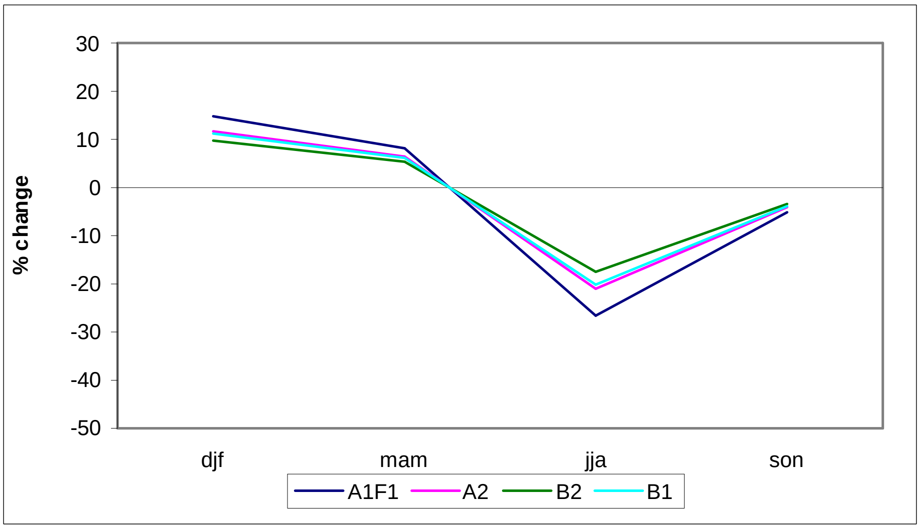

Figure1.5 % change in precipitation, 2050s for all emissions scenarios.

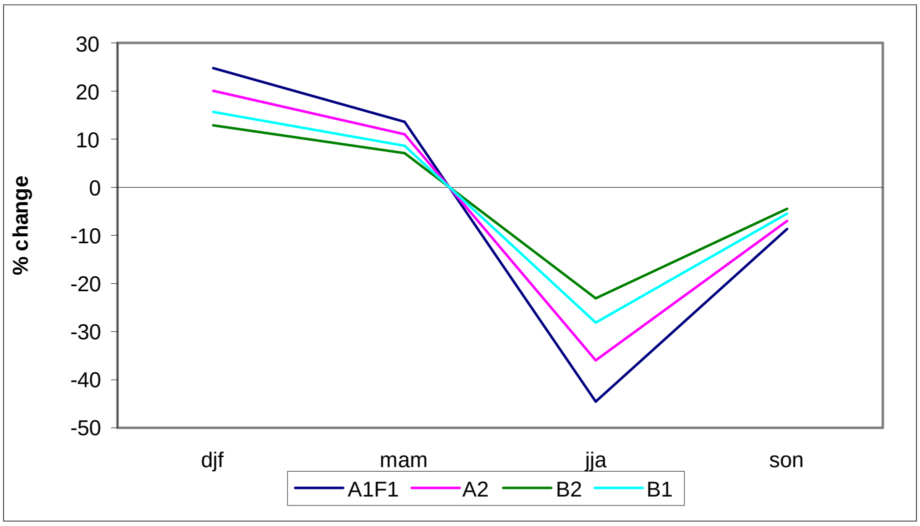

Figure1.6 % change in precipitation, 2080s for all emissions scenarios.

