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Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal

EC-CONTRACT : FIKW-CT-2000-00024

Deliverable D8a :

Development of the rule-based downscaling methodology for BIOCLIM Workpackage 3.

Work package 3: Simulation of the future evolution of the biosphere system using the hierarchical strategy

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 will consolidate the needs of the European agencies of the consortium and summarise how environmental change has been treated to date in performance assessments.

Work packages 2 and 3 will 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 will explore and evaluate the potential effects of climate change on the nature of the biosphere systems.

Work package 5 will disseminate 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, which are listed below.

- Agence Nationale pour la Gestion des Déchets Radioactifs (Andra), France – **J. Brulhet, D.Texier**
- Commissariat à l'Energie Atomique/ Laboratoire des Sciences du Climat et de l'Environnement (CEA/LSCE) France – **N. de Noblet, D. Paillard, D.Lunt, P.Marbaix, M. Kageyama**
- United Kingdom Nirex Limited (NIREX), UK – **P. Degnan**
- Gesellschaft für Anlagen und Reaktorsicherheit mbH (GRS), Germany – **A. Becker**
- Empresa Nacional de Residuos Radioactivos S.A. (ENRESA), Spain – **A. Cortés**
- Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT), Spain – **A. Aguero, L. Lomba, P. Pinedo, F. Recreo, C. Ruiz,**
- Universidad Politecnica de Madrid Escuela Tecnica Superior de Ingenieros de Minas (UPM-ETSIMM), Spain – **M. Lucini , J.E. Ortiz, T. Torres**
- Nuclear Research Institute Rez, plc - Ustav jaderneho vyzkumu Rez a.s. (NRI), **Czech Republic – A. Laciok**
- Université catholique de Louvain/ Institut d'Astronomie et de Géophysique Georges Lemaître (UCL/ASTR), Belgium – **A. Berger, M.F. Loutre**
- The Environment Agency of England and Wales (EA), UK - **R. Yearsley, N. Reynard**
- University of East Anglia (UEA), UK – **C. Goodess, J. Palutikof**

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For this report, deliverable D8a of the BIOCLIM project, the main contributors are UEA and Mike Thorne and Associates Limited (subcontractor to NIREX). Public should be aware that BIOCLIM material is working material.

Acknowledgements:

David Lister of the Climatic Research Unit is thanked for compiling the analogue station lists, producing maps showing station locations and providing climate normals to BIOCLIM participants. Marie-France Loutre (UCL/ASTR) is thanked for providing the MoBidiC and LLN 2-D NH output.

Content List

1. Introduction and objectives

One of the tasks of BIOCLIM WP3 was to develop a rule-based approach for downscaling from the MoBidiC model of intermediate complexity (see Ref.1) in order to provide consistent estimates of monthly temperature and precipitation for the specific regions of interest to BIOCLIM (Central Spain, Central England and Northeast France, together with Germany and the Czech Republic). Such an approach has been developed and used in a previous study funded by Nirex to downscale output from an earlier version of this climate model covering the Northern Hemisphere only, LLN 2-D NH, to Central England, and evaluated using palaeoclimate proxy data and General Circulation Model (GCM) output for this region. This previous study [Ref.2] provides the starting point for the BIOCLIM work.

A statistical downscaling methodology has been developed by Philippe Marbaix of CEA/LSCE for use with the second climate model of intermediate complexity used in BIOCLIM – CLIMBER-GREMLINS (see Ref.1). This statistical methodology is described in Deliverable D8b [Ref.3]. Inter-comparisons of all the downscaling methodologies used in BIOCLIM (including the dynamical methods applied in WP2 – see Ref.4 and Ref.5) are discussed in Deliverable D10-12 [Ref.6].

The rule-based methodology assigns climate states or classes to a point on the time continuum of a region according to a combination of simple threshold values which can be determined from the coarse scale climate model. Once climate states or classes have been defined, monthly temperature and precipitation climatologies are constructed using analogue stations identified from a data base of present-day climate observations. The most appropriate climate classification for BIOCLIM purposes is the Køppen/Trewartha scheme (Ref.7 ; see Appendix 1). This scheme has the advantage of being empirical, but only requires monthly averages of temperature and precipitation as input variables.

