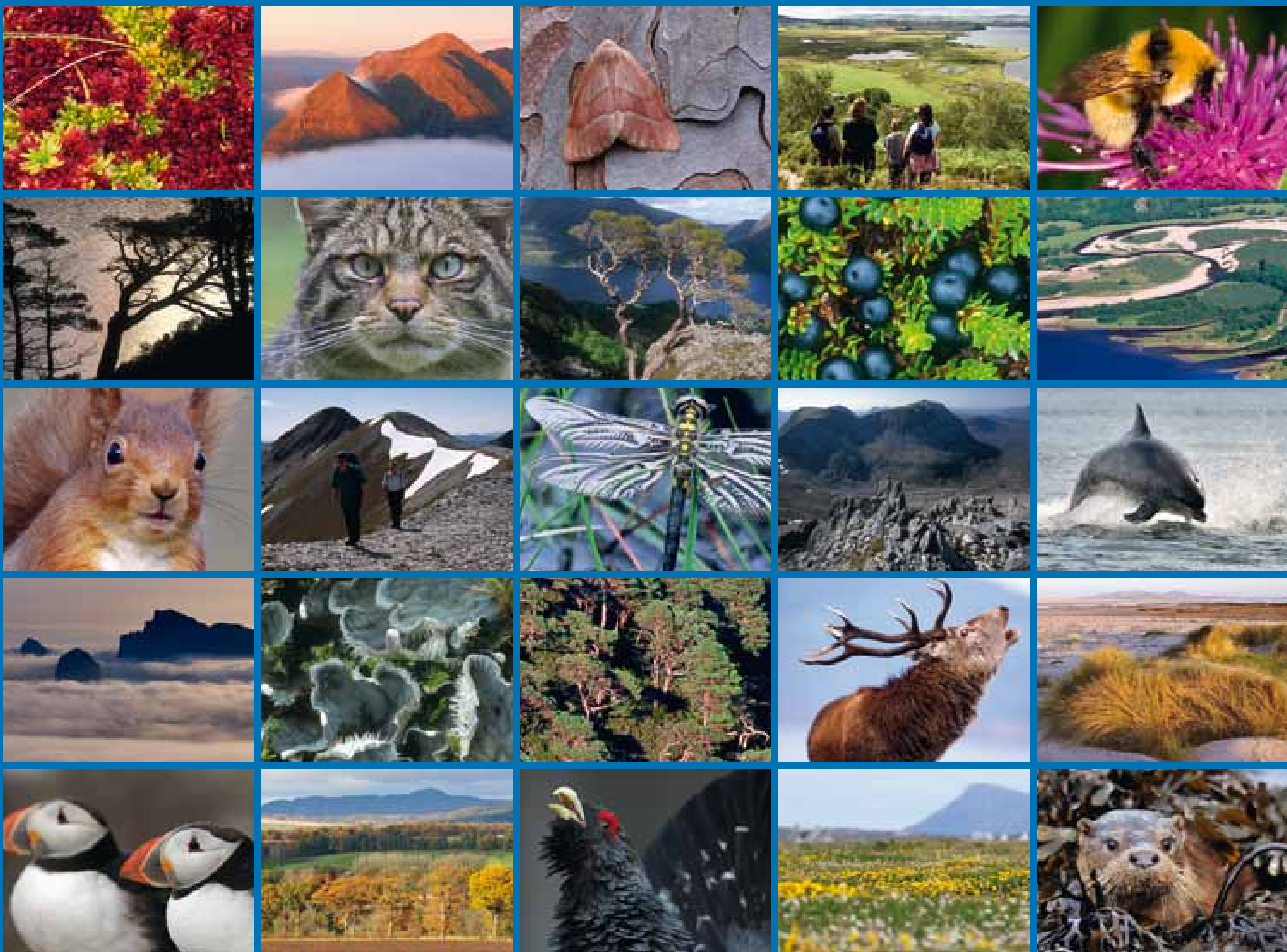
Scottish Natural Heritage
Commissioned Report No. 488

An assesment of the impacts of climate change on Scottish landscapes and their contribution to quality of life: Final report



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COMMISSIONED REPORT

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An assessment of the impacts of climate change on Scottish landscapes and their contribution to quality of life: Final report

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Preface

Note on the status of this report

This report supersedes the Phase 1 Interim Report. It updates the findings of the Interim Report to take account of the UKCP09 climate change projections. The symbol 09 has been used to indicate where the Interim Report findings have been modified to reflect the UKCP09 projections. Sections 2 and 3, and Appendix 11 of this report provide a detailed analysis of the implications of the UKCP09 projections for the study findings. These find that under UKCP09 and for Scotland, one variable – winter precipitation – is likely to be significantly different in terms of scale and spatial distribution, when compared to the relevant UKCIP02 projections.

Acknowledgements

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COMMISSIONED REPORT

Summary

An assessment of the impacts of climate change on Scottish landscapes and their contribution to quality of life: Final report

Commissioned Report No. 488
Contractor: Land Use Consultants
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BACKGROUND

Climate change will have implications for Scottish landscapes and the social, economic and environmental benefits they provide. Bringing together current research on the effects of climate change across a range of sectors, including forestry, agriculture, ecology and the built environment, this study explores how these changes could interact and alter Scottish landscapes and townscapes, and their benefits to people. This study represents Phase 1 of a two stage research process. The second stage will explore ways of communicating the key messages, thereby influencing climate change policy and practice so that it takes account of landscape and quality of life concerns.

MAIN FINDINGS

- There is uncertainty associated with climate change information, and the potential landscape impacts, and therefore the research has focused on potential scenarios and overall directions of change rather than predictions.
- Landscape change will result from the direct impacts of a changing climate as well as from indirect impacts of human attempts to slow climate change (mitigation) and the way that we respond to a changing climate (adaptation). Overall, mitigation and adaptation measures are likely to have a more significant influence on landscape character than the direct effects of climate change, i.e. analysis of UKCP09 probabilistic projections suggests that changes associated with temperature are, all other things being equal, more likely to occur thanthose associated with rainfall.
- The combined influence of these direct, mitigation and adaptation effects are likely to be greatest in lowland and coastal landscapes reflecting the dominance of land management, settlement and land use in shaping landscape character, and the likely impacts of changing sea levels. In the uplands landform is a more dominant factor. Here, with the exception of developments such as windfarms and related infrastructure, change may be gradual and subtle.
- Using the framework of ecosystem services at a local level, the study revealed a mixed pattern of effects on quality of life, broadly reflecting the pattern of landscape change, although cultural heritage values were affected across the local study area.

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Adaptation	The Intergovernmental Panel on Climate Change (IPCC) defines climate change adaptation as "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*"[1]. Adaptation can be planned or unplanned.
Confidence	The degree of certainty that a given climate or landscape change may occur.
Designated sites	Sites protected by local or national designation as defined by local or national policy.
Historic Designed Landscape	Grounds in which, either singly or in combination, flowers, fruits, vegetables, trees and shrubs are consciously laid out for artistic effect, to create a beautiful prospect, or for public resort.
Direct impact	The direct results of changes in climate, e.g. tree death as a result of drought stress, migration of species in relation to a warmer climate, erosion resulting from sea-level rise.
Ecosystem services	The benefits that people obtain from ecosystems. These include provisioning, regulating and cultural services that directly affect people and the supporting services provided by the environment to maintain other services.
Green and blue infrastructure	Includes open spaces for outdoor recreation and aspects of the marine and water environment.
Historic Land Use Assessment (HLA)	HLA is a GIS-based mapping project that shows the historic origin of land-use patterns, describing them by period, form and function. The HLA has identified some 55 individual historic land-use types, which can be grouped under 14 thematic headings (or categories) to simplify the data. It also depicts relict land-use, including relict archaeological landscapes greater than 1 hectare in area.[2]
Isostatic rebound	The rebound of the earth's surface following the release of a heavy load such as the melting of the glaciers following the last ice age.
Landscape character	The pattern that arises from the way that different components of the environment including natural (the influences of geology, soils, climate, flora and fauna) and cultural (the historical and current impact of land

[1] IPCC Fourth Assessment Report, see http://www.ipcc.ch/ipccreports/ar4-syr.htm
[2] www.historic-scotland.gov.uk

	use, settlement, enclosure and other human interventions) aspects and how they interact together and are perceived.[3]
Landscape character area	Unique areas that are the discrete geographical areas of a particular landscape type (see landscape character type definition below).
Landscape character assessment	The characterisation of landscapes involving identifying, mapping, classifying and describing landscape character, and the process of making judgements based on landscape character to inform a range of different decisions.[4]
Landscape character type	These are distinct types of landscape that are relatively homogeneous in character. They are generic in nature in that they may occur in different areas in different parts of the country, but wherever they occur they share broadly similar combinations of geology, topography, drainage patterns, vegetation and historical land use and settlement pattern.
Miscanthus	A perennial grass originating from south east Asia and grown as a biomass crop in the UK, reaching typical heights of 4m.
Mitigation	An human intervention to reduce the sources or enhance the sinks of greenhouse gases.[4]
Muirburn	The controlled burning of moorland is a traditional management tool used to help regenerate heather, and in turn benefit livestock and wildlife.
Natural Heritage Futures	The SNH Natural Heritage Futures initiative promotes integrated management of the natural heritage and is based on three main outputs. National documents consider the natural heritage across 6 themes. Local documents consider the natural heritage in 21 areas each of which has its own distinctive identity resulting from the interaction of geology, landforms, landscapes, wildlife and land use. These are underpinned by the supporting reference documents - National Assessments - which provide data and information about the natural heritage, presented both at the national level and within each of the 21 areas.
Natural Heritage Zones	21 areas covering Scotland defined by SNH as part of the Natural Heritage Futures programme which represent areas with similar natural heritage characteristics which contribute a distinctive identity resulting from the interaction of geology, landforms,

[3] The Countryside Agency Scottish Natural Heritage (2002) Landscape Character Assessment: Guidance for England and Scotland
[4] IPCC (2001) Climate Change 2001: Synthesis Report Annexes

	landscapes, wildlife and land use.
Peri-urban	Areas of land in close proximity to urban areas.
Pluvial flooding	Flooding resulting directly from overland flow of rainfall before the water enters drainage systems.
Quality of life	There is no one definition, but it is taken here to mean the degree of satisfaction of the physical needs of the residents of an area (e.g. food and health), together with enriching cultural, environmental and intellectual stimuli.
Regional character area	Areas recognisable as distinct landscape regions at a broad scale, based upon general characteristics such as landform, geology, soils, land use, ecological associations, historical associations and urban and industrial activity.
Socio-economic scenarios	UKCIP has recognised the importance of uncertainties about the adaptation and mitigation responses of humans, particularly over the medium to longer terms, and has developed four alternative socio-economic scenarios to illustrate the different directions in which society might develop.
Short rotation coppice	An energy crop which usually consists of densely planted, high-yielding varieties of poplar or willow, harvested on a 3-5 year rotation.
Surge risk	Coastal flood risk during a storm surge event which occurs when low pressure and high winds raise the water level above mean levels.
Sustainable Urban Drainage Systems (SUDS)	Sustainable Urban Drainage Systems are a sequence of water management practices and facilities designed to drain surface water in a manner that will provide a more sustainable approach than the practice of routing run-off through a pipe to a watercourse, controlling water retention in the system and reducing flood risk.
UKCIP02	The United Kingdom Climate Impacts Programme 2002 (UKCIP02) climate change scenarios provide four alternative descriptions of how the climate of the UK might evolve over the course of this century. The alternatives result from uncertainty about future trends and behaviour and how these might influence future global emissions of greenhouse gases. To address this emissions uncertainty, the UKCIP02 scenarios describe future climate change under four alternative futures, ranging from rapid economic growth with intensive use of fossil fuels (High Emissions) to increased economic, social and environmental sustainability with cleaner energy technologies (Low Emissions). Each of the four UKCIP02 scenarios, changes are described for three

	future thirty-year time-slices: 2011 to 2040 (the 2020s), 2041 to 2070 (the 2050s) and 2071 to 2100 (the 2080s). All changes in climate are given relative to the baseline period of 1961 to 1990. The information is displayed on a grid of 50km squares which cover the whole of the UK.
UKCP09	More up to date and detailed projections than UKCIP02. See http://ukcp09.defra.gov.uk/.
Urban heat island effect	The increased temperature of urban air compared to its rural surroundings, caused by the storage of solar energy in the urban fabric during the day and release of this energy into the atmosphere at night.
Wave fetch	The distance over which wind blows from a constant direction, which has a direct influence on wave height.
Wild land	Uninhabited and often relatively inaccessible countryside where the influence of human activity on the character and quality of the environment is, or appears to be, minimal.

ABBREVIATIONS

Abbreviation	Explanation
CLIO	Climate Impacts and Options
CMP	Catchment Management Plan
CP	Coastal Processes and Climate Change Predictions in the Coastal Study Areas
CRU Scoping	Climate change: Scottish Implications Scoping Study (1999)
FCS	Forestry Commission Scotland
FF	Farming Futures (topic pages)
IFS	Indicative Forestry Strategies
LCA	Landscape Character Assessment
LFA	Less Favoured Areas
NIWT	National Inventory of Woodlands and Trees
OS	Ordnance Survey
RBMP	River Basin Management Plans
RSPB	Royal Society for the Protection of Birds
SCAPE	Scottish Coastal Archaeology and the Problem of Erosion
SCCIP	Scottish Climate Change Impacts Partnership
SEERAD	Scottish Executive Environment and Rural Affairs Department
SEPA	Scottish Environment Protection Agency
SNH CC AP	SNH Climate Change Action Plan
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SRC	Short Rotation Coppice
SRDP	Scottish Rural Development Programme
SRNLS	Scottish Road Network Landslides Study
SUDS	Sustainable Urban Drainage Systems
TCPA	Town and Country Planning Association
TS	Transport Scotland
UDG	Urban Design Group

1. INTRODUCTION

1.1. Land Use Consultants, in association with CAG Consultants, Sheffield University and the Environmental Change Institute at Oxford, have been commissioned by Scottish Natural Heritage to carry out the first stage of a study into the landscape implications of climate change in Scotland.

1.2. The aim of the study is as follows:

> *To develop a more detailed understanding of the predicted impacts of climate change on Scottish landscapes and their contribution to quality of life, taking account of natural processes, mitigation and adaptation responses.*

1.3. The first phase of the study (the subject of this research) develops and applies a methodology to determine the nature, scale, distribution, significance and likelihood of landscape change and what these mean for quality of life. Detailed consideration of implications for quality of life lay beyond the scope of this study so the project focused on developing a commentary based on the analysis of cultural ecosystem services (see paragraph 2.28) provided by the landscape in a series of four local case studies (see Section 5).

1.4. The second phase of the study will focus on raising awareness and engaging with stakeholders and communities to develop objectives and practical approaches to managing climate change impacts on the landscape and to influence decision making and practice in development planning and land-use management.

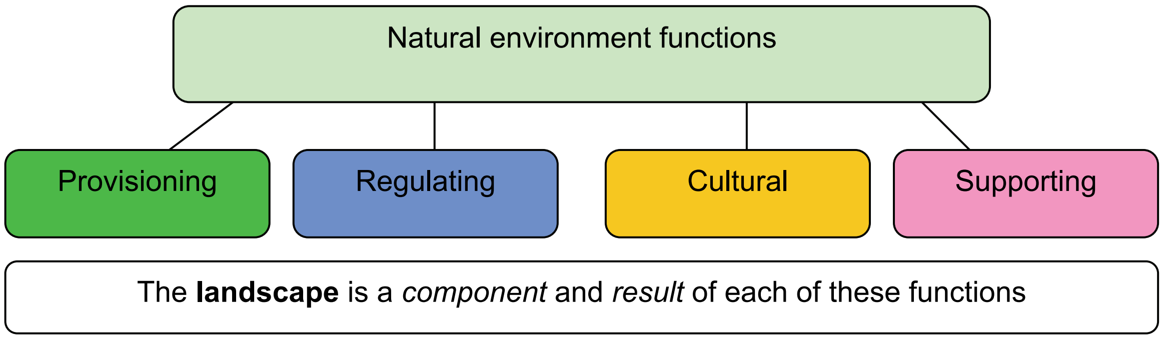
Purpose of the study

1.5. This study represents a starting point for the more detailed understanding and recognition of the landscape impacts of climate change and the role and value of landscapes within our everyday lives.