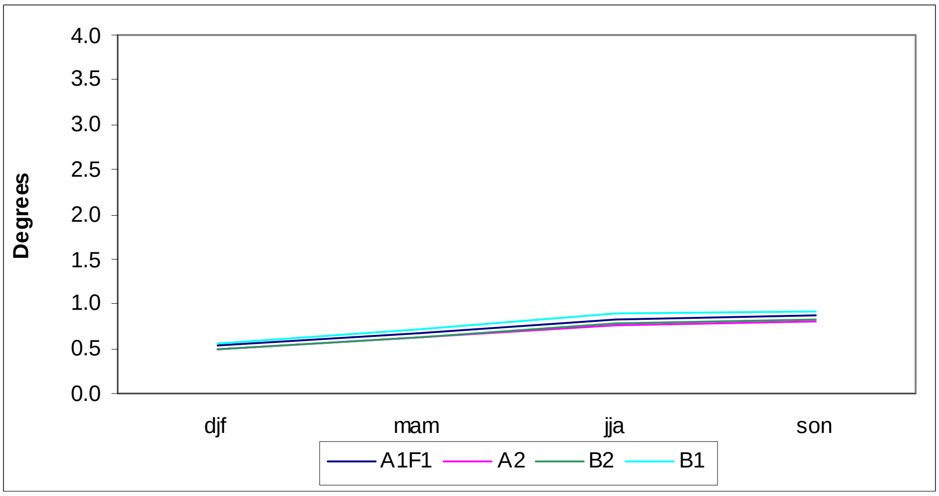

Figure1.7 Change in temperature (ºC), 2020s for all emissions scenarios.

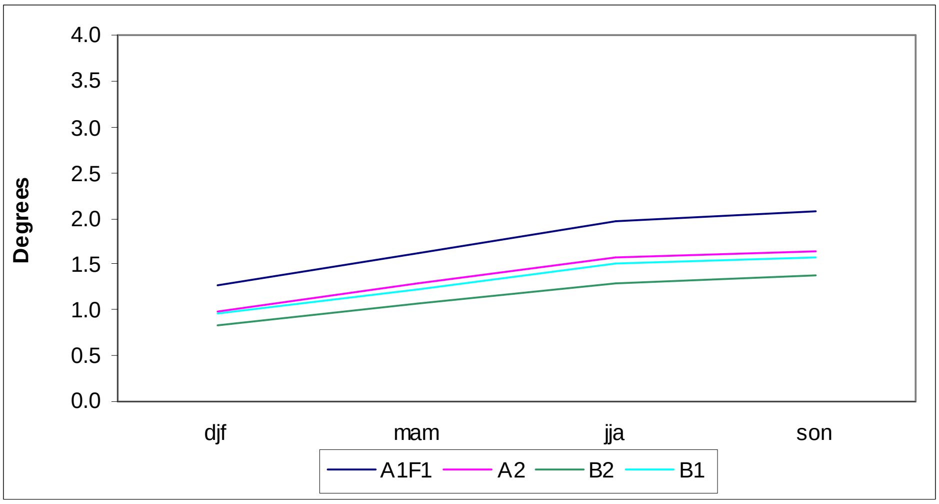

Figure1.8 Change in temperature (ºC), 2050s for all emissions scenarios.

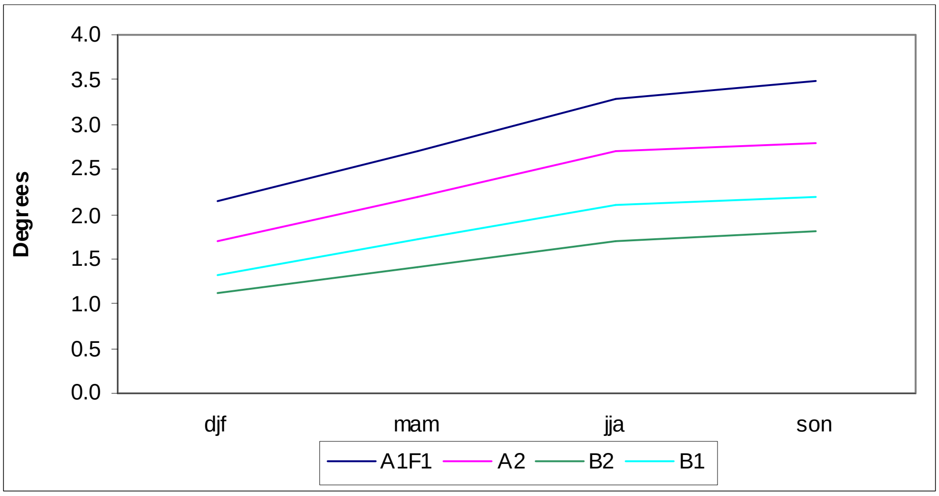

Figure1.9 Change in temperature (ºC), 2080s for all emissions scenarios.