The rule-based downscaling procedure developed for BIOCLIM entails the following eight steps:

1. Development of regional climatic sequences and indices for the last climatic cycle including Køppen/Trewartha climate classes
2. Identification of relationships between climate states and Køppen/Trewartha climate classes
3. Identification of appropriate analogue stations to describe each climate class
4. Manipulation of analogue station data into appropriate formats for presentation of results and input to performance assessments
5. Selection of appropriate MoBidiC simulations and variables for the identification of downscaling rules/thresholds
6. Identification of objective rules/thresholds for defining climate classes in MoBidiC and LLN 2-D NH output
7. Evaluation of the rule-based downscaling methodology for the last climatic cycle
8. Application of the rule-based downscaling methodology to MoBidiC and LLN 2-D NH output for future time periods

The methodology uses both climate states (e.g., periglacial, glacial) and climate classes (e.g., Køppen/Trewartha subarctic continental (EC) and tundra (FT)). The use of climate states in performance assessment is discussed in Section 4 of Deliverable D10-12 [Ref.6]. The key paragraph is:

"In some safety assessments, possible future climate sequences have been generated based on a number of discrete climate states, for example, temperate, boreal, periglacial and glacial. Use of discrete climate states is one of the simplifications adopted to represent long-term biosphere change in safety assessments of radioactive waste disposal facilities. Discrete climate states can be defined based on data from the historical record, from pollen and ice core studies and from information from existing analogue sites where the climate conditions are considered likely to be similar to a future state at a particular repository site. Use of climate analogues often provides a useful means of gathering relevant information on, for example, vegetation patterns, meteorological data and human activities to fulfil modelling data requirements. Evidence from the past climate record may also be used to define, and possibly justify, selection of future climate change sequences for safety assessments."

The use of climate classes is preferred as the basis of the downscaling methodology because they can be empirically defined using monthly temperature and precipitation values.

Section 2 of this deliverable (D8a) outline how each of the eight methodological steps have been undertaken for each of the three main BIOCLIM study regions (Central England, Northeast France and Central Spain) using MoBidiC output.

The original rule-based downscaling methodology [Ref.2] has been modified in order to be as objective and quantitative as possible. However, some of the steps still inevitably involve subjective judgement and qualitative analysis. Thus, in order to provide complete traceability and detailed guidance for implementation of the methodology in other regions, the detailed region-specific work involved at Steps 1, 3 and 4 is reported in appendices to this deliverable or in BIOCLIM technical notes (which are also relevant to the work undertaken in Workpackage 4). Many of these appendices and technical notes were initially produced in the form of external memoranda circulated to BIOCLIM participants during the course of the project HYPERLINK. The rule-based downscaling methodology developed here is based on an earlier study for Central England [Ref.2]. Thus, development initially focused on Central England, with similar work then undertaken for the other two regions (drawing on the expertise of the French and Spanish country teams and modifying the analyses as appropriate to reflect inter-regional climatic variations). Thus, the Central England work tends to be reported in somewhat greater detail.

According to the BIOCLIM proposal, it was intended to apply the rule-based downscaling methodology to MoBidiC output only. However, after completion of Step 5: Identification of appropriate MoBidiC simulations and variables for the identification of downscaling rules/thresholds (see Section 2.5), it became clear that the methodology could also be applied to the BIOCLIM simulations for the next one Million years (Myr) performed with LLN 2-D NH (described in Deliverable D3). The application of the downscaling methodology to these simulations is outlined in Section 3.

Finally, Section 4 provides a summary and conclusions of the rule-based downscaling methodology.

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2. The eight steps required to develop and apply the rule-based downscaling methodology

2.1. - Step 1: Development of regional climatic sequences and indices for the last climatic cycle including Køppen/Trewartha climate classes

The first step is to develop regional sequences of Køppen/Trewartha climate classes (see Appendix 1) for the last climatic cycle (i.e., the last ~125 kyr). It is assumed that these sequences and classifications are applicable to an approximate 400 km x 400 km study region in each country of interest.

The starting point for developing these sequences was the tables constructed for each study region as part of Deliverable D2 (Consolidation of Needs of the European Waste Management Agencies and the Regulator of the Consortium, Ref.8). The relevant tables are:

- Central England: Table 5-4
- Northeast France: Tables 3-1 and 3-2
- Central Spain: Table 4-5

They are reproduced here in Appendix 2. The tables outline the basis for the classification. That for Central England includes a list of supporting references. Each country research group reviewed these initial classifications to check if they were appropriate, at the two letter level of the Køppen/Trewartha classification (see Appendix 1), to their region of interest and modified them as necessary in order to construct the final classification (providing, where possible, information on the certainty/uncertainty of the underlying data/classification). Køppen/Trewartha is the preferred climate classification system for the rule-based downscaling (see Section 1), although the Walter zonobiome classification [Ref.9] has also been used or Central Spain (see Ref.8, Table 4.5 and Section 4.6).

For Central England, the initial classification was considered appropriate after review, with the exception of the periods 22-38 ka BP and 41-77 ka BP. A revised classification for these periods was developed by members of the UK country team (i.e., Mike Thorne in consultation with Paul Degnan and Clare Goodess) using SPECMAP oxygen isotope ratios, as described in Appendix 3.

