BIOCLIM

Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal

EC-CONTRACT : FIKW-CT-2000-00024

WORK PACKAGE 2 :

Simulation of the future evolution of the biosphere system using the hierarchical strategy.

DELIVERABLE D6b :

Application of statistical downscaling within the BIOCLIM hierarchical strategy: methods, data requirements and underlying assumptions.

FOREWORD

The BIOCLIM project on modelling sequential BIOsphere systems under CLIMate change for radioactive waste disposal is part of the EURATOM fifth European framework programme. The project was launched in October 2000 for a three-year period. The project aims at providing a scientific basis and practical methodology for assessing the possible long term impacts on the safety of radioactive waste repositories in deep formations due to climate and environmental change. Five work packages have been identified to fulfil the project objectives:

Work package 1 consolidates the needs of the European agencies of the consortium and summarises how environmental change has been treated to date in performance assessments.

Work packages 2 and 3 develop two innovative and complementary strategies for representing time series of long term climate change using different methods to analyse extreme climate conditions (the hierarchical strategy) and a continuous climate simulation over more than the next glacial-interglacial cycle (the integrated strategy).

Work package 4 explores and evaluates the potential effects of climate change on the nature of the biosphere systems.

Work package 5 disseminates information on the results obtained from the three year project among the international community for further use.

The project brings together a number of representatives from both European radioactive waste management organisations which have national responsibilities for the safe disposal of radioactive waste, either as disposers or regulators, and several highly experienced climate research teams. Contributing organisations are listed below.

Agence Nationale pour la Gestion des Déchets Radioactifs (Andra), France
Commissariat à l'Energie Atomique/ Laboratoire des Sciences du Climat et de l'Environnement (CEA/LSCE) France
United Kingdom Nirex Limited (NIREX), UK
Gesellschaft für Anlagen und Reaktorsicherheit mbH (GRS), Germany
Empresa Nacional de Residuos Radioactivos S.A. (ENRESA), Spain
Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT), Spain
Universidad Politecnica de Madrid Escuela Tecnica Superior de Ingenieros de Minas (UPM-ETSIMM), Spain
Nuclear Research Institute Rez, plc - Ustav jaderneho vyzkumu Rez a.s. (NRI), Czech Republic
Université catholique de Louvain/ Institut d'Astronomie et de Géophysique Georges Lemaître (UCL/ASTR), Belgium
The Environment Agency of England and Wales (EA), UK
University of East Anglia (UEA), UK

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For this specific deliverable, the sole contributor is UEA (Clare Goodess).

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History

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1. INTRODUCTION

The coarse spatial scale of the EMICs used in BIOCLIM compared with the BIOCLIM study regions and the needs of performance assessment creates a need for downscaling. Downscaling can be defined as 'sensibly projecting the large-scale information on the regional scale' (von Storch *et* al., 1993).

Most of the developmental work on downscaling methodologies undertaken by the international research community has focused on downscaling from the general circulation model (GCM) scale (with a typical spatial resolution of 400 km by 400 km over Europe in the current generation of models) using dynamical downscaling (i.e., regional climate models (RCMs), which typically have a spatial resolution of 50 km by 50 km for models whose domain covers the European region) or statistical methods (which can provide information at the point or station scale) in order to construct scenarios of anthropogenic climate change up to 2100 (Hewitson and Crane, 1996; Schubert and Henderson-Sellers, 1997; Wilby and Wigley, 1997; Wilby *et al*., 1998, Zorita and von Storch, 1999; Giorgi *et al*., 2001). Dynamical downscaling (with the MAR RCM) is used in BIOCLIM WP2 to downscale from the GCM (i.e., IPSL_CM4_D) scale (see Deliverable D6a).

In the original BIOCLIM description of work, it was proposed that UEA would apply statistical downscaling to IPSL_CM4_D output in WP2 as part of the hierarchical strategy. Statistical downscaling requires the identification of statistical relationships between the observed large-scale and regional/local climate, which are then applied to large-scale GCM output, on the assumption that these relationships remain valid in the future (the assumption of stationarity). Thus it was proposed that UEA would investigate the extent to which it is possible to apply relationships between the present-day large-scale and regional/local climate to the relatively extreme conditions of the BIOCLIM WP2 snapshot simulations.