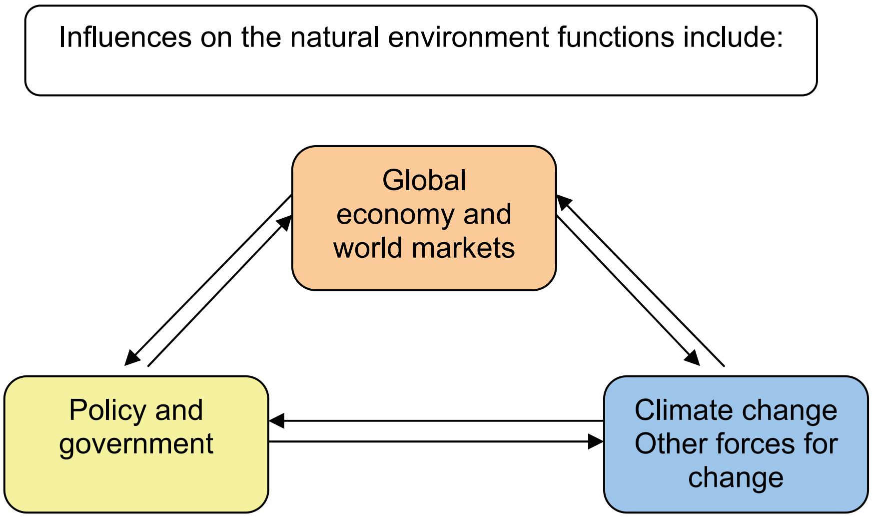
1.6. The following sections of the introduction provide a framework for the study, explaining the study scope and limitations.

Overview of study context

1.7. The following diagrams illustrate the framework for the study and the acknowledgement of the role of landscape within the wider environment. The natural environmental performs a range of functions, which can be defined under their role as ecosystem services (for further detail, see paragraph 2.28 and Appendix 1).



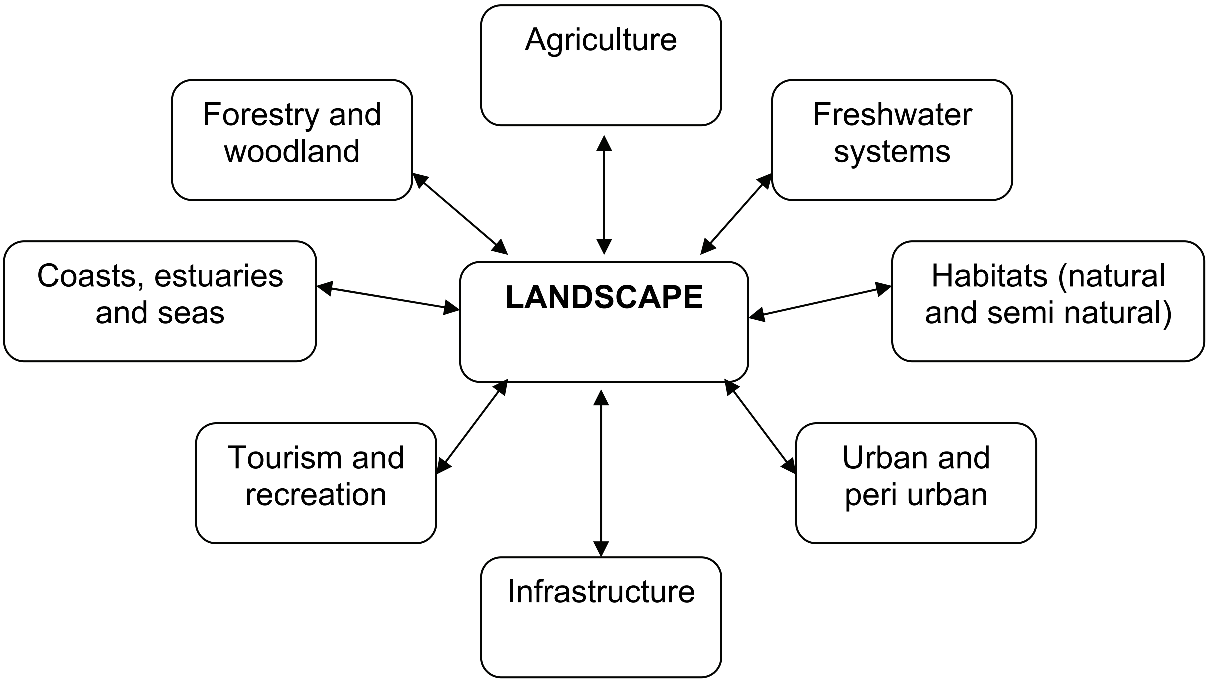
1.8. The role of the natural environment (and therefore the landscape) in fulfilling these functions is affected by a wide range of outside influences, of which climate change is one:



1.9. These influences interact with and affect each other and, as a result, the landscape we see. The study does not seek to address these wider influences, but acknowledges their role in shaping the future landscape. These are complex interactions and the study does not aim to define precisely or predict the landscape impacts resulting from climate change, but to explore a number of potential scenarios which may be influenced to varying degrees by global issues and policy and individual responses.

1.10. The impact of climate on the evolution of the landscape since the last ice age is inexorably linked to a range of processes from sea level rise, erosion, sediment transport and nutrient availability. This, alongside key variables such as temperature and precipitation, influences the natural vegetation growth, the nature of the habitats and species which they support and the patterns of settlement and land management. However, while past climate change and the subsequent landscape impacts of this have resulted from natural processes, the current climate changes are occurring as a result of human activities and progressing at a rapid rate. With knowledge of the likely future climate changes, we occupy a unique position which provides an opportunity to respond to these changes and manage their landscape impacts.

1.11. The following diagram illustrates the key topic areas within which landscape change has been explored through the study.



1.12. The study includes consideration of the relationship between the landscape and quality of life. This is explored through the concept of ecosystem services, i.e. what services does the landscape provide which contribute to quality of life, for four local case studies. The ecosystem services of relevance to this study have been identified as the following:

- inspiration and enrichment;
- health and wellbeing - physical and mental (links to regulating services, and includes human comfort such as urban temperatures);
- aesthetic values;
- sense of place;
- cultural heritage values;
- recreation and tourism.

1.13. The climate change impacts on the landscape and human responses to climate change are likely to alter the range of ecosystem services being delivered by the landscape.

Study scope and limitations

1.14. The Phase 1 Report does not seek to set objectives for landscape change, but to illustrate and raise awareness about the nature of such changes and the impacts that are most likely and most significant. From this it will be possible to identify the landscape changes which can be addressed, which will form a key focus of Phase 2 of the study.

1.15. Whilst aiming to provide a robust analysis of the likely landscape changes that will be associated with climate change, it is inevitable that the research has to deal with several layers of uncertainty.

1.16. The study is based largely on the interpretation and application of the UKCIP02 climate change scenarios. At the time of conducting the research, these were the most comprehensive and commonly used climate change scenarios for this type of project within the UK, and provided the most well informed projection of the changes that will affect the Scottish climate over the coming decades. It is possible that the magnitude, speed and distribution of these changes will differ from those currently being projected. Similarly, there are uncertainties about the way in which natural systems will respond to changes in rainfall, temperature, storminess and growing seasons. There is a further series of uncertainties associated with human responses to such change, in terms both of measures to mitigate and adapt to climate change (not least since an aim of the work is to inform policy in these areas). The indirect effects of climate change in Scotland may also be significantly influenced by the nature and severity of changes elsewhere in the UK, Europe and across the world. A final set of uncertainties relates to external factors such as the price of oil, or the overall direction of society's future development (e.g. as reflected in the UKCIP socio-economic scenarios). These uncertainties underpin the decision that the work should concentrate on the broad direction and magnitude of change, rather than aiming to reflect relatively subtle differences between different climate change scenarios and time frames.

1.17. As discussed previously, climate change is only one influencing factor on the landscape, and as a result the United Kingdom Climate Impacts Programme (UKCIP) socio-economic scenarios[5] (see Appendix 2) have been used to inform the interpretation of the study results, to explore the potential impact of different scenarios on the extent and degree of landscape change. There is also uncertainty within the climate change scenarios, which is discussed in more detail in Section 3.

UKCIP02 and UKCP09[6]

1.18. It was originally proposed that the study would make use of new climate change scenario data which had been due to be published in 2008. Delays meant that these data were published as the UKCP09 climate change projections, after the completion of this study. A review of the differences between the two sets of projections was carried out to determine the extent to which the research and its conclusions needed to be updated. The review, which is summarised in Chapter 2 and reported in detail in Appendix 11, concluded that, for most climate change variables, the differences between the two projections were relatively modest. Only one variable (winter precipitation) was identified as being significantly different in terms of scale and spatial distribution, requiring some parts of the analysis to be updated. Most of the research is therefore based on UKCIP02 data, with selective use of UKCP09 data. The validity of this approach was confirmed with the Scottish Climate Change Impacts Partnership (see Appendix 11 for more information).

1.19. The UKCIP02 climate change scenarios provide four alternative descriptions of how the climate of the UK might evolve over the course of this century. The alternatives result from uncertainty about future human trends and behaviour and how these might influence future global emissions of greenhouse gases. To address this emissions uncertainty, the UKCIP02 scenarios describe future climate change under four alternative futures, ranging from rapid economic growth with intensive use of

[5] See glossary
[6] Information obtained from www.ukcip.org.uk

fossil fuels (High Emissions) to increased economic, social and environmental sustainability with cleaner energy technologies (Low Emissions). For each of the four UKCIP02 scenarios, changes are described for three future thirty-year time-slices: 2011 to 2040 (the 2020s), 2041 to 2070 (the 2050s) and 2071 to 2100 (the 2080s). All changes in climate are given relative to the baseline period of 1961 to 1990. The information is displayed on a grid of 50km squares which cover the whole of the UK. The changes described for the next 30 or 40 years are broadly similar for all four scenarios, as they are largely influenced by past and current emissions of greenhouse gases. Over the second half of this century, the four scenarios are influenced to a greater extent by the amount of greenhouse gases we emit now and over future years and decades. The future climates that the scenarios describe therefore become increasingly different.

1.20. Not all of the changes described by UKCIP02 are given with the same confidence. Based on both expert judgment and comparison with other global climate models, some changes in future UK climate have been assigned a higher confidence than others.

1.21. UKCP09 scenarios provide more up to date and detailed projections than UKCIP02, employing recent advances in climate science to better quantify some of the uncertainties associated with climate modelling and information on projected future climate change for the UK up to 2099. The UKCP09 scenarios are presented as probabilistic projections including:

- The 10% probability projections indicate that the likelihood that the change in question will be less than that shown is 10%. UKCP uses the term 'very unlikely to be less than' (and therefore very likely to be more than) to describe such changes indicating a higher level of confidence of the effect occurring.

- The 90% probability projections indicate that the likelihood that the change in question will be less than that shown is 90% - it is very unlikely to be greater than that shown and therefore very likely to be less.

- The 50% probability projections indicate that the projected change is just as likely to be greater as it is to be less than the value shown. This is the central estimate and, importantly, does not indicate the projection that is most likely to occur.

1.22. Analysis of the more extreme probabilistic projections (e.g. 90% and 10%) allows the variation in potential changes to be explored, helping to inform the way in which the projections should be applied. For example, if there is relatively little difference between the scales of change which have a 90%, 50% and 10% probability of being exceeded, any conclusions based on the projections are likely to be reasonably reliable, providing a firm foundation for policy or other responses. On the other hand, if there is a significant difference between either the 90% or 10% projections and the 50% projection, the conclusions will be more tentative and, importantly, a judgment will need to be made about the level of risk that any subsequent response should adopt. Appendix 11 includes detailed comparison of probabilistic projections for temperature and precipitation for the three UKCP regions of Scotland (Eastern, Northern and Western Scotland). The analysis concluded that climate related landscape changes associated with temperature are, all other things being equal, more likely to occur than those associated with changes in rainfall.

Data scale and mapping

1.23. The issue of data scale adds a further level of uncertainty to the study. Different data sources are mapped at varying scales, and the UKCIP02 climate change scenarios are mapped at a 50km grid scale. This presents key issues for the mapping process, whereby the different levels of accuracy from different data sources are brought together. This issue is discussed further in paragraphs 4.7 to 4.10.

1.24. The mapping is based primarily on direct impacts of climate change, as there are greater difficulties in mapping mitigation and adaptation impacts due to the lack of data on the locations where these may occur.

Structure of the report

1.25. The remainder of the report is structured as follows:

- Section 2: Methodology.
- Section 3: Future climate change in Scotland.
- Section 4: Scotland-wide pattern of climate related change.
- Section 5: Tayside detailed study area.
- Section 6: Conclusions.

How to use this report

1.26. The research is intended to provide an overview of climate related landscape change, illustrated by national, regional and local case study analysis. In particular, the national analysis, reported in Section 4, is based on GIS analysis of climate change variables and the location of relevant landscape features. The resulting maps are indicative, suggesting where, all other things being equal, change is more or less likely to occur as a result of climate change. The maps are not intended for use at the local level, particularly because they use climate data which are provided at a much coarser scale (50km squares in the case of UKCIP02 and 25km squares in the case of UKCP09).

2. METHODOLOGY

INTRODUCTION

2.1. This section of the report sets out the project methodology and explores the application of the socio-economic scenarios and ecosystem services approach to the study. The diagram below provides an overview of the main study stages:

Phase 1

- literature review
  - benchmarking
  - identify impacts
- methodology
- national analysis
  - climate changes
  - Landscape features
- local analysis
  - Tayside
  - 4 localities
- reporting
  - descriptions
  - maps
  - photomontages
- UKCP09 review
  - Comparison of UKCIP02 and UKCP09 projections
  - Re-analysis where UKCP09 could alter the study findings
  - Review and updating of research findings
  - Review of UKCP09 data on uncertainty and risk

Recommendations for Phase 2

- Raising awareness
  Engaging with stakeholders
- Managing climate related landscape change

LITERATURE REVIEW

Benchmarking approaches to climate change and the landscape

2.2. The first study task was to review current practice in the analysis of climate change impacts on the landscape to ensure that the study is informed by current thinking. The study reviewed the way that climate related landscape change has been considered in:

- England and Wales, including the outcomes of the Research Council funded programme on building knowledge on climate change, including the Adaptation Strategies for Climate Change in the Urban Environment (ASCCUE) project conducted by Professor John Handley and Centre for Urban Regional Ecology (CURE) at the University of Manchester; and work at the University of East Anglia by Andrew Lovett and others in the School of Environmental Science. It also drew on experience from the Wittenham Clumps Heritage Landscape Project: Future Landscape Scenarios work conducted by the University of Oxford Environmental Change Institute;
- The rest of Europe, including the work on the effects of climate change on mountain landscapes used for skiing, carried out for the Alps, which formed part of the Visulands project. The Visulands project was carried out at the Swiss Federal Institute of Technology, ETH Zurich, and developed visualisation tools to support public involvement in the assessment of landscape change. Further detail is provided in Appendix 4.

2.3. The literature review also examined non-landscape work relating to climate change in Scotland in order to consider the kinds of changes that are being anticipated, and approaches to uncertainty.

2.4. This part of the literature review is presented in Appendix 4.

Identification of impacts

2.5. The literature review was used to identify potential types of climate related landscape changes. This included direct effects together with mitigation and planned and unplanned adaptation responses. The potential changes were recorded in a matrix and grouped by topic. Inevitably there is some overlap between topic areas (e.g. between forests and woodlands, habitats and agriculture), though each change has been recorded only once to avoid double counting. The matrix recorded the following information:

- topic area;
- type of change (direct, planned adaptation, unplanned adaptation, mitigation)[7];
- the landscape effect of the climate change;
- the climate variable(s) causing the landscape change (e.g. winter rainfall changes or increase in summer temperatures);
- the level of certainty attached to the climate change scenario information;
- a broad assessment of the likely timescale over which the change in question might be expected to occur;
- the broad geographic extent of the change.

[7] See glossary

2.6. Each change was also assigned a reference number. The changes recorded in an initial long matrix were prioritised in discussion with the project Steering Group to identify those that would be analysed in greater detail. The longer and shorter matrices are included in Appendix 5. The prioritisation of changes was based on the information recorded in the bullet points above and was intended to identify those which were most likely to have significant implications for the landscape and, consequently, for quality of life.

DEVELOPMENT OF STUDY METHODOLOGY

2.7. The literature review informed the development of the methodology which addressed the following questions:

- What are the climate changes likely to affect Scotland taking account of:
  - timescale;
  - geographic distribution;
  - scale and magnitude;
  - certainty /likelihood.

2.8. This included overall and seasonal changes in rainfall, temperature, winds and storminess and sea level changes.

- What kinds of landscape change could result from these climate changes?
  - Direct changes. Examples include flooding (fluvial, pluvial and tidal), changing patterns of vegetation and species distribution, coastal erosion and deposition, snow-lie, land instability and visibility;
  - Indirect 'adaptation' changes. Examples include planned measures to help species respond to climate change (e.g. habitat networks), measures to address direct changes such as flooding and less 'planned' changes such as changing patterns of agricultural production. These changes will themselves be influenced by policy factors (e.g. whether to work with natural flood processes or alternatively to implement 'hard' flood defences) and external factors (e.g. wider changes affecting the market for agricultural and forest products). This is likely to be particularly true in urban areas, reflecting, for example, the way that greenspaces and urban trees are planned for and managed;
  - Indirect 'mitigation' measures designed to reduce carbon emissions or increase carbon sequestration. Examples include on shore and offshore wind energy developments of various scales, hydro schemes, biomass production, active and passive solar, carbon capture and storage, nuclear power plants and energy related infrastructure including transmission lines and substations. Measures designed to reduce the need to travel, particularly by road and air could also have landscape implications at local and broader scales.