The initial classification for Northeast France was reviewed by Mike Thorne (in consultation with Jacques Brulhet and Delphine Texier from the French country team and Paul Degnan and Clare Goodess from the UK team) in order to ensure a consistent approach to that used for Central England (see Appendix 3). The final sequences for the two regions are summarised in Table 1. Less certain attributes of the classification (i.e. for the period 41-76 ka BP) are identified in the table by the use of red italics. There are also a number of periods when the palaeodata supporting the classification cannot be used to assign a unique class, which may be a reflection of climatic variability. Thus, two classes are considered equally plausible for 28-41 ka BP (EC or FT), 41-60 ka BP, 70-76 ka BP and 85-95 ka BP (EO or EC) in the English classification and 76-85 ka BP (DC or

EO), 85-95 ka BP (EC or FT) and 95-105 ka BP (DC or EO) in the French classification.

Although the final sequences for these two regions are chronologically correlated, this assumption was not made at the start of the analysis, but emerged naturally from the data (Appendix 3). The rules and thresholds used to define the climate classes using climate model output (see Section 2.6), are different for each region. Thus, there is no presumption of chronological correlation in future climate sequences.

The initial climate classification for Central Spain (which is based on palaeodata from Southern Spain) was reviewed by the Spanish country team and a substantially modified classification produced [Ref.10]. The same age divisions and names are used in both schemes, but revised estimates of mean annual temperature and precipitation are given. The main difference is in the Køppen/Trewartha climate classes used. The original scheme used the Aw, Cs, Cr, BSk, DO, DC, EO, EC and FT classes (Table 4.5, Ref.8, reproduced here in Appendix 2), whereas the revised scheme uses the Csa, Csb, BSk, BWk and FT classes (Table 3.1 from Ref.10 reproduced here as Table 2). The English and French sequences (Table 1) employ the two-letter level of the Køppen-Trewartha classification scheme. It is, however, considered appropriate to use three letters for Spain (the third letter is determined from mean annual temperature classified using the Universal Thermal Scale – see Appendix 1), in order to distinguish between the dry and 'cool' (BWk or BSk) conditions experienced over the last climatic cycle and the dry and 'very hot' conditions (BWh or BSh) likely to be experienced during a period of enhanced greenhouse warming, and between subtropical hot (Csa) and subtropical warm (Csb) conditions.

The main uncertainty in the revised Spanish classification (Table 2) concerns the dating of the Younger Dryas, Bölling-Alleröd Interstadial, Late-glacial and end of the Oldest Dryas (i.e., ~ 10-13 ka BP). Following further advice received from the Spanish BIOCLIM team (Recreo, personal communication), this period has been divided into two sub-periods classified as Csb and BSk (Table 3). OIS 5c, 96-104 ka BP is subdivided into four sub-periods, although dates are not given (Table 2). A climate model such as MoBidiC with a 500 year time step, forced by orbitally-driven insolation changes and CO2, is not, however, likely to be able to reproduce events such as St. Germain Ia to Ic. St. Germain Ib and Ic could be considered as a single period classified as Csb, whereas Ia is distinguished by BSk conditions. However, it is not possible, at the present time, to assign a date to these events. Thus, for the purposes of developing and quantitatively evaluating the rule-based downscaling methodology, the Csb, BSk and Csa climate classes have to be considered equally possible during the period 96-104 ka BP (Table 3). Similarly, the BSk and FT climate classes are considered equally possible during the Final Würm period (15.2-19.8 ka BP). Finally, it is noted that the Spanish classification starts at OIS 5c, i.e., at 104 ka BP, whereas the French and English classifications start at 127 ka BP, thus encompassing OIS 5d and 5e.

The climate indices for the three regions are plotted in Figures 1 to 3.

Period (ka BP)	**Central England**	**Northeast France**
0-10	DO	DO
10-11	EC	EC
11-13	DC	DC
13-18	FT	FT
18-28	FT	FT
28-32	EC/FT	EC
32-41	EC/FT	FT
41-51	*EO/EC*	*FT*
51-60	*EO/EC*	*EC*
60-70	*FT*	*EC*
70-76	*EO/EC*	*FT*
76-85	EO	DC/EO
85-95	EO/EC	EC/FT
95-105	EO	DC/EO
105-117	EC	EC
117-127	DO	DO

Table 1: *Summary of the climatic sequences for Central England and Northeast France. Less certain attributions are shown in blue italics. See Appendix 1 for definitions of the climate classes.*