An important caveat when assessing these results is that they are derived from just one GCM. Therefore, GCM model uncertainty has not been addressed. While the climate sensitivity of the Hadley GCM lies close to the mid-range of a number of GCMs, no measure of confidence can be attributed to the scenarios. Figure 1.10 illustrates between-model differences in temperature and precipitation for Northern Europe for a selection of GCMs. While the direction of change is consistent between models for a number of seasons, the magnitude of change is shown to differ greatly between models. During the summer season, contradictory results are shown in terms of the direction of change between the various models.

4 Sea Level Rise

Global projections for a rise in mean sea level, from a range of global climate models (GCMs), indicate an increase of between 0.09 and 0.88 metres over the period 1990 to 2100 (Table 1.3) (IPCC, 2001). These ranges are based on an IS92a forcing, which represents an increase of effective CO_2 concentrations by 1% per annum after 1990. The Best Estimate value reported in Table 1.3 is based on more recent data derived from the 35 SRES (Special Report on Emissions Scenario) emissions, with an ensemble mean of 0.48 metres sea level rise by the end of the present century.

Experiment	**Min**	**Max**
CGCM1 GS	0.45	0.77
CSIRO Mk2 GS	0.29	0.60
ECHAM4/OPYC3 GS	0.19	0.48
GFDL_R15_A GS	0.37	0.67
HadCM2 GS	0.21	0.48
HadCM3 GSIO	0.18	0.46
MRI2 GS	0.11	0.31
DOE PCM GS	0.12	0.37
Range (IS92a)	0.11	0.77
Central Value (IS92a)	0.44	
Best Estimate (SRES)	0.48	
Range (SRES)	0.09	0.88

Table 1.3 Sea level rise 1990-2100 derived from different AOGCM experiments with the IS92a and SRES emissions forcing (Source: IPCC, 2001)

Sea level may also change as a result of a change in the elevation of the land. A change in absolute sea level, a eustatic change, occurs over all the oceans, while a localised sea level change resulting from a change in the absolute level of the land is termed an isostatic change. Shennan and Horton (2002) in their analysis of sea level changes in Great Britain suggest that the best estimate net rate of relative land uplift for the Isle of Man at 0.45 mm/yr^{-1}. This would result in an isostatic change in the level of the Isle of Man by approximately +5cm by the end of the present century, above 1990 levels.

Emissions Scenario	2020s	2050s	2080s
Low-emissions	4-14cm	7-30cm	9-48cm
Medium-Low emissions	4-14cm	7-32cm	11-54cm
Medium-High emissions	4-14cm	8-32cm	13-59cm
High emissions	4-14cm	9-36cm	16-69cm

Table 1.4 Ranges of global mean sea-level (IPCC, 2001) averaged over three future 30-year periods (Jenkins et al., 2003)

As the geographical distribution of sea-level changes will be dependant on regional factors, such as thermal expansion, sediment loadings and isostatic changes, some regions are likely to experience above average sea level rise, while other areas may experience a fall in relative sea level (IPCC, 2001). To assess future sea level rise for the Isle of Man, the global estimates are employed. Future sea level rise, accounting for isostatic rebound, for the Isle of Man for a medium-high emissions scenario results in a rise of 2.4-12.4cm for the 2020s, 5.1-29.1cm for the 2050s and 8-54cm by the 2080s.