2.9. In identifying these changes, consideration was given as to the extent and means by which they could be influenced through development planning or land management planning. This explored:

- Where these changes will occur, and where they will be most pronounced, bringing together analysis of the coincidence between climate changes (direct and indirect) and the landscapes or landscape elements which would be affected.

- What this means in terms of landscape character and ecosystem services provided by the landscape. This considers the extent to which the character of the landscape would be affected by the change in question and how this could, in turn, affect (negatively or positively) its ability to deliver ecosystem benefits. This analysis considers the nature, scale, distribution, likelihood and significance of the landscape changes (distinguishing in particular between the last two aspects).

2.10. It is at this stage that the analysis brought together information on different climate related landscape changes to identify those landscapes which could experience the greatest change, either as a consequence of the nature or magnitude of a given change, or due to the combined impact of multiple changes. This information is explored at a national level and also at strategic and local levels, focusing on Tayside as a case study.

2.11. Finally, the research considered the extent to which negative effects could be reduced or positive changes enhanced through different policy frameworks at national, strategic or local levels. This could consider development planning, land management planning (e.g. through the Scottish Rural Development Programme) and mechanisms such as catchment management planning.

APPLICATION OF STUDY METHODOLOGY

National analysis

2.12. The application of the methodology at a national level is based on the prioritised list of landscape related climate changes (Table 5.5 Appendix 5). The landscape features identified as subject to change in this matrix were selected in terms of the relevant available data sources which could be used to graphically illustrate the distribution of these features.

2.13. The national level analysis explores the combined effects of different types of climate related landscape change. It also specifically explores coastal issues and the potential impacts on designated landscapes and on SNH wildland search areas.

National level mapping

2.14. National level mapping was carried out for a number of individual changes identified from the prioritised list of landscape changes in Appendix 5, Table 5.5. This process combined spatial datasets representing the distribution of the landscape 'feature' in question (for example, woodland, or areas over a particular altitude) and relevant components of the UKCIP02 climate change scenarios showing where climate changes could be more pronounced. This provides an indication of where the landscape 'feature' in question could be most affected by climate change. This is a relatively simplistic analysis, particularly given the coarse spatial resolution of the UKCIP02 data, but does represent a first attempt to map the likely scale and distribution of a selection of climate related landscape changes. Further detail on the national mapping is provided in Appendix 10.

2.15. A review of the UKCP09 climate change projections (which were published after the first phase of this research was completed) was used to identify areas where the new projections differed significantly from those published under UKCIP02. As a result some of the national level mapping was re-run with updated climate change data. This is described in more detail later in this Chapter, and in Appendix 11.

Workshop discussion

2.16. As part of the study process a half day workshop for SNH and staff from across a wide range of disciplines was convened on 7th January 2009 to provide a forum for discussion on the study and its findings. This workshop involved presentation of the study findings to date and opportunity for discussion of the landscape impacts identified. The findings from the workshop informed the list of landscape impacts identified and included in the national and local level analysis. The key issues identified from the Workshop, together with a list of attendees, are set out in Appendix 3.

2.17. In addition to participation through the workshop, the project Steering Group and SNH staff provided valuable inputs to the study throughout the project process assisting in the identification of literature and data sources. The project Steering Group included representatives from Forestry Commission Scotland (FCS), Natural England (NE), Scottish Environment Protection Agency (SEPA), Historic Scotland (HS), Department of Environment Northern Ireland (DoENI), Perth and Kinross Council and from the People and Places Unit in SNH. The project team would like to acknowledge the assistance of the Steering Group throughout the course of the research.

Local analysis

2.18. This allowed more detailed analysis of landscape character and ecosystem services at a local level. This provided an opportunity to explore the combined effects of different types of climate related landscape change on the key characteristics of specific landscapes, and consideration of the likely implications for the provision of ecosystem services.

Methodology for selection of local study area

2.19. Criteria for selecting a study area included:

- the presence of a good cross section of landscape character types. While it was recognised that no single area could represent the full range of landscape character types found across Scotland, it was considered important that the study area should include upland, lowland, urban and coastal areas as far as possible;
- the likely incidence of a number of significant climate related landscape changes already explored at a national level. In part this reflected the types of areas identified in the previous bullet point, but also the presence of particular issues such as flooding or agricultural change;
- in addition, the study area was required to include an area designated for its special landscape qualities, such as a National Scenic Area or National Park.

2.20. On this basis, the Tay catchment provides the best fit. Key features include:

- Four National Scenic Areas and parts of the two National Parks;
- Tay Forest Park;
- Arable and horticultural farmland of Strathmore;

- Pasture and moorland;
- The River Tay, with a history of flooding;
- Firth of Tay;
- The sandy estuary and coast at Tentsmuir and Buddon Ness;
- Urban areas of Perth and Dundee
- Upland areas of mountain and moorland
- Importance of tourism around Loch Tummel, Pitlochry and Dunkeld.

Mapping

2.21. The catchment level mapping draws on the findings of the national level mapping exercise. This provides an overview of the key areas of change within the study area and informs the more detailed analysis described below.

Analysis

2.22. The first stage in the local analysis is the review of the 'shortlist' matrix (table 5.5, Appendix 5) and identification of the landscape elements which would be subject to the landscape changes identified in each of the three regional character types (Tayside Lowlands, West Highlands and Mounth Highlands) within Tayside. The main changes in the landscape character are summarised under the topic headings as used in the matrix.

2.23. The second stage is to take this information down to the landscape character unit level, drawing on the identified key landscape features subject to change, and to produce a revised landscape character unit description for the landscape character areas used for the more detailed study, illustration through photomontages for three landscape areas and an annotated map for the Perth urban area.

2.24. The finer grain analysis allows exploration of landscape changes at a more detailed and comprehensible scale, within the context of wider change across the area as a whole. This allows the exploration of more significant changes supported by both text description and illustrations. These significant changes are based on those landscape changes which were identified as having a higher degree of confidence and a higher landscape significance attached to them. However, there are a number of uncertainties and risks associated with the changes identified. The potential influence of these is explored through the interpretation of the four socio-economic scenarios.

2.25. The following sets out the approach to the analysis of landscape changes for the individual landscape character areas:

- description of landscape character area based on Tayside Landscape Character Assessment (1999);
- description of landscape character area in 2050 incorporating potential landscape change scenarios;
- exploration of variations in landscape scenarios under the four socio-economic scenarios;

- exploration of the implications of the changes in relation to the provision of ecosystem services.

2.26. The data presented in the SNIFFER Handbook of Climate Trends Across Scotland[8], provides information on historic patterns of change for different climate variables on a 5km grid. This information is interpreted in relation to the UKCIP02 projected trends and identifies the spatial variation across Scotland. This information has been used to inform the landscape character area analysis of future landscape scenarios at the more detailed, local scale.

SOCIO-ECONOMIC SCENARIOS

2.27. The UKCIP socio-economic scenarios have been used to inform the local level analysis. This information is used to provide a framework to illustrate how landscape change may vary according to different broad policy directions. Within this study, these scenarios are used descriptively to assist in addressing the issue of uncertainty, associated with human responses to climate change and their influence of different socio-economic and political futures. A number of strong policy messages associated with these scenarios are explored in Section 5.

2.28. The following table provides a brief summary of the scenarios, drawing out the key differences. Further information on the socio-economic scenarios is set out in Appendix 2, and explored in Section 5.

Table 2.1 Summary of UKCIP socio-economic scenarios

Scenario	Description
World Markets	Very rapid economic growth; population peaks mid-century; social, cultural and economic convergence among regions; market mechanisms dominate.
National Enterprise	Self reliance; preservation of local identities; continuously increasing population; economic growth on regional scales.
Global Sustainability	Clean and efficient technologies; reduction in material use; global solutions to economic, social and environmental sustainability; improved equity; population peaks mid-century.
Local Stewardship	Local solutions to sustainability; continuously increasing population at a lower rate than in 'national enterprise'; less rapid technological change than in 'global sustainability' and 'world markets'.

ECOSYSTEM SERVICES

2.29. The study brief suggested that research into climate related landscape change should include consideration of the effects in terms of ecosystem services - the benefits that people obtain from ecosystems.

2.30. The main categories of ecosystem services include:

- provisioning services – products obtained from ecosystems;

[8] See reference list at the end of this report

- regulating services – the benefits obtained from the regulation of ecosystem processes;

- cultural services - the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences;

- supporting services - those that are necessary for the production of all other ecosystem services, such as water cycling. They differ from provisioning, regulating and cultural services in that their impacts on people are often indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. Some services, like erosion regulation, can be categorised as both a supporting and a regulating service, depending on the timescale and immediacy of their impact on people.

2.31. Many ecosystem services are highly interlinked. For example, primary production, photosynthesis, nutrient cycling and water cycling all involve different aspects of the same biological processes.

2.32. It was agreed that the study should be limited to examine the impacts on cultural services, and the following list identifies those cultural services agreed with the project steering group for inclusion within the study:

- Inspiration and enrichment. Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture and advertising. They also provide a more informal aspect of inspiration and enrichment through providing an attractive and stimulating environment;

- Health and wellbeing. Physical and mental (links to some of the regulating services), and includes human comfort resulting from urban temperatures and people's immediate environment, where they live, work and undertake recreation;

- Aesthetic values. Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks and scenic drives and in the selection of housing locations;

- Sense of place. Many people value the 'sense of place' that is associated with recognised features of their environment, including aspects of the ecosystem;

- Cultural heritage values. Many societies place high value on the maintenance of either historically important landscapes ('cultural landscapes') or culturally significant species;

- Recreation and tourism. This is dependant on healthy & attractive environments, landscape diversity, special landscapes and species. People often choose where to spend their leisure time based, in part, on the characteristics of the natural or cultural landscapes in a particular area.

2.33. A fuller description of the ecosystem services, based on work carried out by Defra, is set out in Appendix 1.

OUTPUTS

2.34. The final output of these two stages of the work included preparation of materials to communicate the results to a wider audience. This includes a plain English description of the changes that are judged most likely to occur or most significant in terms of their impact, maps showing their likely geographic distribution, a plain

English description of the landscapes that would be affected and the changes that they would experience, digitally manipulated photographs illustrating the changes (individually or in combination).

RECOMMENDATIONS FOR PHASE 2 OF THE RESEARCH

2.35. The final part of the work sets out recommendations for the second phase of the research. This focuses on raising awareness and engaging with stakeholders and communities to develop practical approaches to managing climate change impacts on the landscape and to influence decision making and practice in development planning. A key element of this is encouraging consideration of landscape change within wider climate change strategies and policies.

UKCP09 REVIEW

2.36. The UKCP09 climate change projections were published after the completion of the research described in previous sections. A review was therefore carried out to identify the key differences between the UKCIP02 and UKCP09 projections with the aim of identifying areas where differences between the two datasets could have implications for the research findings

2.37. The UKCP09 review comprised a series of discrete steps, as follows:

- Comparison of the UKCIP02[9] and UKCP09 projections[10], including comparative mapping for key climate change variables. This review was informed by discussions with a specialist adviser[11] from Scottish Climate Change Impacts Partnership (SCCIP);
- Identification of those elements of the Phase 1 analysis that require updating in the form of revised GIS mapping to reflect major differences between the UKCIP02 and UKCP09 projections;
- Re-running GIS mapping and analysis of the results for national, regional and local descriptions of climate related landscape change;
- Analysis of UKCP09 probabilistic projections to provide a commentary on the uncertainty associated with different climate change variables;
- Auditing of the Phase 1 Interim Report to identify those sections which require to be updated to reflect the differences between the UKCIP02 and UKCP09 projections, including the updated mapping;
- Consideration of how updated information should be presented within the updated (Final) Phase 1 Report.

2.38. The detailed results of the review are contained in Appendix 11, and reflected throughout this report.

UKCP09 climate change projections

2.39. UKCP09 projections differ from their predecessors in a number of respects, including:

- UKCIP02 projections were provided on a 50km grid whereas the UKCP09 projections use a 25km grid. The two grids are differently oriented and not directly comparable as a result;

[9] http://www.ukcip.org.uk/index.php?id=161&option=com_content&task=view
[10] http://ukclimateprojections.defra.gov.uk/
[11] See advice received from J. Hagg, SCCIP adviser in Appendix 11, Annex 2

- UKCIP02 scenarios were derived from a single UK climate model whilst the UKCP09 projections are based on an ensemble of different models. This limits the comparability of the two datasets;

- UKCIP02 used four emissions scenarios whereas the UKCP09 projections are based on 3 emissions scenarios. While the high and low emission scenarios are comparable, the medium scenarios are different (UKCIP02 included 'medium/low' and 'medium/high' emissions scenarios, whereas UKCP09 includes a single 'medium' emissions scenario). It is however worth noting that the differences between emissions scenarios are greatest after 2050, so qualified comparison of the UKCIP02 medium/high or medium/low emissions scenarios with the UKCP09 medium emissions scenario may be acceptable[12];

- UKCIP02 projections provided a single value for each emissions scenario / timeframe, whereas the UKCP09 projections provide a range of probabilistic values.

Differences between UKCIP02 and UKCP09 climate variables

2.40. The comparison of UKCIP02 and UKCP09 projections explored differences in the direction, scale and spatial pattern of climate change for a series of variables including winter precipitation, summer precipitation, winter temperatures, summer temperatures, autumn temperatures, annual temperatures and sea level rise.

2.41. For most of these variables, the analysis concluded that while the rate of change indicated by UKCP09 differed from that indicated by UKCIP02, the direction and broad spatial pattern of change remained the same (with one exception). Given that the mapping analysis carried out during the first phase of the research placed each variable onto a common scale (from least change to greatest change), it was concluded that, although the change should be reflected in the updated text where appropriate, there was no requirement to re-run the GIS mapping analysis since the overall patterns of change would be the same.

2.42. The one exception is the winter precipitation variable, where the UKCP09 projections suggest different rates, directions and spatial patterns of change than projected under UKCIP02. It was therefore concluded that a total of 13 national maps from the Phase 1 report should be re-run using the UKCP09 winter precipitation variable. It was confirmed that, where relevant, such analysis could combine information from the two sets of projections, though this should be noted in the accompanying text.

[12] See advice received from J. Hagg, SCCIP adviser in Appendix 11 (Annex 2)

3. FUTURE CLIMATE CHANGE IN SCOTLAND

INTRODUCTION

3.1. This section of the report provides a summary of the UKCIP02 climate change projections upon which the original research was based. It also includes the results of a comparison of these projections with the UKCP09 projections which were published after the research had been completed. This identifies those climate variables where there is significant difference between the two projections, requiring the analysis to be repeated using the more up to date information. This part of the report also summarises research by SNIFFER into past climate trends in Scotland providing a finer grain of information.

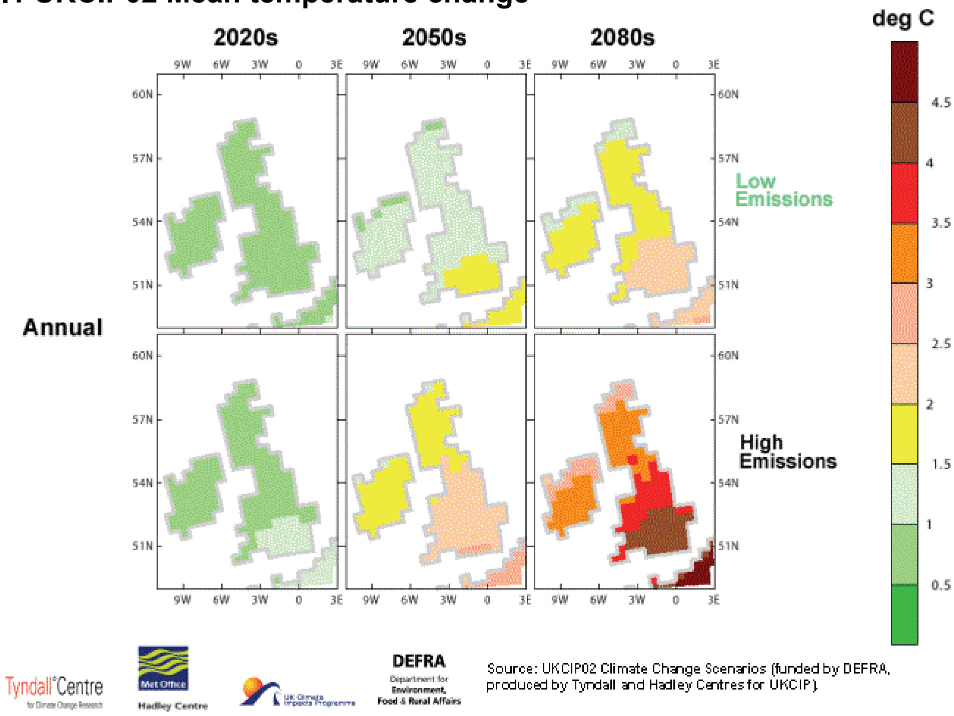
UKCIP02 CLIMATE CHANGE SCENARIOS FOR SCOTLAND

3.2. The UK Climate Impacts Programme (UKCIP) provides the most up to date information on future climate change in Britain at the time of undertaking this study. The UKCIP02 scenarios provide information relating to 2020, 2050 and 2080, covering high, medium and low emission scenarios. The implications for Scotland are described in SNIFFER – Business Risks of Climate Change to Public Sector Organisations in Scotland (2005) and summarised below. It should be emphasised that the scenarios provide descriptions of potential future conditions, but do not represent firm predictions or forecasts. The level of confidence for each of the changes is noted below. The maps illustrated are sourced from UKCIP02 Climate Change Scenarios (funded by Defra, produced by Tyndall and Hadley Centres for UKCIP).