Calendar Age (Ka BP)	OIS	Name used	Mean annual Precipitation (mm)	Köppen-Trewartha Climate Class	Mean annual Temperature Tm (°C)	
					Best Estimate	Uncertainty
0-5.4	1	Subboreal	<600-1000	Csa	17	±3
5.4-6.3	1	Atlantic	600-1000	Csa	18	±1
6.3-7.9	1	Boreal/Atlantic	-	Csa	17	±3
7.9-8.2	1	Boreal	600-1000	Csa	15	±4
8.2-10.3	1	Preboreal/Boreal	350-600	Csb	14	±3
10.3 or 10.0-11 or 10.7	1or2	Younger Dryas	<350	BSk	6	±2
11.0 or 10.7-13.3 or 12	2	Bølling-Allerød Interstadial Late-glacial	200-600 to 600-1000	Csb	12	±5
13.3 or 12.8-15.2	2	Oldest Dryas	<450	BSk	8	±5
15.2-19.8	2	Final Würm	350 to <200	BSk - FT	3 or less	±5
19.8-23.6	2	Middle Würm/ Final Würm	350 to <200	BSk	4	±4
24-38	3	Middle Würm	600-200	BSk	9	±5
>38	3		-	BWk	5°C to 11°C (M. Garcin, 1994)	-
<63.5	4	Eowürm	<200	BWk	6	±2
>63.5-84	5a	St. Germain II	>200 to 650-1000	Csa	15	±2
84-96	5b	Mélisey II	<450	BSk	10	±3
96-104	5c	St. Germain Ic	650-1000	Csb	13	±4
	5c	St. Germain Ib	650-1000	Csb	14	±3
	5c	St. Germain Ia	200-350	BSk	11	±3
	5c	-	350-650	Csa	17	±2

Table 2: *Climate classes identified in the palaeoclimate record of Padul, Central Spain (Table 3.1. from Ref.10). See Appendix 1 for definitions of the climate classes.*

Period (ka BP)	Central Spain
0-8.2	Csa
8.2-10	Csb
10.-11	*BSk*
11-13.3	*Csb*
13.3-15.2	BSk
15.2-19.8	BSk/FT
19.8-38	BSk
38-63.5	BWk
63.5-84	Csa
84-96	BSk
96-104	*Csb/Csa/BSk*

Table 3: *Summary of the climatic sequence for Central Spain. Less certain attributions are shown in blue italics. See Appendix 1 for definitions of the climate classes.*

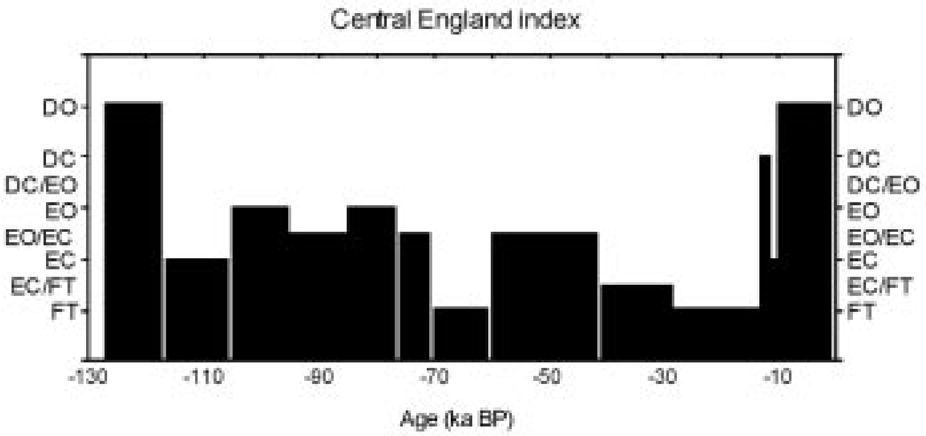

Figure 1: *Climate index for Central England showing the succession of climate classes over the last climatic cycle.*

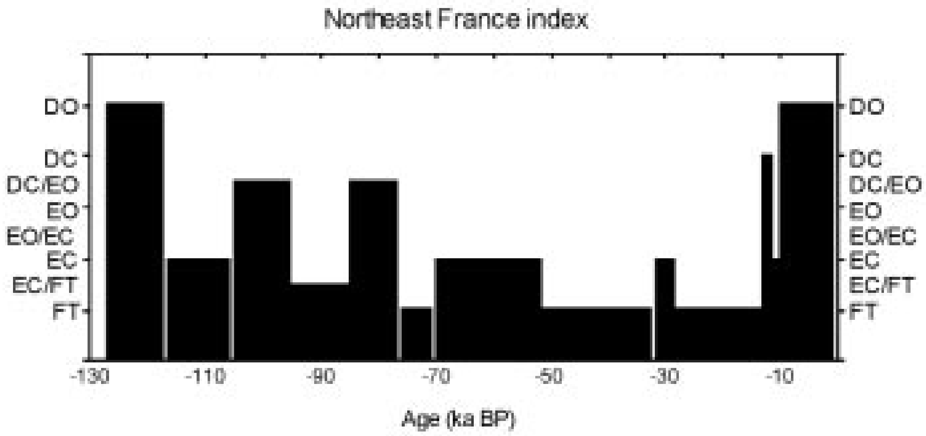

Figure 2: *Climate index for Northeast France showing the succession of climate classes over the last climatic cycle.*