Potential statistical downscaling methodologies were identified from previous work performed at UEA. Appropriate station data from the case-study regions were identified, together with the additional issues which arise in applying these techniques to output from the BIOCLIM simulations. This preliminary work is described in this BIOCLIM technical note. It provides an overview of statistical downscaling methods, together with their underlying assumptions and advantages/disadvantages. Specific issues relating to their application within the BIOCLIM context (i.e., application to the IPSL_CM4_D snapshot simulations – see Deliverable D4/5) are identified, for example, the stationarity issue. The predictor and predictand data sets that would be required to implement these methods within the BIOCLIM hierarchical strategy are also outlined, together with the methodological steps involved.

Implementation of these techniques was delayed in order to give priority to the application of the rule-based downscaling method developed in WP3 to WP2 EMIC output (see Deliverable D8a). This task was not originally planned, but has allowed more comprehensive comparison and evaluation of the BIOCLIM scenarios and downscaling methods to be undertaken. This work is reported in Deliverable D10-12 (Section 3.4), to which UEA has made a greater contribution than originally planned. In view of this additional work and time and budget constraints on UEA, it was not possible to complete the proposed work on statistical downscaling. A statistical downscaling method was, however, developed by LSCE and applied to CLIMBER output in WP3 (see Deliverable D8b). Thus BIOCLIM still employs dynamical, rule-based and statistical downscaling methods as originally planned.

2. STATISTICAL DOWNSCALING: METHODS, UNDERLYING ASSUMPTIONS AND ADVANTAGES/DISADVANTAGES

In statistical downscaling, relationships between larger-scale climate variables (such as atmospheric circulation) and local surface climate variables (such as monthly or daily temperature and precipitation), derived empirically using observed data, are applied to large-scale output from GCMs in order to generate climate change scenarios. It is based on two major assumptions:

- that large-scale climate variables are more reliably simulated by climate models than local/regional variables; and,
- that the relationships between the large-scale and regional/local scale variables remain valid in a changed climate (i.e., the assumption of stationarity).

The major advantages and disadvantages of statistical downscaling (Goodess *et al*., 2001; 2003; 2004) are summarised in Table 1.

Table 1: Summary of the advantages and disadvantages of statistical downscaling. + = advantage, - = disadvantage, ? = advantage/disadvantage of the method is uncertain.

+	Provides station/point values
+	Less computer intensive than dynamical downscaling
+	Can be applied to GCM and/or RCM output
-	Assumes that predictor/predictand relationships will be unchanged in the future (the stationarity issue)
-	Requires long/reliable observed data series
-	Affected by biases in the underlying GCM
-	Tends to perform less well for precipitation than temperature
?	May be possible to 'correct' predictors for systematic model biases
?	Scenarios may indicate changes which differ substantially in magnitude, and even in direction, from those based directly on model output
?	Ideally, downscaling methods should reflect the underlying physical mechanisms and processes, but statistical downscaling is unlikely, for example, to treat convective rainfall events in a physically realistic way
?	Sensitive to specific methodology, choice of predictor variables, etc.

A number of principles and criteria for reliable statistical downscaling can be identified (Goodess, 2000):

- reliable/appropriate observational data sets must be available for the predictor(s) and predictand;
- the predictor(s) must be readily available from GCM output;
- the predictor(s) must be reliably reproduced by GCMs;

- there must be strong predictor/predictand relationships;
- ideally, these relationships should be supported by an understanding of the underlying physical processes; and,
- the extent to which these relationships have changed in the past, and may change in the future, must be considered.

A range of statistical downscaling methods has been developed in recent years (see reviews by: Hewitson and Crane, 1996; Wilby and Wigley, 1997; Wilby *et al*., 1998; Zorita *et al*., 1999; Wilks and Wilby, 1999; Goodess, 2000; Goodess *et al*., 2001; 2003, 2004)). These include:

- multiple regression;
- artificial neural networks;
- canonical correlation analysis;
- non-parametric models;
- studies in which circulation classifications are used to describe the large-scale climate;
- stochastic weather generators; and,
- analogue methods.