3.3. **Average temperature –** As in the rest of the UK, by the end of this century Scotland will experience mean annual temperatures of between 0.5 and 1.0°Celsius warmer than present. In the 2050s the increase in average annual temperature for Scotland (1.0-1.5°C) will be less than that for most of England and Wales (1.5-2.0°C). However, these figures hide seasonal variations: in the 2050s most of Scotland will be warmer by 1.5-2.0°C in autumn and central and east Scotland will be warmer by 1.5-2.0°C in summer. The thermal growing season will lengthen. The number of very cold days will fall and the number of very hot days will rise. The confidence attached to these projected changes is high.

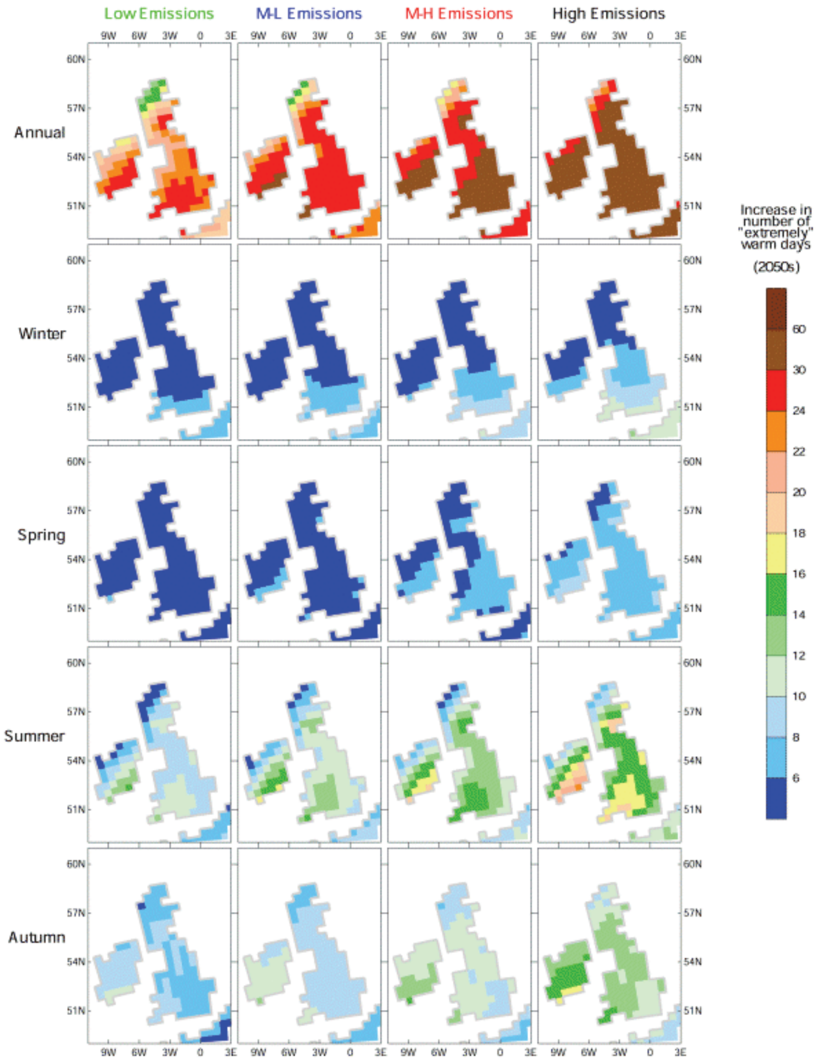
3.4. **Inter-annual temperature variability –** Inter-annual temperature variability is an indication of variability of climate from year to year. Winter and spring temperatures over the whole of the UK will become less variable, with north-west Scotland seeing a reduction in inter-annual variability of up to 20%. Summer and autumn temperatures will become more variable over the whole of Scotland, increasing by 20% or more in most of south and west by 2050. The average annual diurnal temperature range will also show an upward trend in Scotland over summer, though this will be more noticeable in south England. The confidence attached to these projected changes is high.

Figure 3.1 UKCIP02 Mean temperature change



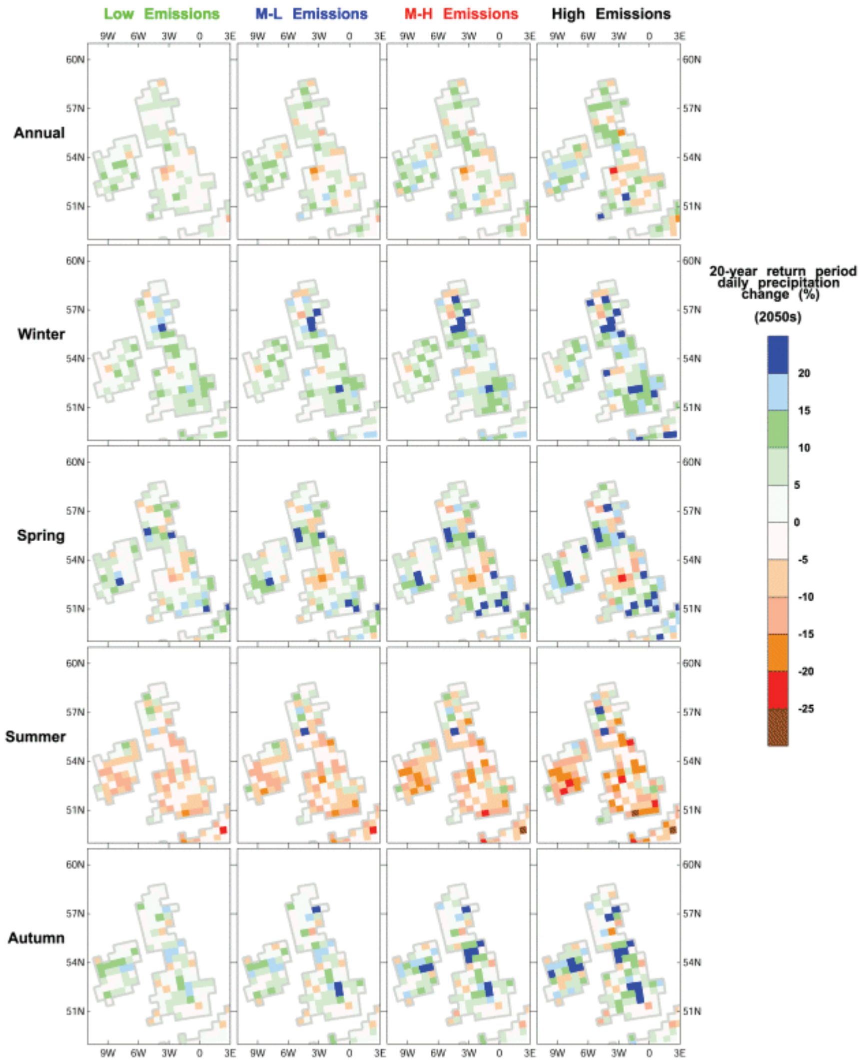
3.5. **Heat wave and rain storm frequency –** By 2080 rainfall events will, on average, be unaffected in north-west Scotland, 25-75% more intense in east Scotland, up to 100% more intense in west Scotland and more than 150% more intense in parts of south-west Scotland. Unlike changes in average temperature and rainfall, changes in rainfall intensity will increase the likelihood of flash flooding of Scottish rivers. Precipitation intensity will increase in winter. The confidence attached to these projected changes is high. The hottest (defined as those exceeding the 90th percentile) days will also get hotter in Scotland, by up to 4°C in the summer and autumn in the south. The situation will be more dramatic in England, with the hottest days getting hotter by up to 6°C. Changes will be less pronounced in winter, with the hottest days getting hotter by 1.5°C over most of Scotland. The confidence attached to these projected changes is high.

Figure 3.2 UKCIP02 Increase in number of 'extremely' warm days



Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP)

Figure 3.3 UKCIP02 20-year return period daily precipitation change (%)

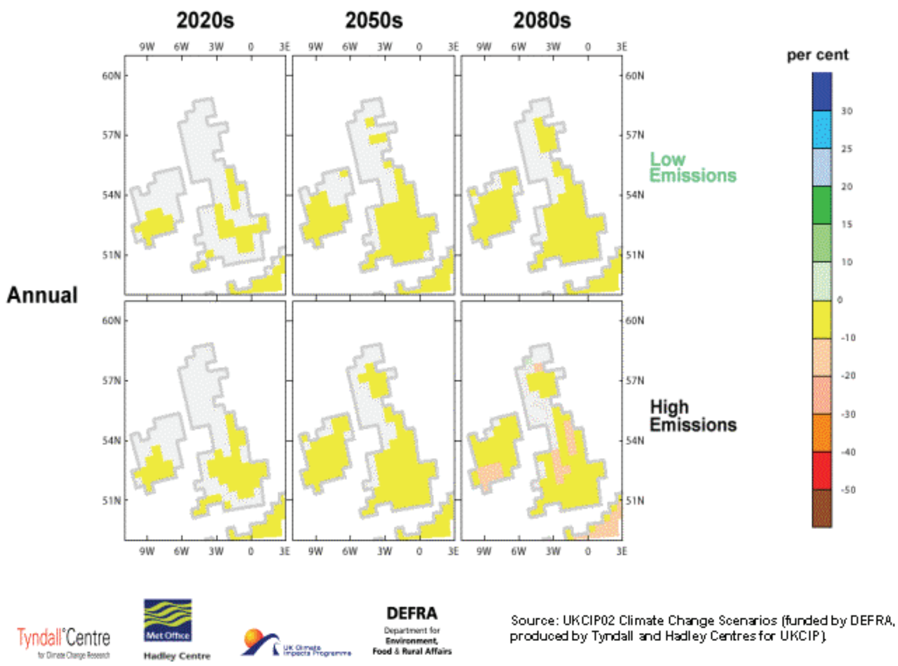


Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP)

3.6. **Sea level rise –** The UKCIP02 scenarios suggest a net sea-level rise for Scotland of between 15-28cm (accounting for changes in post-glacial vertical land movement) by the 2080s, an increase in peak surges and a modest annual average increase in tidal surges and waves due to an increasing frequency of severe winter gales. The confidence attached to these projected changes is high or medium.

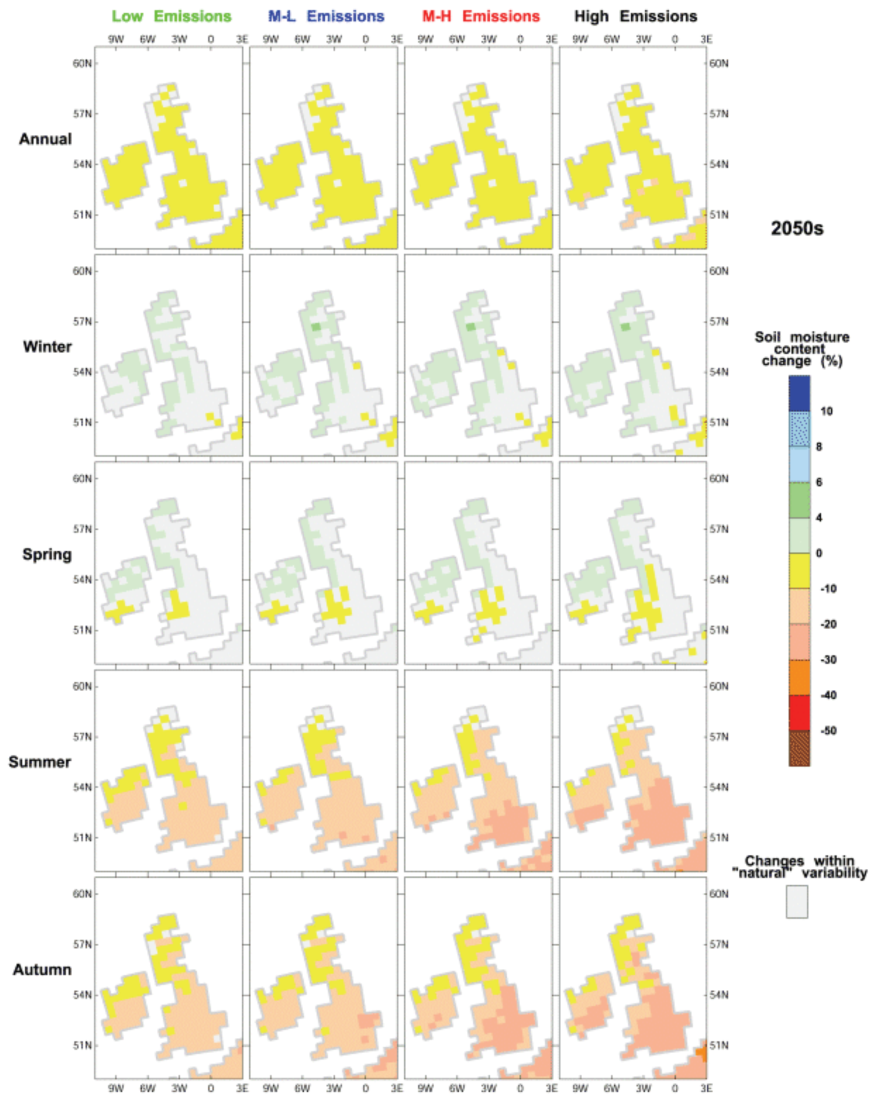
3.7. **Average precipitation –** Annual precipitation in the 2020s and in the 2050s will be similar to present, although there may be a decline of up to 10% along the Scottish east coast. Again, these figures hide more significant seasonal variations for Scotland. In the 2020s, winters along the east and Argyll and Ayrshire coasts will be up to 10% wetter than present, whereas summers in Scotland will be up to 10% dryer than present, with a 10-20% decrease in precipitation over central parts and the Borders. By the 2080s, there will be 40-60% less winter snowfall over the Cairngorms, with up to 80% less along parts of the Scottish east coast. This could change the pattern of river flows associated with snow melt. The confidence attached to these projected changes is high or in the case of snowfall changes, medium.

Figure 3.4 UKCIP02 Mean precipitation change



3.8. **Soil moisture** – The greatest changes are in summer and autumn with a reduction in soil moisture in summer and autumn of 10-40% across the whole of lowland Scotland. Soil moisture levels are likely to be up to 10% higher across the whole of Scotland in winter. The confidence attached to these projected changes is medium.

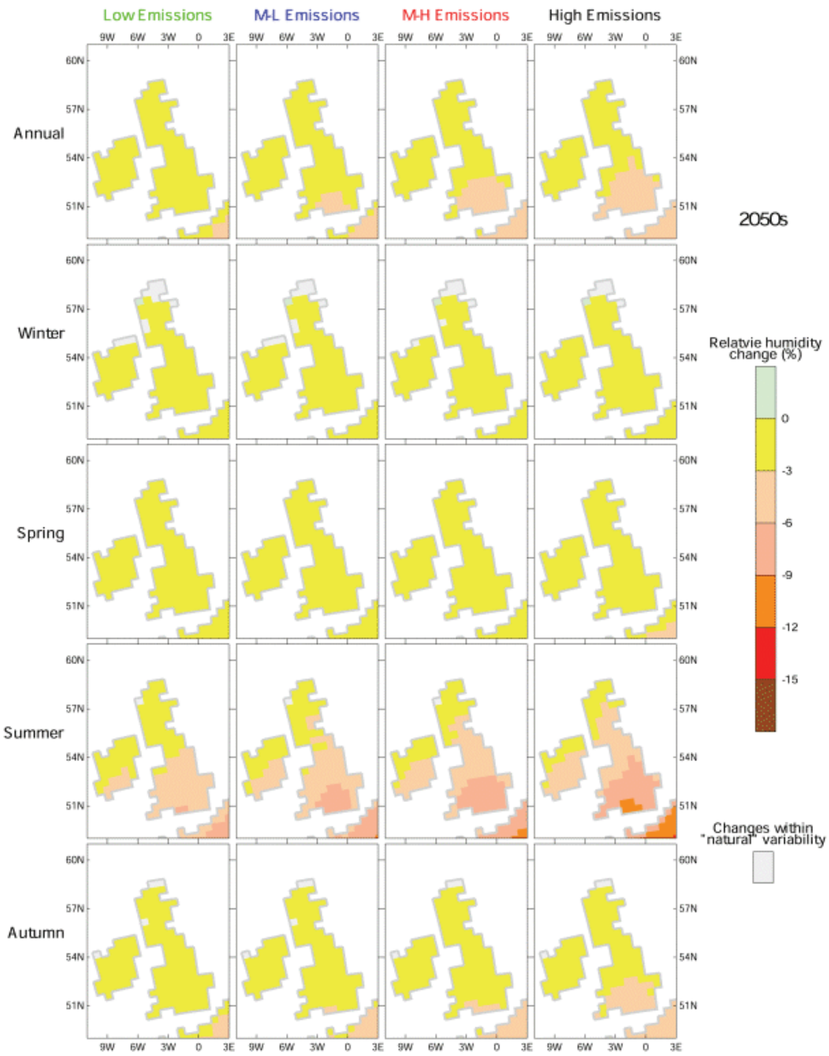
Figure 3.5 UKCIP02 Soil moisture content change (%)



Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP)

3.9. **Humidity** – Relative humidity decreases slightly across the whole of Scotland in spring and summer and all of Scotland bar the extreme north and north west in autumn and winter. The confidence attached to these projected changes is medium.