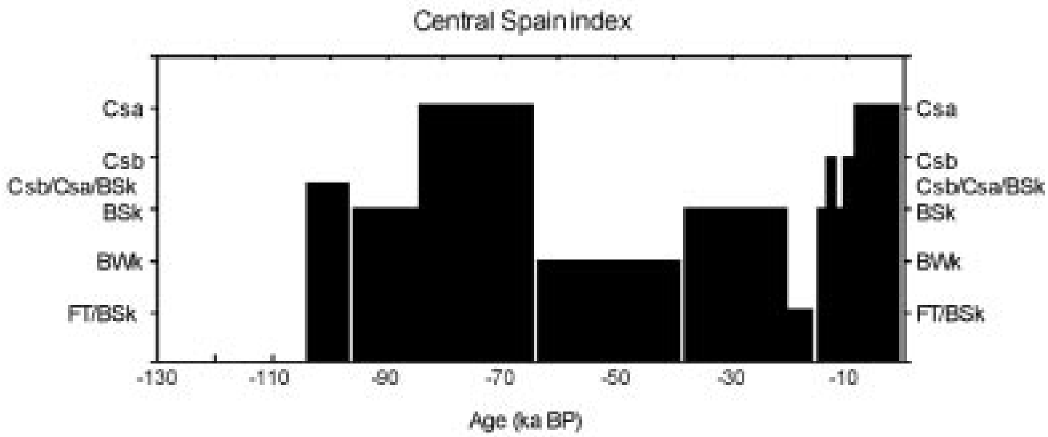

Figure 3: *Climate index for Central Spain showing the succession of climate classes over the last climatic cycle.*

2.2. - Step 2: Identification of relationships between climate states and Køppen/Trewartha climate classes

Although climate classes rather than climate states are preferred as the basis of the downscaling method, because they provide a common empirical framework, the latter may still be used for some performance assessment purposes (see Ref.6). Thus, Step 2 is to identify those climate states which may be used for performance assessment in each region and relationships with the climate classes.

Deliverable D2 proposes the use of the following climate states for the last climatic cycle:

Central England (see Table 5-6, Ref.8):

- temperate
- boreal
- periglacial
- glacial

Northeast France (see Table 3-3, Ref.8):

- temperate
- boreal
- periglacial

Central Spain (see Table 4-6, Ref.8):

- interglacial
- interstadial
- stadial
- glacial

The climate state approach to performance assessment was originally developed for the UK, where there is reasonable correspondence between the regional and global climate states, i.e., those defined from global palaeoclimate records such as the SPECMAP ice volume record [Ref.11]. The schemes presented in Deliverable D2 (see above) indicate that somewhat different approaches were taken by each of the three country teams. For Central Spain and Central England, global states were used (i.e., the full interglacial-glacial range, but with different underlying climate descriptions – see Table 4), whereas for Northeast France, only those global states which had occurred regionally were used. These different approaches reflect real climate differences between the three study regions, e.g., the spatial extent of ice sheets. The glacial state is not used for Northeast France, for example, because ice sheets did not reach this region during the last climatic cycle.

The empirically-based climate classes allow direct comparison of the different climate state definitions used in each region. Having identified the appropriate climate classes (see Section 2.1) and the climate states used in each region (see above), relationships can be identified between the classes and states. Table 4 shows the climate states and classes that are used to describe the last climatic cycle in each region.

The rule-based downscaling method is designed to be applied to MoBidiC simulations which incorporate anthropogenic greenhouse gas forcing scenarios (see Sections 2.5 and 2.8), thus an enhanced greenhouse gas warming state is also used. Two climate classes are used to describe this state in each region, with the second class reflecting more extreme warming (Table 4). These two classes were selected based on examination of MoBidiC output and general circulation and regional climate model simulations undertaken for the Intergovernmental Panel on Climate Change Third Assessment Report [Ref.12] and the UKCIP02 climate scenarios report [Ref.13]. The Cw (summer rain) subtropical class is not used because climate model simulations indicate drier rather than wetter summers and wetter winters in the study regions, thus it is considered unlikely that summer rainfall will exceed winter rainfall during an enhance greenhouse warming state.