For application within BIOCLIM, where monthly temperature and precipitation (rather than information at a daily timescale and/or concerning extremes) are required, a relatively simple and robust statistical method is considered appropriate. From a review of available methods completed in BIOCLIM Year 2, it was concluded that the most appropriate were regression-based methods. The advantages and disadvantages of these (Goodess *et al., 2003, 2004)* are summarised in Table 2. However, more recent work within the STARDEX (http://www.cru.uea.ac.uk/cru/projects/stardex/) EU-funded project indicates that canonical correlation analysis (Haylock and Goodess, 2004), may be as/more appropriate.

Table 2: Summary of the advantages (+) and disadvantages (-) of regression-based downscaling methods.

+	Relatively simple and versatile method
+	A wide range of potential predictors can be used
+	Atmospheric circulation classification is not required (i.e., uses continuous rather than discrete predictors)
-	Danger of over-extrapolation in the future and of over-fitting
-	Difficult to identify the best suite of predictors for present-day and future climates

Whether regression and/or canonical correlation analysis is used, the data requirements (Section 3) and methodological steps (Section 4) are the same. And in both cases, the stationarity issue must be addressed.

The assumption of stationarity underlies all statistical downscaling methods (Table 1). Theoretically, it should be valid if all the necessary predictor variables (such as atmospheric circulation, temperature and humidity) are used and if the statistical model is appropriately structured to enable it to represent interactions and non-linearities (Goodess *et al*., 2004). In the BIOCLIM case, however, we do not have sufficiently long data series to be confident of determining the important predictors on all necessary time scales. Any BIOCLIM statistical downscaling model has to be calibrated on 20-30 years of observed data representative of the present-day (Section 3), but should also be applicable to snapshots at 67 and 178 ka AP (see Deliverable D4/5). Those simulations with no Greenland Ice Sheet (i.e., snapshots B, C and D) or more extensive ice sheets than present (i.e., snapshot F) are likely to cause particular problems with regards to stationarity. Clearly this assumption cannot be fully tested, however, analyses which would allow some exploration of this issue are proposed in Section 4.

3. BIOCLIM DATA REQUIREMENTS

The predictand and predictor data sets required to implement regression and/or canonical correlation analysis downscaling of the IPSL_CM4_D snapshot simulations have been identified. All are available from the BIOCLIM data archives - either on the Business Collaborator system or held by individual BIOCLIM partners.

For the predictands, monthly temperature and precipitation time series (ideally 30-50 year records) are required for the BIOCLIM study regions. The following time series are available:

- Central England: the Central England Temperature (CET) series (Manley, 1974; Parker *et* al., 1992 – see http://www.cru.uea.ac.uk/~mikeh/datasets/uk/cet.htm) which begins in 1659 and the England and Wales Precipitation (EWP) series (Wigley *et* al., 1984; Jones and Conway, 1997 – see http://www.cru.uea.ac.uk/~mikeh/datasets/uk/engwales.htm) which begins in 1766

- Central Spain: 19 meteorological stations from the Toledo area with monthly temperature and precipitation data (mainly 1951-2000) provided to UEA by CIEMAT

- Northeast France: monthly temperature and precipitation for Langres and Saint Dizier, 1950-2002 (purchased from Meteo-France – can only be used by UEA for BIOCLIM-related work) together with Nancy (temperature for 1951-2001 and precipitation for 1811-2000) and Luxembourg (temperature for 1878-2002 and precipitation for 1841-2000), available from the Climatic Research Unit data archives

For the predictors, two data sets are required:

- Observed – from monthly NCEP Reanalysis data (Kalnay *et* al., 1996) for 1958 onwards (available from http://www.cru.uea.ac.uk/cru/data/ncep/), for calibration/validation; and,

- Simulated by IPSL_CM4_D:
    - PRS control-run output for validation and to provide a baseline for the future changes;
    - Output from snapshots A-F for scenario construction and analysis of stationarity (see Section 4); and,

- Output from the baseline simulation for the Last Glacial Maximum for analysis of stationarity (see Section 4).

From previous work in the Climatic Research Unit, a list of potential predictor variables has been identified (Table 3). The circulation-related variables (such as sea level pressure) would be required for a larger window that encompasses the main pressure centres in the North Atlantic. For other variables, particularly the surface variables, a smaller window covering the BIOCLIM study regions should be sufficient. The largest window that is required is estimated to be 20N to 80N by 60W to 60E. Before use, the NCEP-based predictor variables (which have a gridded resolution of 2 x 2 degrees) should be interpolated to the same grid as IPSL_CM4_D (i.e., 4 latitudes by 5 degrees longitude) or *vice versa*.