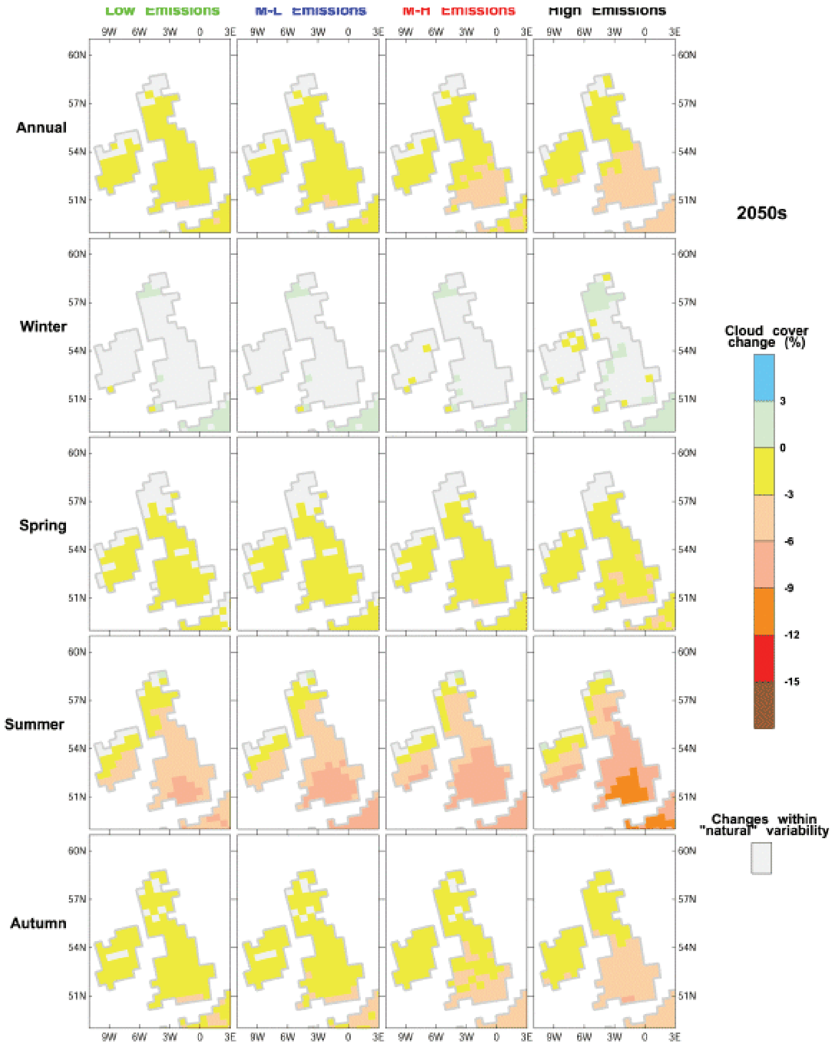
Figure 3.6 UKCIP02 Relative humidity change (%)



Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP)

3.10. **Cloud cover –** There is anticipated to be a slight reduction in cloud cover in the summer, except in the extreme north and north west, and a slight increase in winter cloud cover in some northerly areas. The confidence attached to these projected changes is low.

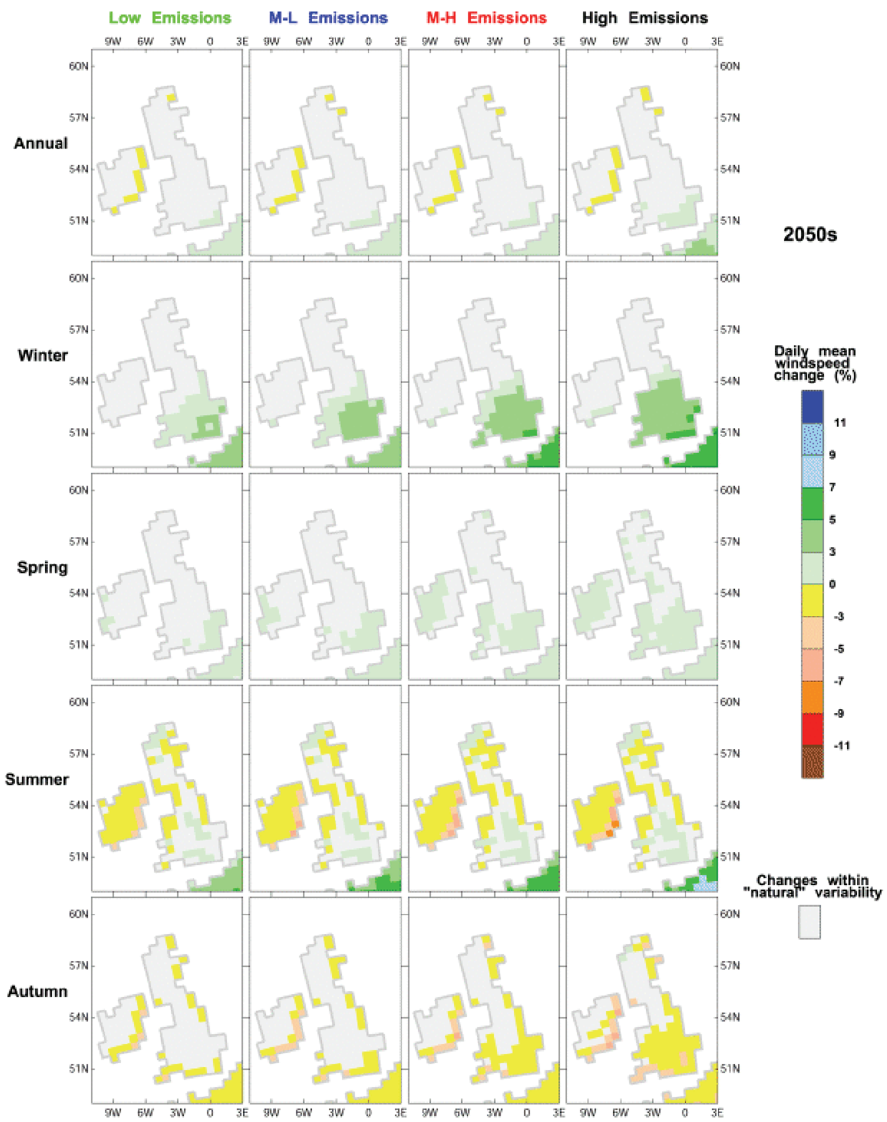
Figure 3.7 UKCIP02 Cloud cover change (%)



Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP)

3.11. **Average wind speed –** By 2080, the wind speed with a recurrence interval of 2 years (i.e. a typical wind speed) is set to increase in south west Scotland by 2-4% in winter and decrease across most of south and central Scotland by up to 2-6% in summer. The changes are of similar magnitude to those projected for parts of England and Wales. The confidence attached to these projected changes is low.

Figure 3.8 UKCIP02 Daily mean windspeed change (%)



Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP)

Comparison of UKCP02 and UKCP09 climate change variables

3.12. This section sets out a comparison of the UKCIP02 and UKCP09 projections, focusing on climate change variables most relevant to Phase 1 of this research into the effects of climate change on landscape and quality of life. This analysis compares the high emissions scenarios for both sets of projections, focusing on the 30 year time slice, centred on 2050. This reflects the lack of an equivalent to the UKCIP02 medium-high emission scenario (used in the Phase 1 research) in the suite of UKCP09 projections. This section also explains the changes made to the Phase 1 Interim Report as a result of the differences between the two sets of projections.

Winter precipitation

3.13. The UKCIP02 2050 high emissions scenario projections (Figure 3.9a) suggested that virtually all of Scotland could experience an increase in winter precipitation in 2050, with the smallest changes affecting the north west (up to 5% increase), large increases experienced along the east coast and central and southern Scotland (up to 16% increase) and largest increases in localised areas in the east (up to 24%).

3.14. While the largest increases suggested by the UKCP09 2050 high emissions scenario projections (Figure 3.9b) are similar to those in the 02 projections (23%), there are some important differences in the spatial pattern of change. Firstly, some areas may now be more likely to experience a slight decrease in winter rainfall of up to 1.5%. These areas include the wider Cairngorms massif. Secondly, it now appears that parts of the west coast, Hebrides and Northern Isles, along with the east coast may experience the largest increases in winter rainfall (up to 24%), with most of the remaining coastal fringes and southern Scotland experiencing increases of up to 16%.

3.15. Figure 3.9c shows a comparison of the two projections confirming that UKCP09 projections show some areas as having up to 14% less winter precipitation than the 02 projections and large areas of the eastern Highlands and Southern uplands experiencing reductions of up to 8% than previously projected. Parts of the west coast, the Hebrides and Northern Isles are shown as having between 8 and 24% more rainfall than previously predicted.

3.16. These are significant differences in the direction, scale and spatial pattern of change and it was therefore concluded that all the GIS analyses using the winter precipitation climate change variable should be re-run.

Other changes

3.17. The following variations did not require maps to be re-run, however, the changes are noted in the commentaries in Sections 4 and 5. More detail is also contained in Section 2 of Appendix 11.

Summer precipitation

3.18. The UKCIP02 projections suggested that all of Scotland with the exception of parts of the inner and Outer Hebrides and the Northern Isles could experience a decrease in summer precipitation. These decreases might be greatest in parts of central Scotland, southern Scotland and in the central Highlands. The UKCP09 2050 projections show a similar pattern, though the scale decrease is now lower than previously suggested. See **Figure 3.10**.

Winter temperature

3.19. The UKCIP02 projections suggested that all of Scotland could experience an increase in average winter temperatures. The increases could be greatest in southern and central Scotland, together with the Grampians and lowest around the western coastal fringes and Outer Hebrides. The UKCP09 projections show a broadly similar pattern, though the maximum projected increase is now greater than previously suggested. See **Figure 3.11**.

Summer temperature

3.20. The UKCIP02 projections suggested that all of Scotland could experience an increase in average summer temperatures. The increases could be greatest in southern and central Scotland, together with the Grampians and lowest around the western coastal fringes and Outer Hebrides. The UKCP09 projections show a broadly similar pattern, though the maximum increase could now be greater than previously suggested. See **Figure 3.12**.

Autumn temperature

3.21. The UKCIP02 projections suggested that all of Scotland could experience an increase in average autumn temperatures. The increases might be greatest in southern, central and much of Highland Scotland away from the far north and parts of the east coast and lowest around the Outer Hebrides (up to 1° Celsius increase). The UKCP09 projections show a similar pattern. See **Figure 3.13**.

Annual temperature

3.22. The UKCIP02 projections suggested that all of Scotland could experience an increase in average annual temperatures. The increases could be greatest across most of mainland Scotland and lowest around the west coast and Hebrides. The UKCP09 projections show a similar pattern, though the scale of change has increased. See **Figure 3.14**.

Figure 3.9a
Winter precipitation (UKCIP02)

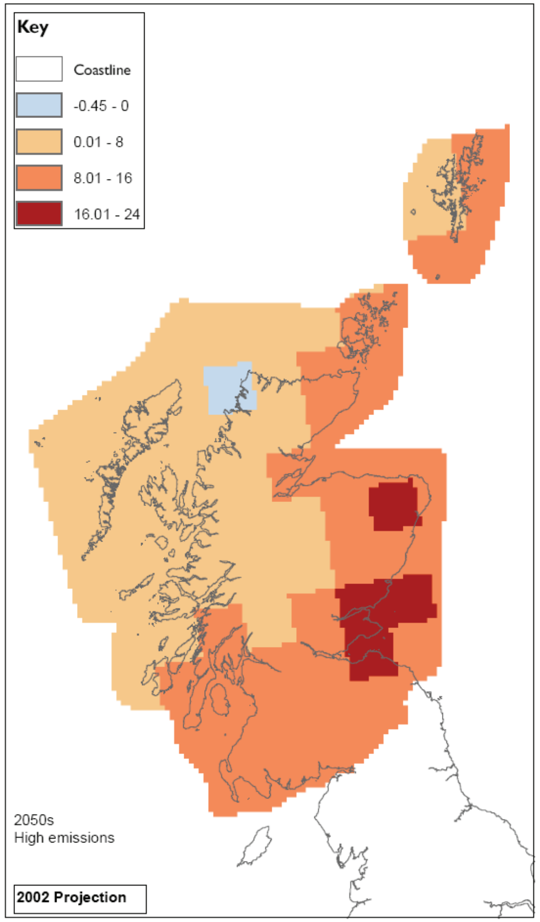


Figure 3.9b
Winter precipitation rainfall (UKCP09)

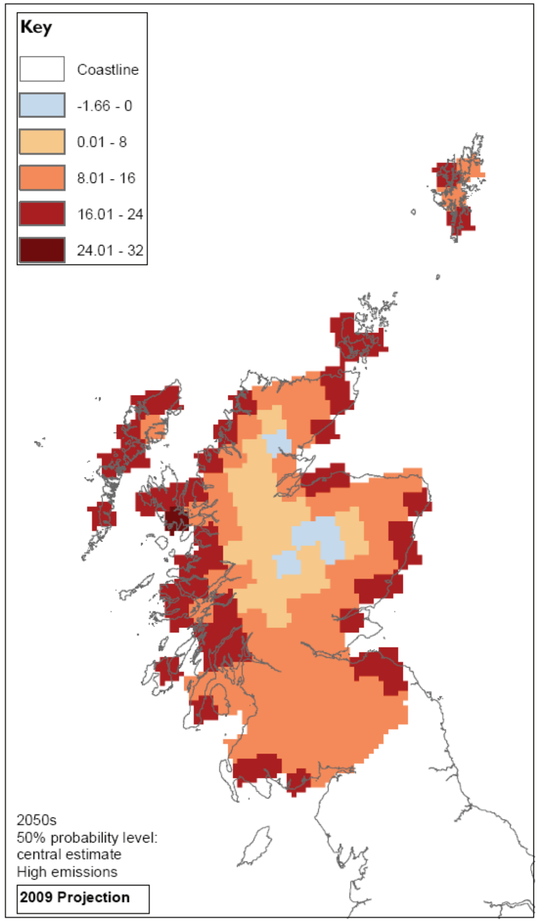
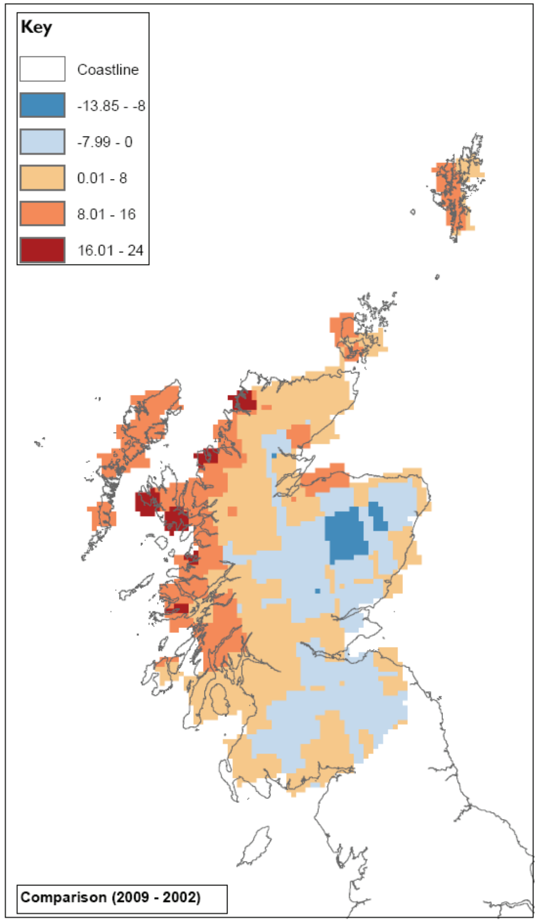


Figure 3.9c
Difference between UKCIP02 and UKCP09



Change in future climate change projections – Winter Precipitation (% change from current precipitation)

UKCIP02 and UKCP09 data are shown on the 5km^2 grid that was used to combine information during Phase 1 of the work. The UKCIP02 data have been interpolated across cell boundaries, whereas the UKCP09 data are based on the value at the centre-point of each 5km cell, reflecting advice that probabilistic projections should not be averaged.