	Northeast France	Central Spain	Central England
Temperate	DO (DC)		DO (DC)
Interglacial		Csa	
Boreal	EO		EO
Interstadial		Csb	
Periglacial	EC		EC, less extreme FT
Stadial		BSk	
Glacial		BSk/BWk/FT	FT
Enhanced warming	Cr Cs	BSh BWh	Cr Cs

Table 3: *Relationships between climate states and climate classes for the three study regions.*

2.3. - Step 2: Identification of relationships between climate states and Køppen/Trewartha climate classes

Within the BIOCLIM context, analogue stations are defined as present-day geographical (i.e., spatial) analogues. The present-day climate characteristics of place B are used to describe the climate characteristics of place A at some time in the past or future, hence B is the analogue for A (e.g., Godthaab in Greenland is a potential analogue station for Central England during any past/future period which is classified as having an FT, tundra, climate). Selection of the analogue stations is based on their Køppen/Trewartha classification. This is primarily temperature-based (Appendix 1), but additional consideration has been given to the precipitation characteristics of potential analogue stations.

Initially, UEA compiled lists of all potential Northern Hemisphere analogue stations that are available in the Climatic Research Unit archives. These lists (available on the BIOCLIM Business Collaborator system, together with maps showing station locations) indicate the Køppen/Trewartha class (at the four-letter level – see Appendix 1) for each station, together with the variables (temperature and precipitation) that are available and for what time period. The data that could be made available to BIOCLIM participants is also indicated (i.e., monthly means and standard deviations only, climate normals (long-term averages, usually for the period 1961-1990), or monthly time series). Stations whose elevation falls between 400 and 2499 m are flagged, while stations at elevations greater than 2500 m are not included. For some classes (i.e., Cr, Cs, DO, DC and EO), sufficient stations are available in the 'greater' European region (i.e., a region extending from Iceland in the northwest to Turkey in the southeast). For other classes, all Northern Hemisphere stations are listed. The number of potential analogue stations available for each region is listed in Table 5.

In the original Rudloff [Ref.7] classification scheme, temperature and precipitation values for stations at elevations above 500 m are ‘corrected’ to sea level. It was not considered appropriate to apply such a ‘correction’ for the purposes of the BIOCLIM project. Thus, stations between 500 and 2500 m were processed in exactly the same way as those below 500 m. Stations above 2500 m were not processed.

It should be noted that there are a few ‘grey’ areas within the rules of classification as set out by Rudloff [Ref.7]. There is another possible sub-division for the ‘dry’ stations, i.e., BM (humid coastal desert). It would take substantial further analysis to identify this subset and hence this has not been undertaken. Another potential discrepancy concerns the sub-division of temperate climate stations. Rudloff states that ‘inner continental regions’ can be identified as a subset of the DC class. However, no precise rules are given for this sub-division and hence it cannot be implemented here.

Having identified a generic set of analogue stations for each climate class, each country team then selected the most appropriate analogues for their region of interest. This was completed for Central England initially (by Mike Thorne in consultation with Clare Goodess) in two stages. First (see Appendix 4), a set of 76 potential analogues was identified on the basis of information available from the station listings on the BIOCLIM Business Collaborator system (i.e., altitude, length of record, latitude/longitude and the warmth of summer and cold of winter as indicated by the third and fourth letters of the Køppen/Trewartha class (see Appendix 1) and regional palaeodata (summarised in Ref.8).

The following two general rules were used to make this first selection for Central England (see Appendix 4 for details):

- Altitude 0 to 200 m; and,
- Complete record for 1961-90 and time series spanning an interval of at least 50 years.

The class specific rules used for Central England are summarized in Table 6.

Following this first stage, the climate characteristics of these 76 stations were explored in more detail using the climate normals provided by UEA (i.e., long-term monthly temperature and precipitation averages). As a result of this second stage (described in full in Appendix 5), seven stations were identified as unsuitable analogues. Two stations from the Azores, for example, were considered unsuitable as Cr analogues because of their hyperoceanic conditions, and Bodo and Orland in Norway were considered unsuitable as DC analogues because of heavy winter precipitation that might be more representative of western than Central Britain. Thus a total of 69 analogue stations was identified for Central England (Appendix 5).