4.1 Storm surges

A great deal of uncertainty surrounds future projections of changes in the frequency, strength and storm tracks of depressions in the North Atlantic and wind speeds. While a change in storminess, in terms of their strength, could be expected as a consequence of global warming due to increased moisture in the atmosphere, their frequency may decreases due to heat being transferred more efficiently in a moister atmosphere (IPCC, 2001). Findings, based on the Hadley Centre global model, suggest that the number of deep depressions (<970 hPa) crossing the UK in winter may increase by 40% by the 2080s (Jenkins et al., 2003).

Hulme et al. (2002) estimated the change in frequency of the present day 50-year return period surge event under various emissions scenarios for the end of the century. Under a low emissions scenarios, which results in an increase in sea level of 9cm, the likely return period of a surge of this magnitude, relative to the present day, decreases to a one-in-10 year return period. While under a high emissions scenario, for which a 69cm rise in sea level is projected, a surge of this magnitude is likely to occur more than once a year.

5 Uncertainty in climate projections

Future projections of anthropogenic climate change arising from increased concentrations of atmospheric CO_2 are subject to a high degree of uncertainty (Jones, 2000). This uncertainty arises as a consequence of both 'unknowable' knowledge and 'incomplete' knowledge' (Hulme and Carter, 1999). The major uncertainties in the projected ranges of future climate change arise from four main areas (after Hulme and Carter, 1999; Jones, 2000):-

1. Emissions scenarios- due to human actions being unpredictable, emissions scenarios, which are influenced by population growth, energy

use, economic activity and technology, are also unpredictable in any deterministic sense.

2. Climate sensitivity- the sensitivity of the climate system to forcing due to greenhouse gases. According to the IPCC, the sensitivity of the climate system is in the range of 1.5°C-4.5°C. For the full range of SRES marker scenarios, the climate sensitivity has a slightly range of 1.4°C-5.8°C (IPCC, 2001).
3. Climate system predictability- a large degree of variation occurs both between and within GCMs at the regional level which results from different modes of variability, especially multi decadal variability and chaotic behaviour of the models (Figure 1.11) (Jones, 2000).
4. Sub-grid scale variability- due to computational limitations, the grid box output from GCMs is generally in the order of 100s kms. While this is adequate to capture large scale variability, many important process in the climate system occur at much smaller spatial scales, such as, convective clouds, and thus are too fine to be resolved in the modelling process.

Regional climate projections can therefore contain a considerable degree of uncertainty due to the ‘cascade of uncertainty’, which results from translating future socio-economic storylines into greenhouse gas emissions and subsequent climate change scenarios. Due to uncertainties in the climate system, modelling the future climate for a given emissions scenario will always result in a range of future scenarios being simulated (Hulme and Carter, 1999).

In addition, we also need to allow for the possibility of ‘surprise’ outcomes or *imaginable abrupt events* which may occur due to the non-linear responses of the climate system to anthropogenic forcing (Hulme and Carter, 1999; Moss and Schneider, 2000). While no GCM to date has produced a sudden collapse in the thermohaline circulation (THC) in the North Atlantic, most GCMs do show a reduction in the strength of the THC due to increasing anthropogenic emissions, which may partially offset the resulting warming (Hulme and Carter, 1999).