Source: UKCIP02, UKCP09

File: S:\4800\4809 Climate Change and Landscape Phase 2\GIS\Themes\ArcGIS9\4503-02_005_Winter_Rain_Comparison_High.mxd

Figure 3.10a
Summer precipitation (UKCIP02)

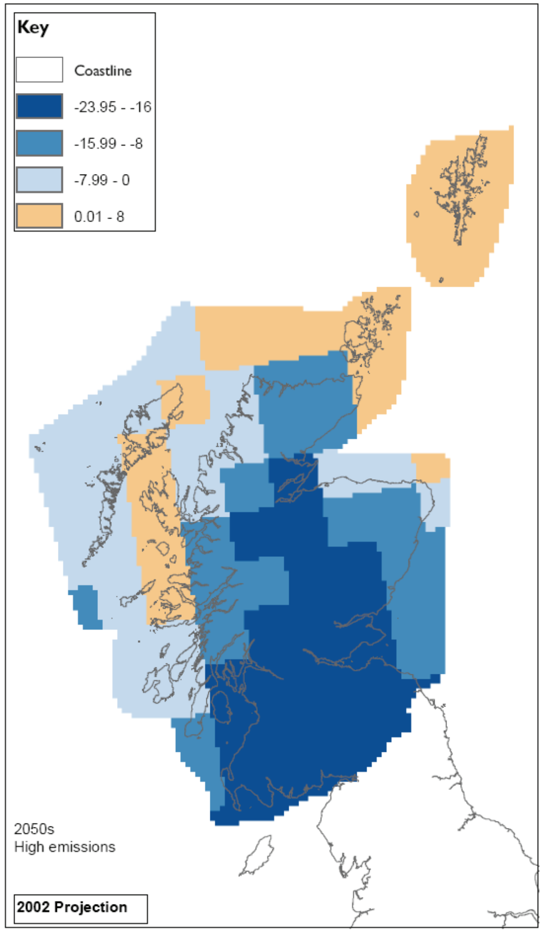


Figure 3.10b
Summer precipitation (UKCP09)

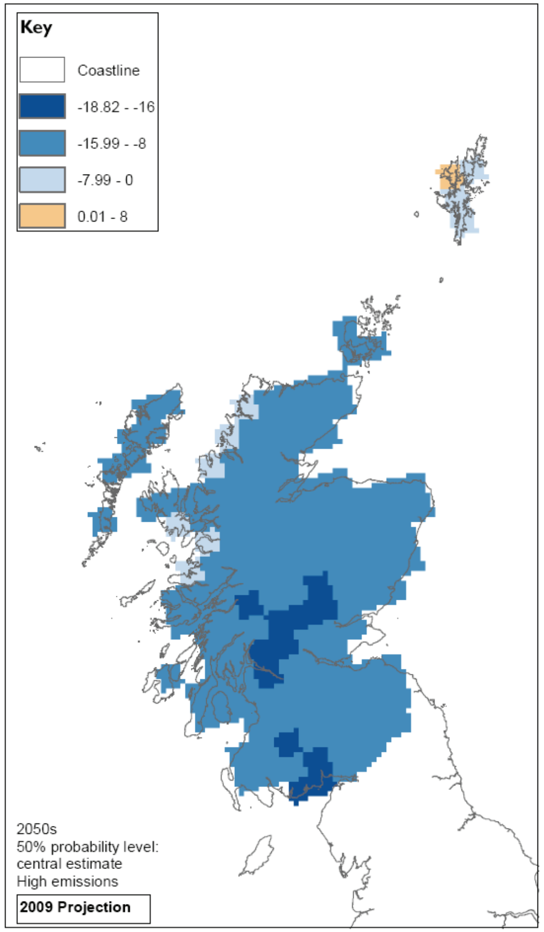
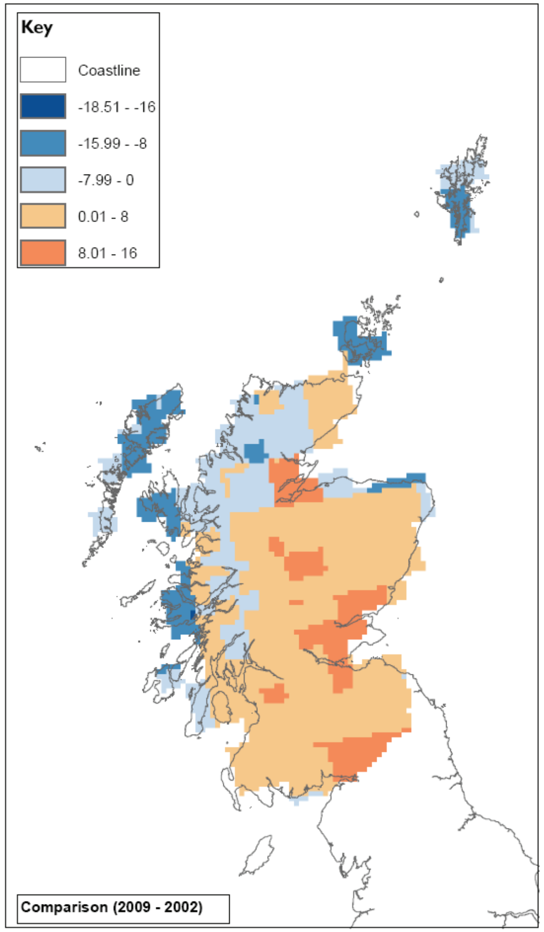
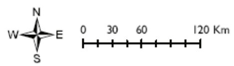


Figure 3.10c
Difference between UKCIP02 and UKCP09



Change in future climate change projections – Summer Precipitation (% change from current precipitation)

UKCIP02 and UKCP09 data are shown on the 5km^2 grid that was used to combine information during Phase 1 of the work. The UKCIP02 data have been interpolated across cell boundaries, whereas the UKCP09 data are based on the value at the centre-point of each 5km cell, reflecting advice that probabilistic projections should not be averaged.



Source: UKCIP02, UKCP09

File: S:\4800\4809 Climate Change and Landscape Phase 2\GIS\Themes\ArcGIS9\4503-02_004_Summer_Rain_Comparison_High.mxd

Figure 3.11a
Winter temperature (UKCIP02)

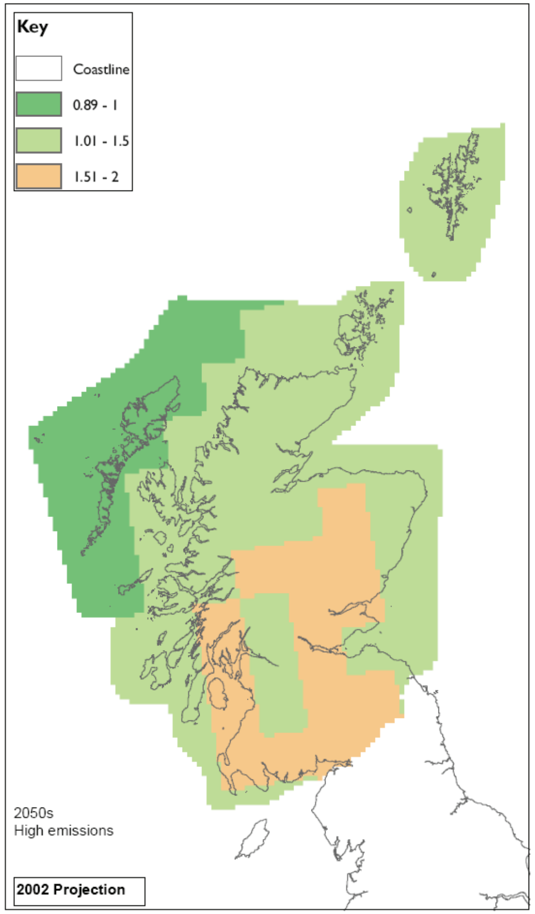


Figure 3.11b
Winter temperature (UKCP09)

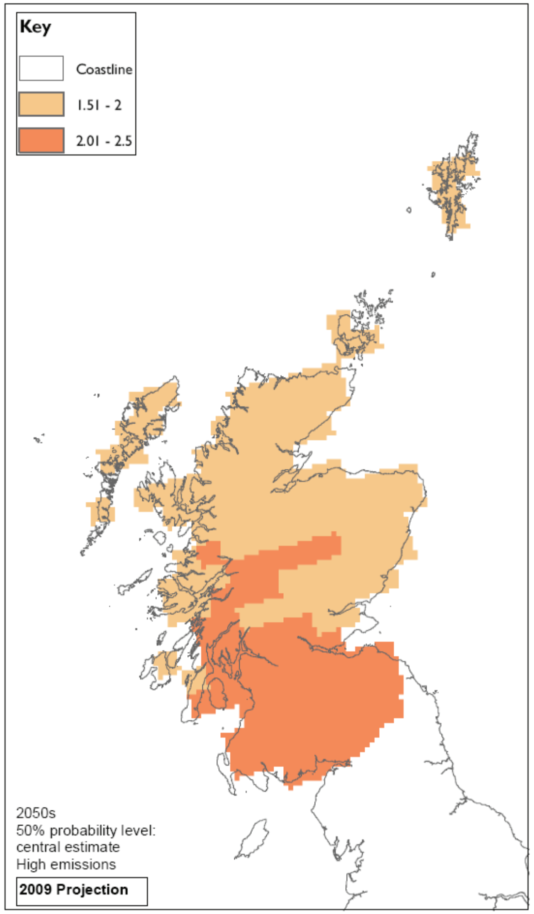
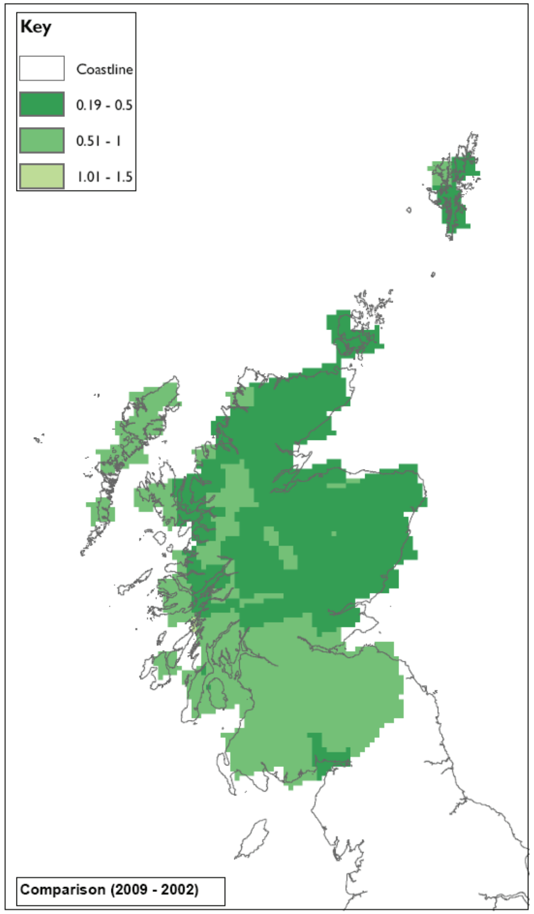


Figure 3.11c
Difference between UKCIP02 and UKCP09



Change in future climate change projections – Winter Temperature (°C)

UKCIP02 and UKCP09 data are shown on the 5km^2 grid that was used to combine information during Phase 1 of the work. The UKCIP02 data have been interpolated across cell boundaries, whereas the UKCP09 data are based on the value at the centre-point of each 5km cell, reflecting advice that probabilistic projections should not be averaged.

N W E S 0 30 60 120 Km

Source: UKCIP02, UKCP09

Figure 3.12a
Summer temperature (UKCIP02)

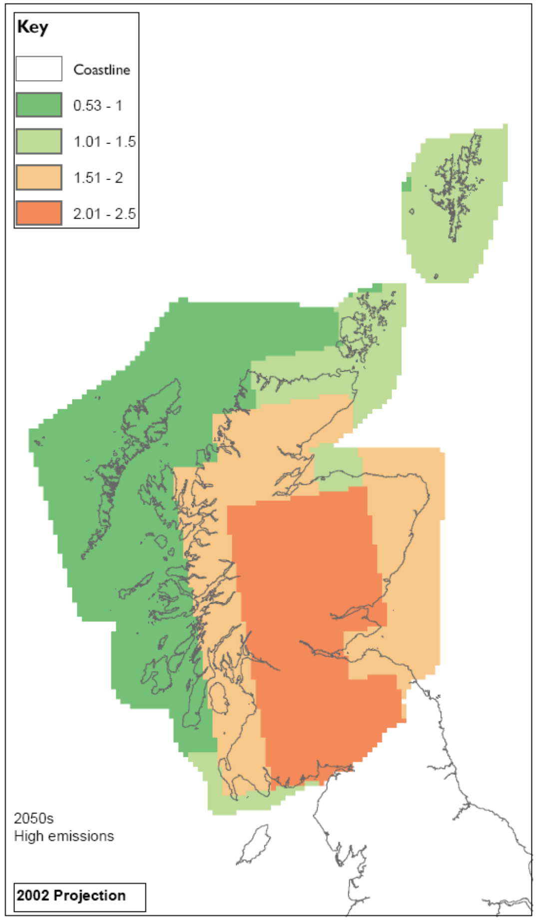


Figure 3.12b
Summer temperature (UKCP09)

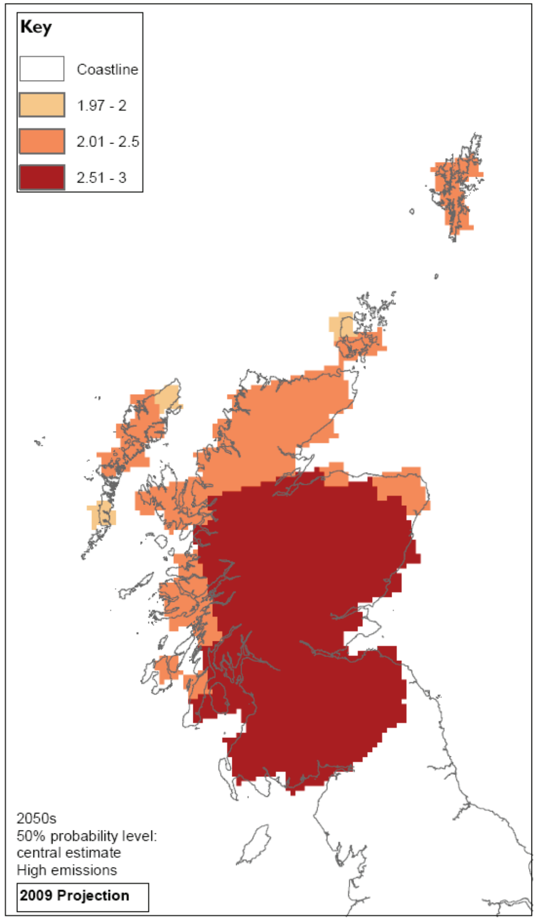
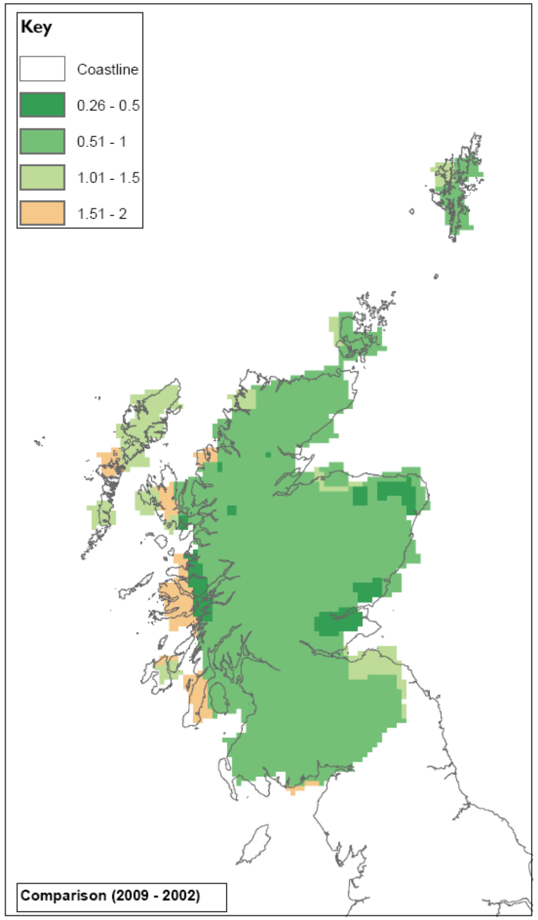
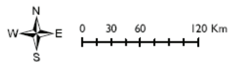


Figure 3.12c
Difference between UKCIP02 and UKCP09



Change in future climate change projections – Summer Temperature (°C)

UKCIP02 and UKCP09 data are shown on the 5km^2 grid that was used to combine information during Phase 1 of the work. The UKCIP02 data have been interpolated across cell boundaries, whereas the UKCP09 data are based on the value at the centre-point of each 5km cell, reflecting advice that probabilistic projections should not be averaged.