Table 3: Potential predictor variables for statistical downscaling.

Fields	***Levels***	***Time Resolution***
Geopotential heights	1000, 850, 700, 500, 300, 200 hPa	Monthly
Relative humidity	1000, 850, 700, 500, 300, 200 hPa	Monthly
Geostrophic wind (u,v)	1000, 850, 700, 500, 300, 200 hPa	Monthly
Geostrophic vorticity	1000, 850, 700, 500, 300, 200 hPa	Monthly
Temperature	1000, 850, 700, 500, 300, 200 hPa	Monthly
Mean sea level pressure	Surface	Monthly
Surface temperature (max/min/mean)	2m	Monthly
Sea surface temperature	Surface	Monthly
Total precipitation	Surface	Monthly
Surface relative humidity (max/min)	2m	Monthly
Surface wind (u,v)	10m	Monthly

4. METHODOLOGICAL STEPS

Implementation of statistical downscaling (whether based on regression or canonical correlation analysis) within the BIOCLIM hierarchical strategy would require seven methodological steps which are listed below.

1. Evaluation of the ability of IPSL_CM4_D to simulate present-day surface climate:
   - To demonstrate the need for downscaling
   - To provide a benchmark for evaluating the added value/skill of downscaling
2. Identification of appropriate predictors:
   - Using monthly NCEP Reanalysis data
   - Stepwise multiple regression, correlation analysis and principal component analysis are useful tools for this step

- Using potential predictors from Table 3 together with derived indices, e.g., pressure indices, vorticity, strength of flow

3. Calibration and validation of the downscaling model(s) using observed predictors

4. Evaluation of the ability of IPSL_CM4_D to reproduce the predictors for the present day

5. Validation of the downscaling model(s) using IPSL_CM4_D simulated predictors

6. Investigation of stationarity:

    - To what extent is it possible to apply relationships between the present-day large-scale and regional/local climate to the relatively extreme conditions of the WP2 snapshot simulations? Two analyses can be used to investigate this question:

        - An analysis of predictor/predictand relationships in simulations for past, present and future time slices (do these change in the future)?; and,

        - An assessment of the magnitude of projected changes in the predictor variables for past and future timeslices, and comparison with the range of present-day inter-annual variability (are the projected changes large enough to take us outside the range of present-day variability?).

7. Application of the final downscaling model(s) to appropriate BIOCLIM simulations

At Step 6, it would also be appropriate to look at predictor/predictand relationships and the magnitude of predictand changes in the IPSL_CM4_D baseline simulation for the Last Glacial Maximum (see Deliverable D4/5).

5. CONCLUDING REMARKS

Although modifications to the work originally proposed mean that it has not been possible to apply statistical downscaling methods to the IPSL_CM4_D simulations from WP2, appropriate methods and data sets have been identified and are documented here. Thus, it would be possible to complete this work at a later stage.

In the meantime, BIOCLIM has successfully implemented dynamical (in WP2 – see Deliverable D6a), rule-based (in WP2 and WP3 – see Deliverable D8a) and statistical (in WP3 – see Deliverable D8b) downscaling. Within the BIOCLIM context, the IPSL_CM4_D simulations can themselves be considered as dynamical downscaling (from the coarser resolution LLN 2D NH simulations). All four downscaling methodologies are summarized, evaluated and inter-compared in Section 3.4 of Deliverable D10-12.

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BIOCLIM deliverables cited in Technical Note D6b:

D4/5: Global Climatic Characteristics, Including Vegetation and Seasonal Cycles Over Europe, for Snapshots Over the Next 200,000 Years

D6a: Regional Climate Characteristics for the European Region at Specific Sites: The Dynamical Downscaling.
D8a: Development of the Rule-based Downscaling Methodology for BIOCLIM Workpackage 3.
D8b: Development of the Physical/Statistical Downscaling Methodology and Application to Climate Model CLIMBER for BIOCLIM Work Package 3.
D10-12: Development and Application of a Methodology for Taking Climate-Driven Environmental Change into Account in Performance Assessments.