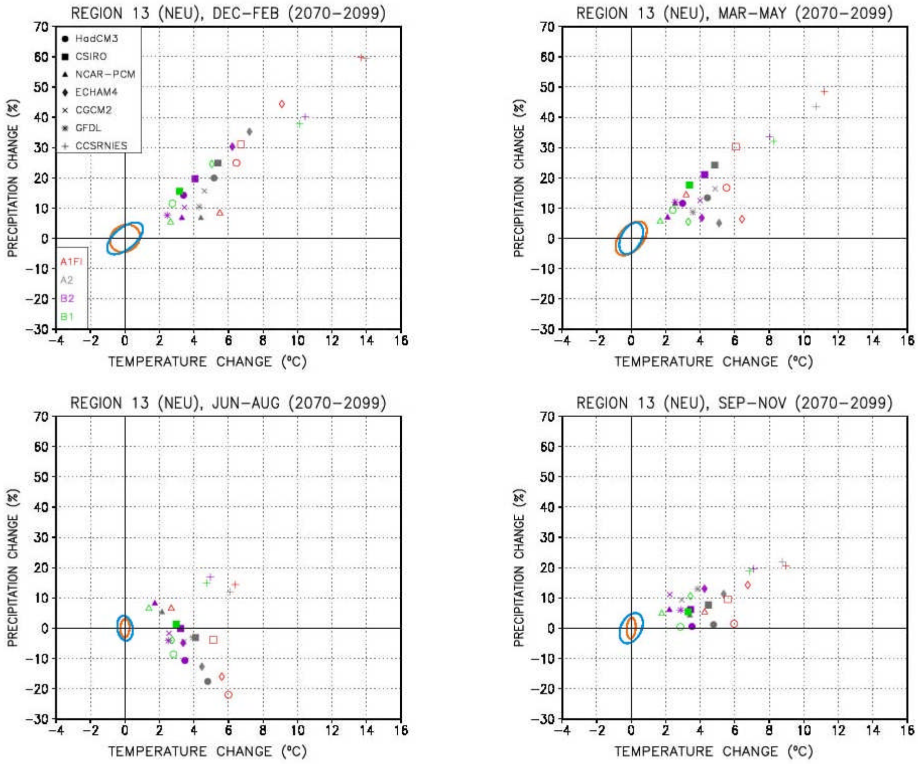

Figure 1.11 Each scatter point represents a single model-simulated temperature/ precipitation response to one forcing scenario. The scenario is depicted by the colour of the point (A1FI - red, A2 - grey, B1 - green and B2 - violet). The shape of the symbol defines the model: CCSRNIES (crosses), CSIRO Mk2 (squares), CGCM2 (X), ECHAM4/OPYC3 (diamonds), GFDL-R30 (snowflakes), HadCM3 (circles) and NCAR DOE PCM (triangles). Solid symbols correspond to responses directly inferred from AOGCM runs; open symbols are those calculated by the pattern-scaling method

(Source: http://ipcc-ddc.cru.uea.ac.uk/sres/scatter_plots/scatterplots_region.html).

6 Conclusions

Regional climate models projections suggest that climate change on the Isle of Man is likely to follow projected regional scale trends for Europe over the course of the present century. Warming in all seasons and for all periods is anticipated, coupled with an increasing tendency towards wetter winters and drier summers than is presently experienced. Changes in wind speeds are projected to decrease marginally in all seasons, except winter, these projections have a high degree of uncertainty associated with them. While changes in the climatological mean of a particular climate variable may be small, changes in extremes are likely to be greater in the future, such as an increase in the frequency of extreme hot days, extreme wind speeds or more intense precipitation events. Resultant changes in secondary meteorological variables, such as, potential evapotranspiration, frost frequency and growing season length and sea level rise, with consequent changes in surge return periods, is likely to impact the Isle of Man both positively and negatively.

While some sectors may be 'isolated' from changes in climate, global scale climate events may play a more significant role than those occurring at the local scale. However, each sector needs to assess the potential impact of climate change, both globally and locally, in order to minimise the potential negative impacts and be better positioned to capitalise on the potential positive impacts. There is a requirement that policy needs to be 'climate proofed' in order to achieve this end.

6.1 Future research needs and recommendations

In order to more fully investigate the trends in the observed meteorological data, an analysis of daily data, as oppose to monthly or annual values, should be undertaken. Daily data would also facilitate an examination of extremes, which was not possible in the current research. In addition, an analysis of precipitation receipts in conjunction with circulation types may also be beneficial in explaining the lack of correlation between the North Atlantic Oscillation and precipitation. Analysis of changes in precipitation intensity would also be possible with higher temporal resolution data.

In order to address issues of uncertainty with regards to future projections of climate on the Isle of Man, output from a range of GCMs should be employed, either by RCMs or statistical downscaling.

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