Source: UKCIP02, UKCP09

File: S:\4800\4809 Climate Change and Landscape Phase 2\GIS\Themes\ArcGIS9\4503-02_001_Data_for_Comparison.mxd

Figure 3.13a
Autumn temperature (UKCIP02)

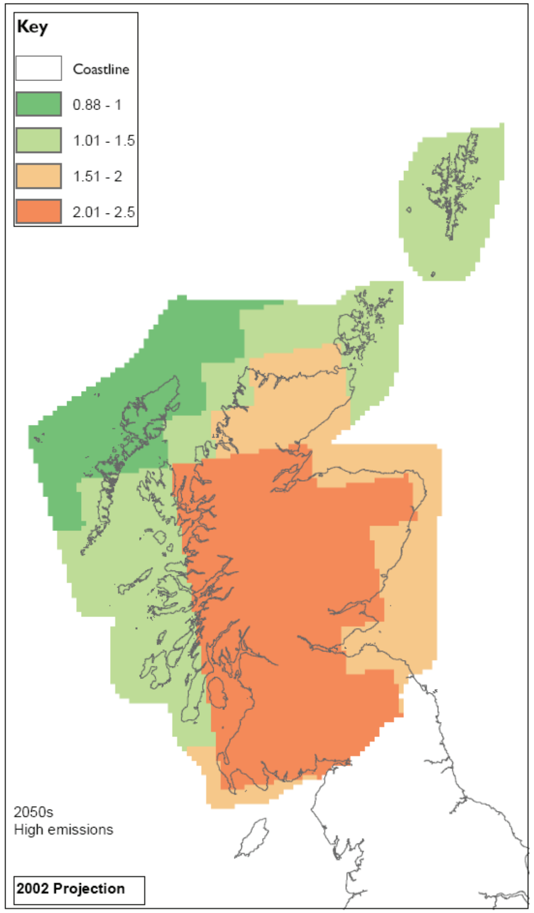


Figure 3.13b
Autumn temperature (UKCP09)

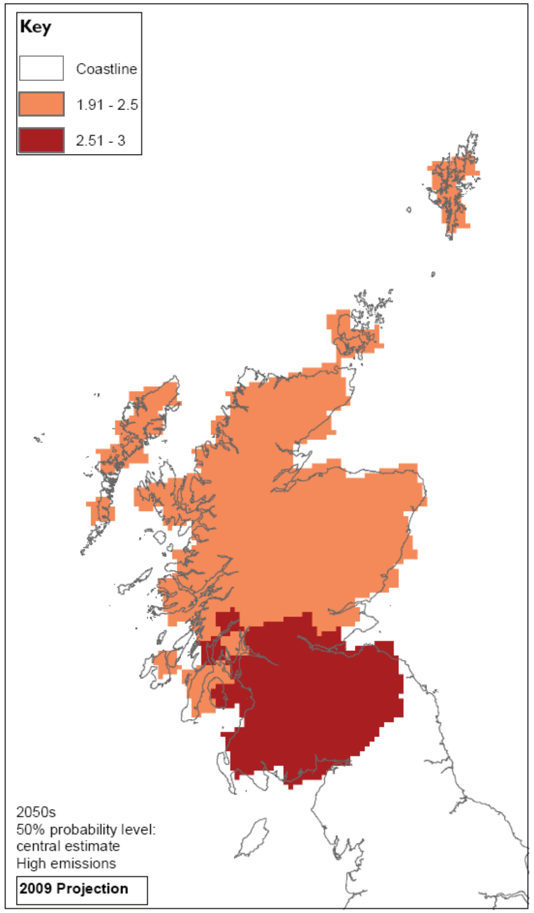
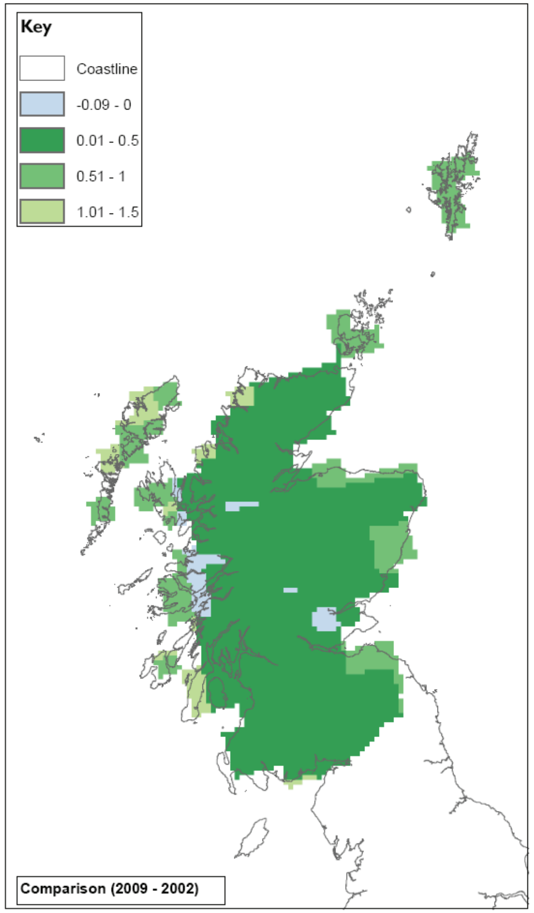
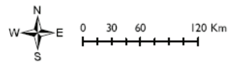


Figure 3.13c
Difference between UKCIP02 and UKCP09



Change in future climate change projections – Autumn Temperature (°C)
UKCIP02 and UKCP09 data are shown on the 5km^2 grid that was used to combine information during Phase 1 of the work. The UKCIP02 data have been interpolated across cell boundaries, whereas the UKCP09 data are based on the value at the centre-point of each 5km cell, reflecting advice that probabilistic projections should not be averaged.



Source: UKCIP02, UKCP09

File: S:\4800\4809 Climate Change and Landscape Phase 2\GIS\Themes\ArcGIS9\4503-02_006_Autumn_Temp_Comparison_high.mxd

Figure 3.14a
Annual temperature (UKCIP02)

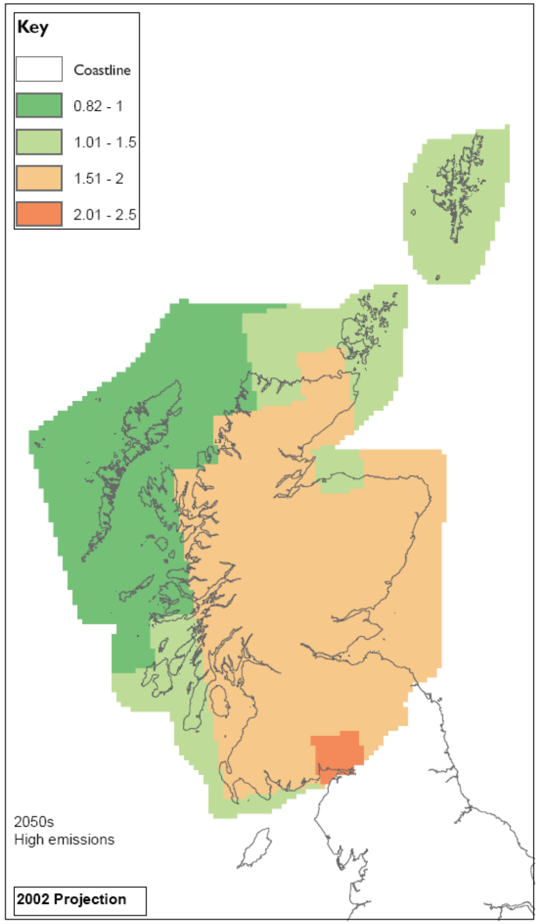


Figure 3.14b
Annual temperature (UKCP09)

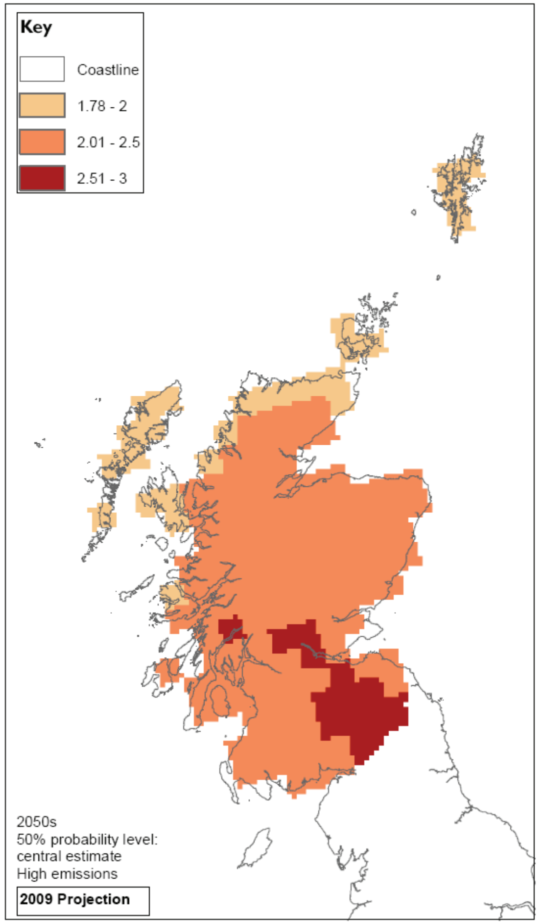
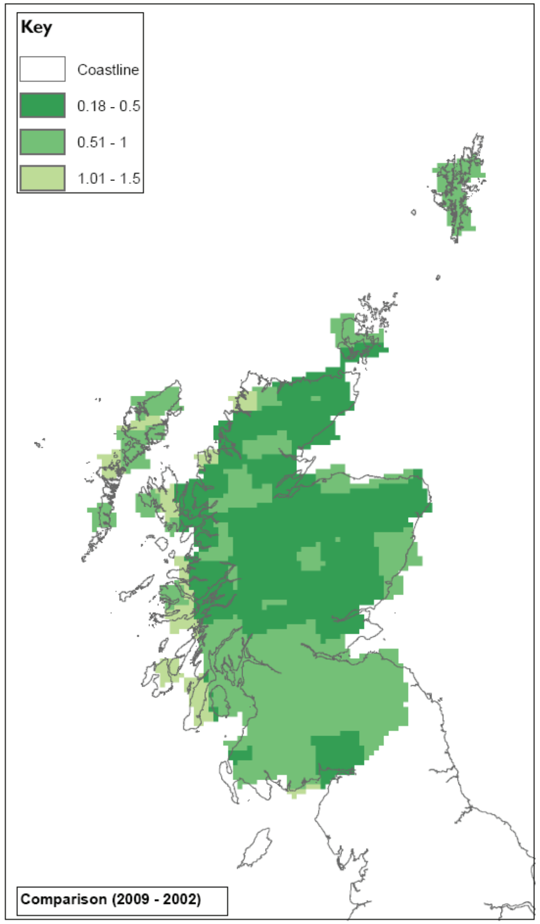


Figure 3.14c
Difference between UKCIP02 and UKCP09



Change in future climate change projections – Annual Temperature (°C)

UKCIP02 and UKCP09 data are shown on the 5km^2 grid that was used to combine information during Phase 1 of the work. The UKCIP02 data have been interpolated across cell boundaries, whereas the UKCP09 data are based on the value at the centre-point of each 5km cell, reflecting advice that probabilistic projections should not be averaged.

Source: UKCIP02, UKCP09

Sea level rise

3.23. Phase 1 of the research into the effects of climate change on landscape and quality of life drew on research into sea level rise carried out for the Scotland and Northern Ireland Forum for Environmental Research (published as FRM10 in 2008[1]). This research presented estimates for sea level change around the Scottish coast between 2000 and 2080. These were based on the IPCC global mean sea level projections adjusted to reflect geological and isostatic rebound modelling, similar to those used in the UKCIP02 projections. This research has been updated in the light of the UKCP09 projections[2].

3.24. The UKCP09 projections include new figures for sea level rise using the modelling approach described above (emission scenarios, timescales, probabilistic projections) combined with the latest assessment of land movement around the UK coast which differ from those used in the earlier research into sea level rise. The latter have been revised downwards slightly, resulting in an upward adjustment in sea level projections.

Table 3.1: 2080 sea level projections for Edinburgh, cm

	High emissions	Medium emissions	Low emissions
FRM10 (in line with UKCIP02)	+6 to +35	+1.6 to +24	
UKCP09 50% percentile	+31.4	+24.4	+18.6
UKCP09 5% / 95% percentiles	+7 to +54	+5 to +45	+4 to +32

See paragraphs 1.21 and 1.22 of Appendix 11 for explanation of percentiles

3.25. These figures suggest that the UKCP09 projections lie towards the upper end of the FRM10 UKCIP02 projections.

3.26. The update to the research concludes that the spatial pattern of change is broadly the same as reported in FRM10, though no new maps are available. A relative sea level rise of around +30-35 cm over the period 1990 to 2095 at Edinburgh compares with 25-30 cm in the Clyde Estuary, around 40-45 cm in the Western Isles and Orkney Islands and around 50-55 cm in the Shetland Islands.

3.27. The UKCP09 projections include an additional scenario based on high plus plus emissions (H++). This scenario is intended to represent the effects of the melting of large ice sheets on sea level rise, an area where there is a current lack of scientific understanding. While this is considered to be a very unlikely scenario, the projections suggest that beyond the end of the century sea levels could rise by between 93cm and 1.9m.

3.28. The updated research also considers the issue of storm surges. It concludes that storm surges show considerable less change in overall height (and consequently less influence on coastal flood risk) compared to sea level rise around the Scottish coast. However, taking the H++ emissions scenario for sea level and combining this with surge predictions from the higher emissions estimate give much more significant increases in the effect of surge tides on coastal flooding.

[1] SNIFFER (2008) Coastal Flooding in Scotland: A Scoping Study, Project FRM10
[2] Update to Project FRM10: Coastal Flooding in Scotland: A Scoping Study, in the light of the UK Climate Projections (2009) report
http://www.sniffer.org.uk/Webcontrol/Secure/ClientSpecific/ResourceManagement/UploadedFiles/updated%20summary%20Nov%2009.pdf

3.29. While the scale of projected sea level rise is somewhat greater than suggested by the UKCIP02 scenarios, the spatial implications (when viewed at a national level) are broadly similar. It was concluded that these differences should be noted, but GIS analysis using the revised sea level projections should not be re-run.

SNIFFER Handbook of Climate Trends

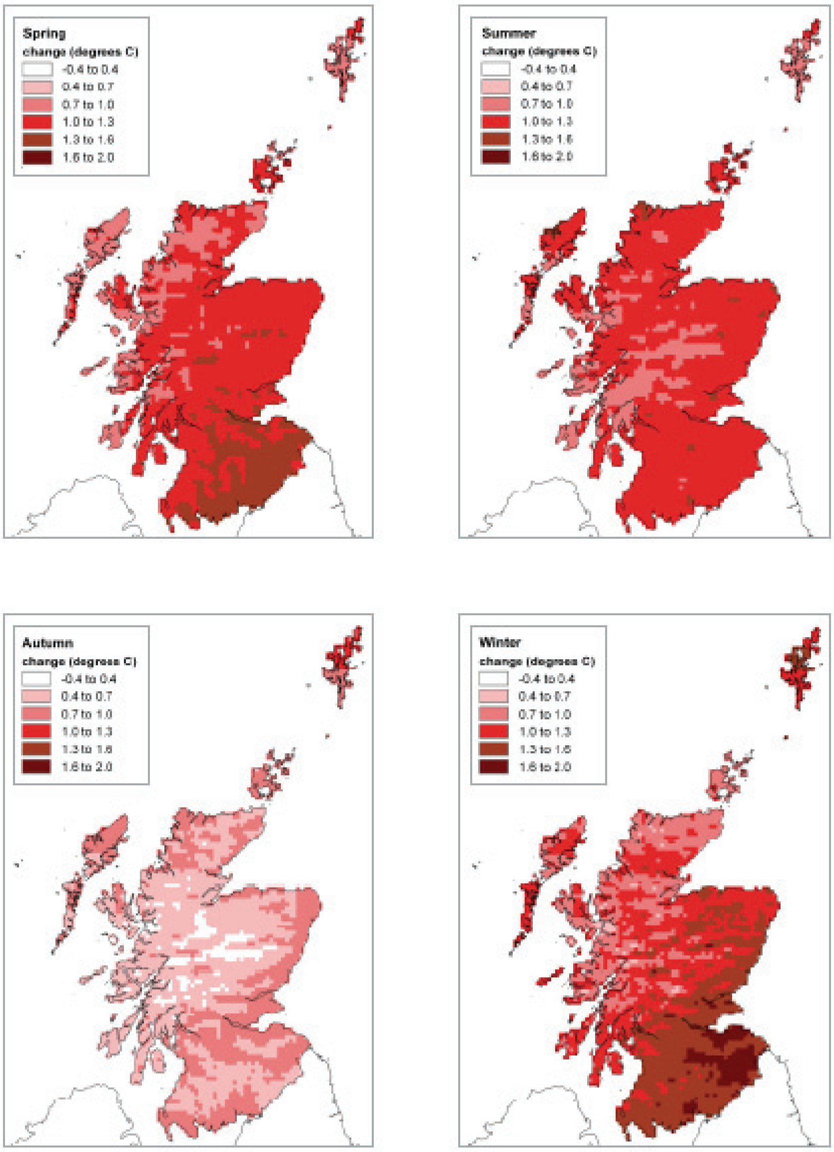
3.30. The SNIFFER (2006) report 'Patterns of Climate Change Across Scotland' presents the changes in climate across Scotland in the last century, and provides a benchmark against which to measure future climate change. The results are examined in relation to the Tayside pilot area in order to draw out any key regional variations in likely future climate change, and the possible implications of these. Tayside lies within the 'East Scotland' region, as defined in the SNIFFER study.