A similar two-stage procedure was used by Delphine Texier of the French country team, under guidance from Mike Thorne and Clare Goodess, to select analogue stations for Northeast France. The stations selected at the end of the procedure are listed in Appendix 6. For this region, slightly more continental stations were selected than for Central England. In the case of the FT climate class, for example, the stations selected at the first stage included two FTkd stations, i.e., stations with ‘cool’ summers and ‘severely cold’ winters, whereas stations with ‘cold’ or ‘very cold’ winters only were used for Central England. All FT analogue stations have ‘cool’ summers, thus it was not possible to specify more continental conditions, i.e., warmer summers, for the French analogue stations. For the climate classes corresponding to the temperate and enhanced warming states (see Section 2.2), slightly warmer stations were selected for Northeast France. All the DO French analogue stations, for example, have ‘warm’ summers and ‘cool’ winters (DObk), whereas only two of the 10 DO stations selected for Central England are DObk, the rest having ‘mild’ rather than ‘warm’ summers (DOlk). These differences are reflected in the Cr and Cs analogue stations selected for the two regions. All the French Cs analogue stations, for example, have ‘hot’ summers and ‘mild’ winters (Csral), whereas some of the Cs stations selected for Central England have ‘warm’ summers and/or ‘cool’ winters.

The procedure developed for selecting appropriate analogue stations for Central England provided useful guidance for the other study regions, particularly Northeast France. It is, however, important that the actual selection was done by the country teams so that appropriate regionally-specific qualitative and quantitative criteria and judgements could be included. This was particularly important for Central Spain, as the climate classification for this region is quite distinct to those of Central England and Northeast France (see Section 2.1). The use of a somewhat different analogue station selection procedure was also considered appropriate because of the broad range of climate classes experienced across the Iberian Peninsula. As for Central England and Northeast France, however, climate normals were again used to inform the process.

The preliminary identification of potential analogue stations for Central Spain over the last climatic cycle is described by Lomba *et al.* [Ref.10]. The following climate classes occur across the Iberian Peninsula at the present day: BW (in a limited area of the Almería province in the extreme southeast corner of Spain), BS, Cs, Cr, DO and DC. The As climate class occurs to a limited extent in the Canary Islands. Thus, it was concluded that appropriate analogues for the climate classes identified in Deliverable D2 as having been experienced over the last climatic cycle were provided by 69 Iberian and Canary Island stations available to the Spanish team. A further 28 stations were identified from the Climatic Research Unit archives as potential BSk and BWk analogues. All these analogue stations are evaluated by Lomba *et al.*, [Ref.10], focusing on those classes that occur in the revised sequence of the last climatic cycle, i.e., Csa, Csb, BWk and BSk (see Section 2.1, Tables 2 and 3).

The preliminary identification of potential enhanced warming analogue stations for Central Spain is described by Lomba *et al.,* [Ref.14]. BWh, BSh and As analogues were identified from the Climatic Research Unit archives. Although As analogues were identified, Lomba *et al.* [Ref.14] do not consider that this class will occur in the future – a view supported by the rule-based downscaling scheme (see Sections 2.6 and 2.8). Following review by Clare Goodess and Mike Thorne, it was suggested that a number of the potential BWk and BSk analogue stations could be eliminated on the basis of unrealistic seasonal cycles, particularly with respect to precipitation – future summers are not expected to become wetter than winters (although in a few areas of the Iberian Peninsula, summer rainfall totals are higher than winter totals). The characteristics of potential Csa, Csb, BWk and BSk analogue stations are considered further by Recreo [Ref.15], focusing on Spanish stations together with a number from other regions.

Climate class	Number of stations	Region
BS	691	Northern Hemisphere
BW	383	Northern Hemisphere
Ar	448	Northern Hemisphere
Am	127	Northern Hemisphere
Aw	448	Northern Hemisphere
As	52	Northern Hemisphere
Cr	96	“greater” Europe only
Cw	101	Northern Hemisphere
Cs	242	“greater” Europe only
DO	385	“greater” Europe only
DC	432	“greater” Europe only
EO	55	“greater” Europe only
EC	374	Northern Hemisphere
FT	106	Northern Hemisphere
FI	1	Greenland

Table 5: *Number of potential analogue stations available in the Climatic Research Unit archives.*

Climate class	Rules	Selected stations
FT	'Cool' summers and 'cold'/'very cold' winters Latitude < 67°N	FTko, FTkc
EC	'Cool'/'mild'/'warm' summers and 'cold'/'very cold' winters Latitude < 60°N	EClc, ECbc
EO	'Mild' summers and 'cool' winters Latitude < 67°N	EOlo
DC	'Cool'/'mild' summers and 'cool'/'cold' winters Longitude west of 25°E	DClo, DClk
DO	Stations from 'Lowland Britain', i.e., ±2°C of Holocene mean annual temperature	DOlk, DObk
Cr	'Mild'/'warm' summers and 'mild'/'cool' winters (oceanic climate)	Crbk, Crbl
Cs	Continuing warming, with limited continentality: 'warm'/'hot' summers and 'mild'/'cool' winters	Csak, Csbk, Csal, Csbl

Table 6: *Class specific rules for the selection of analogue stations for Central England (see Appendix 4 for details).*

2.4. - Step 4: Manipulation of analogue station data into appropriate formats for presentation of results and input to performance assessment

For some of the selected analogue stations only long-term averages (normals), generally for the period 1961-1990, of monthly temperature and precipitation are available from the Climatic Research Unit archives, whereas time series are available for other stations (see Section 2.3).