Temperature

- The greatest increases in average temperature have taken place during spring and winter and the largest are in southern and eastern Scotland in winter.
- There are no significant spatial trends in the 24 hour minimum temperature.
- Daily temperature range: Only east Scotland has demonstrated a fall in average daily temperature range.
- Heating degree days represent those days when heating of homes and businesses is required and represents the difference between internal and average outside temperature. The spatial distribution is similar to that for average temperatures, with the southerly, coastal and lower lying areas showing the greatest reductions in days when heating is likely to be required.
- Growing degree days records the number of days where the mean temperature is above a threshold representing the temperature at which plants are photosynthetically active (taken to be 5°C). All areas show an increase in growing degree days.
- Length of the growing season based on the period of time between the first time mean temperatures rise above 5°C on five consecutive days and the first time mean temperatures fall below 5°C on five consecutive days. East Scotland has the shortest growing season by a few days, however all regions have seen an increase in the length of the growing season. The length of the growing season has increased the least in the more mountainous upland areas.
- Data on the start and end of the growing season show an increase in both the start and end of the growing season, with the greatest increase in the west.
- Extreme temperature range: No clear trend is identified.
- Length of summer heat wave and winter cold spell show an increase in the length of both across the three regions, with a reduction in the length of cold spells in winter in both east and west Scotland.
- Air Frost: Days of air frost show an overall decrease across spring, autumn and winter. The largest changes include some of the islands and upland areas.
- Ground Frost: Days of ground frost show an overall decrease across Scotland, with an increase in Orkney and Shetland.
- Early and late season frosts: The data shows an overall increase in the length of the frost free season.

Figure 3.15 Climate trends: average temperature

Patterns of change in average temperature (in ºC) between 1961 and 2004 for each season (Source: SNIFFER A handbook of climate trends across Scotland, 2006)



Precipitation

- Higher average annual precipitation throughout Scotland.
- Clear upward trend in winter precipitation. The eastern areas show the least increase in winter precipitation, however in autumn the east is the only region to become wetter.
- Snow cover: The percentage change in days of snow cover shows an overall reduction in each region across all seasons, with the largest percentage change in spring and autumn, however the greatest change is in the west.
- Days of heavy rain each year: East Scotland is drier than north and west Scotland and shows the lowest level of increase in precipitation annually and across each season.

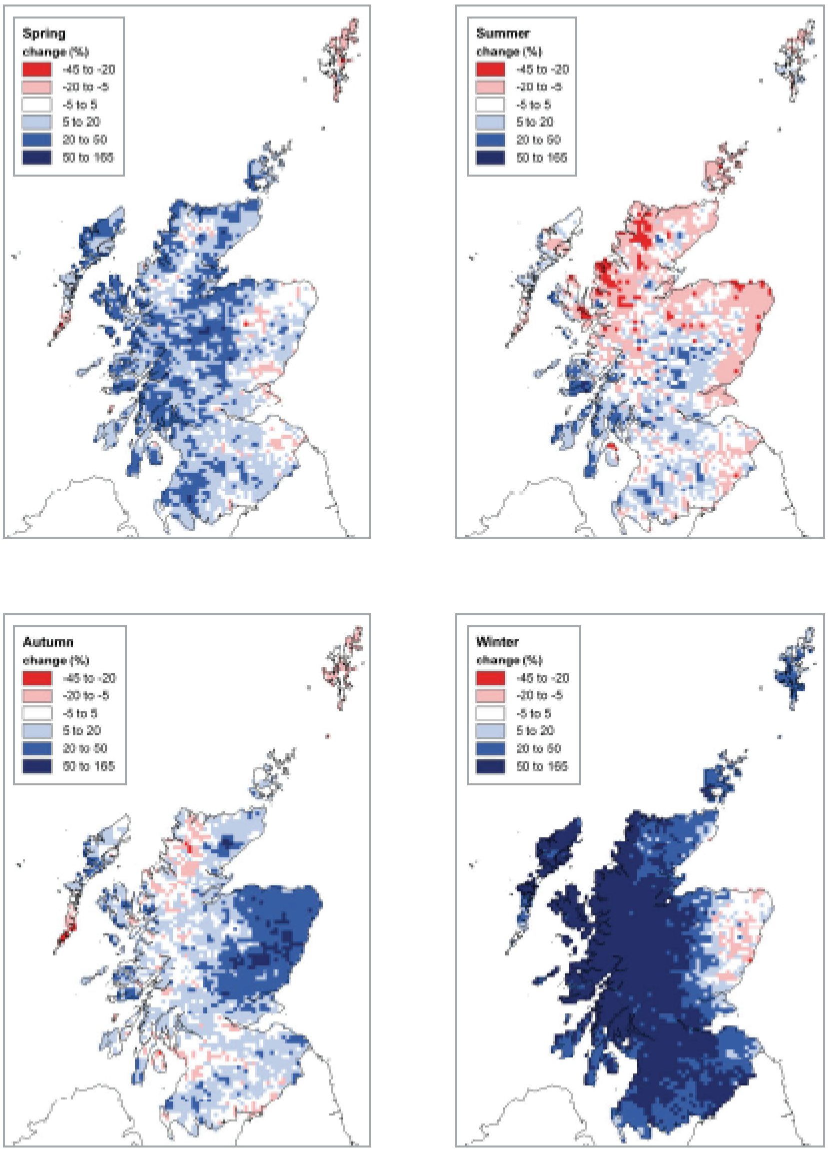
- Number of consecutive dry days: There has been an increase in the number of consecutive dry days in each year in the east.

- Average rainfall intensity: A trend in increasing rainfall intensity in east and west Scotland.

- Maximum five-day precipitation total: A clear increasing trend, with an increase across most of Scotland.

Figure 3.16 Climate trends: precipitation

Patterns of change in precipitation totals (as a percentage) between 1961 and 2004 for each season. (Source: SNIFFER A handbook of climate trends across Scotland, 2006)

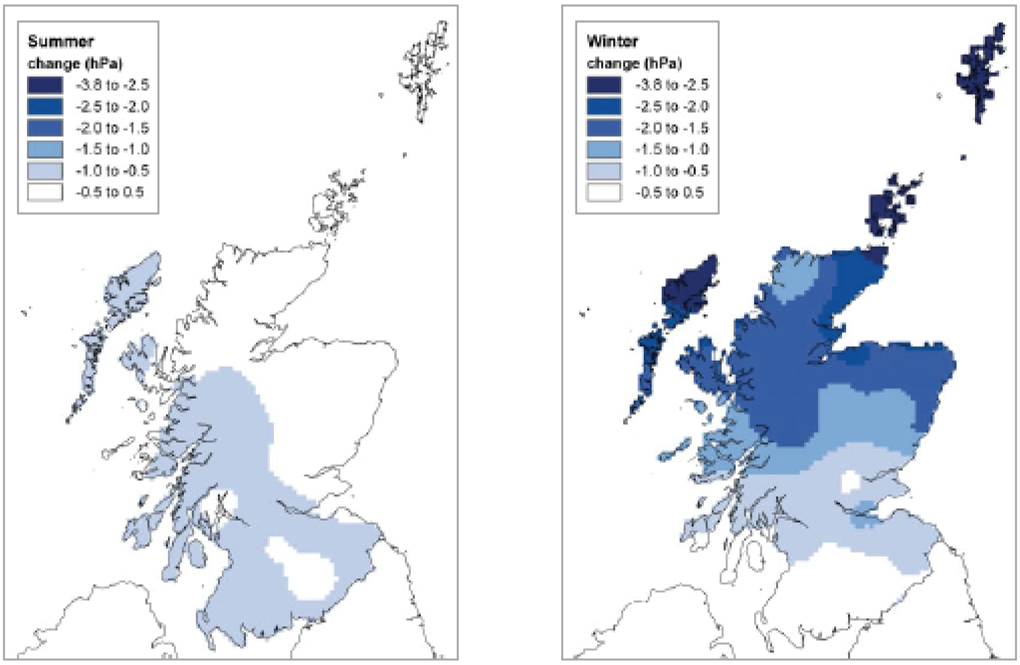


Air pressure related variables

- Average air pressure at sea level: no clear trends.
- Average wind speed each year: Based on the average wind speed at three Scottish recording stations, the records for Leuchars show a trend of decreasing average wind speeds in the last forty years.
- Days of gale each year: No clear trend.

Figure 3.17 Climate trends: sea level air pressure

Patterns of change in the average sea level air-pressure (in hPa) each year, between 1961 and 2004, for the summer and winter quarters (Source: SNIFFER A handbook of climate trends across Scotland, 2006)

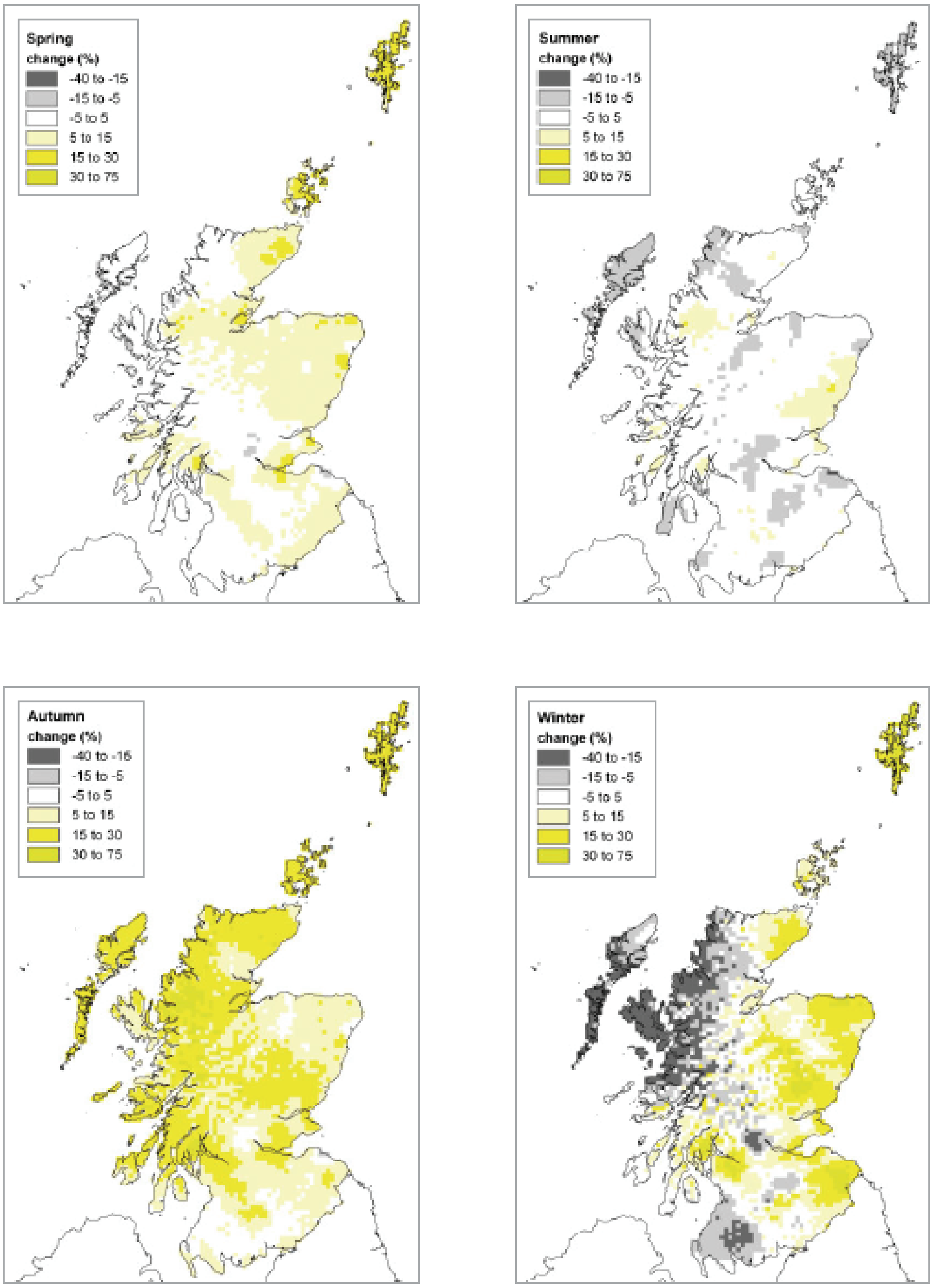


Sunshine related variables

- Sunshine hours: No clear trends, however east Scotland has become sunnier in all three seasons since 1961. In eastern Scotland, greatest increases in autumn and winter, and across parts of Fife and Angus.
- Cloud cover: No obvious trends.

Figure 3.18 Climate trends: sunshine hours

Patterns of change in sunshine hours (as a percentage), between 1961 and 2004, for each season (Source: SNIFFER A handbook of climate trends across Scotland, 2006)



Summary

3.31. The SNIFFER climate trends data provides an indication of how climate changes may vary across Scotland, and in particular how regional variations in Scotland may affect the case study area. The SNIFFER climate trends are based on historical data, and have a finer grain of detail whereas the UKCIP climate change scenarios look to the future and are at a coarser scale.

4. SCOTLAND-WIDE PATTERN OF CLIMATE RELATED CHANGE

INTRODUCTION

4.1. This part of the report sets out the results of the analysis. It describes the potential landscape changes (see Appendix 5) at a national level based on the climate related landscape changes listed in Appendix 5, Table 5.5.

LANDSCAPE CHANGES – NATIONAL LEVEL

4.2. This section provides a descriptive overview of the key climate related landscape changes that were explored at a national level. It is based on the original matrix of landscape changes identified from the literature review and is drawn together under a series of topic area headings. The spatial distribution of a number of changes is mapped and described in relation to the 21 Natural Heritage Zones (see Figure 4.1 and paragraph 4.6). Table 4.1 lists the changes mapped and the data sources used as the basis for this mapping.

4.3. Historic Land Use Assessment (HLA) data could be used in future assessment processes to inform the impact of climate related landscape change on the historic environment. Although historic influences on the landscape are incorporated within the process of landscape character assessment, HLA data provides an additional layer of information which can be used to interpret the landscape. HLA data can be used to provide a picture of the degree of change which a landscape has experienced and whether the existing landscape is likely to include a high proportion of historic features or to have been significantly modified.

4.4. The national maps illustrate the potential locations of areas affected by the climate related landscape changes identified. The maps are based on likely climate trends for 2050, based on the UKCIP02 medium-high emissions scenario. The distribution of landscape features on which the mapping is based draws on the current distribution of these features, and does not take account of future change. The maps provide an indication of the potential degree of landscape change, but do not represent predictions. The mapping has been carried out for a selection of potential landscape changes and is not exhaustive, but provides an illustration of possible patterns of change within the limitations of the study. There is significant scope to further explore the application of the mapping methodology developed, and for the identification of additional data sources.

4.5. The mapping is based primarily on direct impacts of climate change, as there are greater difficulties in mapping mitigation and adaptation impacts due to the lack of data on the locations where these may occur and influence of policy. Exceptions to this include the mapping of areas where pressure for wind energy development, is likely to be greatest. Table 4.1 provides a list of the changes mapped. The table identifies the certainty associated with the climate change variable, and also if the change is a direct impact, an adaptation response or mitigation action. A greater level of certainty can be attributed to direct changes which result from climate change variables with a high level of certainty. A lower level of certainty can be attributed to landscape changes which result from adaptation responses, as there are a greater number of variables which could influence the outcome of these, however some may already be in place through existing policy. Mitigation responses may have a higher or lower level of certainty depending on the existing policy framework.

Table 4.1 Landscape changes mapped at a national level including data sources used for mapping

Topic	Appendix 5, Tables 5.4 and 5.5)	Landscape change	Map figure number	Topographic\ Landscape data	Climate\Flooding data	Timeframe (yrs) <10	10-100	100+	Climate change certainty (for climate change variable)	Landscape change certainty (direct or adaptation or mitigation)
Forests and woodlands	62	Mixed broadleaves – species mix – increase in beech and sycamore – outcompeting oak, ash and elm resulting in changing woodland composition – loss of native species, increase in new species	Figure 4.2a and 4.2b	Broadleaves, National Inventory of Woodlands & Trees (NIWT)	T2: Autumn temperature change (TEMP)				High	Direct, high
Forests and woodlands	63	Damage to woodlands caused by summer drought resulting in early leaf fall and dying trees	Figure 4.3a and 4.3b	National Inventory of Woodlands & Trees (NIWT)	P2: Average decrease in summer precipitation (PREC)				High	Direct, high
Forests and woodlands	64	Damage to woodlands caused by winter flooding resulting in early leaf fall and dying trees especially on poorly draining soils and where linked to summer drought – most evident in eastern Scotland	Figure 4.4a and 4.4b	National Inventory of Woodlands & Trees (NIWT)	P1: Average change in winter precipitation (PREC)				High for precipitation, medium for soil moisture	Direct, high