Long-term average monthly means and standard deviations are adequate for some BIOCLIM and performance assessment purposes and users (see Ref.6). Most of these long-term averages are for the period 1961-1990. Examination of seasonal temperature and precipitation cycles provided the basis, for example, of analogue data selection (see Section 2.3 and, for more details, Appendices 4 and 5; Ref.10 ; Ref.14 ; Ref.15).

Examination of the mean annual temperatures of the complete set of analogue stations selected for each region shows a relatively smooth distribution of stations, with temperature gradually increasing from the glacial/periglacial classes through to the enhanced warming classes. This is illustrated for Central England in Figure 4. Sharp divisions between climate classes are not evident, indicating a reasonable degree of variability across the analogues selected for each climate class. This is considered advantageous and helps to counter one of the potential criticisms of the methodology, i.e., that it is unrealistic to impose artificial divisions on a continuum of change. Thus although it is not possible to calculate error bars which reflect the full range of uncertainty introduced at each methodological step, probability distribution functions and box-whisker plots, for example, could be used to represent the range of variability across the analogue stations chosen to represent each climate class (i.e., the within-class variability).

Plots of mean total annual precipitation (e.g., Appendix 5) do not show a clear trend across the climate classes. This is because the individual classes are distinguished more by differences in the seasonal distribution of precipitation (Figure 5) than annual total. In the case of the English analogue stations, for example, EC stations have a precipitation maximum in summer, whereas the enhanced warming stations (Cr and Cs) have a minimum in summer (Figure 5a).

For evaluation of the methodology (see Section 2.7) and some performance assessment purposes, it may be desirable to use climate class averages and/or ranges. Class averages of the analogue stations selected for Central England and Northeast France are shown in Figures 5 and 6 for precipitation and temperature respectively. These figures indicate the importance of changes in the strength and shape of the seasonal cycle. In the case of the English and French analogue stations, for example, the seasonal temperature cycle is, by definition, much stronger for the EC class than for the EO class, and for the DC class than for the DO class (Figures 6 a, b). Analogue data for Central Spain are not shown in these Figures because the Spanish team has analysed these data is a somewhat different manner. However, various plots of the selected Spanish analogue data are included in Lomba *et al.* [Ref.14] and Appendix C of Deliverable D10-12 [ref.16.

Monthly temperature and precipitation data only are provided for the analogue stations. A review of the requirements of performance assessment by BIOCLIM participants concluded that windspeed is not required in order to produce appropriate estimates of potential evapotranspiration (PET). Instead, PET is calculated from temperature using the Thornthwaite approach to monthly estimation used in the BIOMASS project (Shaw, 1983). For each month, the calculated PET is subtracted from precipitation, to give a measure of moisture excess (see Appendix 5 and Section 3.2, Ref.6). Irrigation requirements are estimated using a simple empirical formula based on monthly temperature and precipitation (see Section 3.2, Ref.6).

Most of the BIOCLIM analyses of analogue data completed to date have used long-term monthly averages. However, preliminary analyses of time-series data have been undertaken for Central England and Germany and indicate that interannual variability may be important, particularly with respect to moisture excess and irrigation requirements (see Ref.6).

The use of the analogue data for performance assessment purposes is illustrated further and discussed in more detail in Deliverable D10-12 [Ref.6]. It is anticipated that additional re-formatting and analyses specific to the requirements of each country team will be undertaken after completion of the BIOCLIM project. Given these requirements, which may be different at different stages of the performance assessment process and for different countries, the downscaling outputs presented in this deliverable are restricted to the climate class for each time-step (see Section 2.8). The BIOCLIM country teams can then manipulate the analogue station information as required. The climate class averages shown in Figures 5 and 6, for example, provide a broad picture suitable for the development of climate and environmental narratives (see Ref.6, Section 5), whereas a single analogue station record could be used as time-series input to future, more quantitative analyses/models. This flexibility is seen as a major advantage of the rule-based downscaling methodology, the results of which provide plenty of scope for work and analysis beyond the end of the BIOCLIM project.

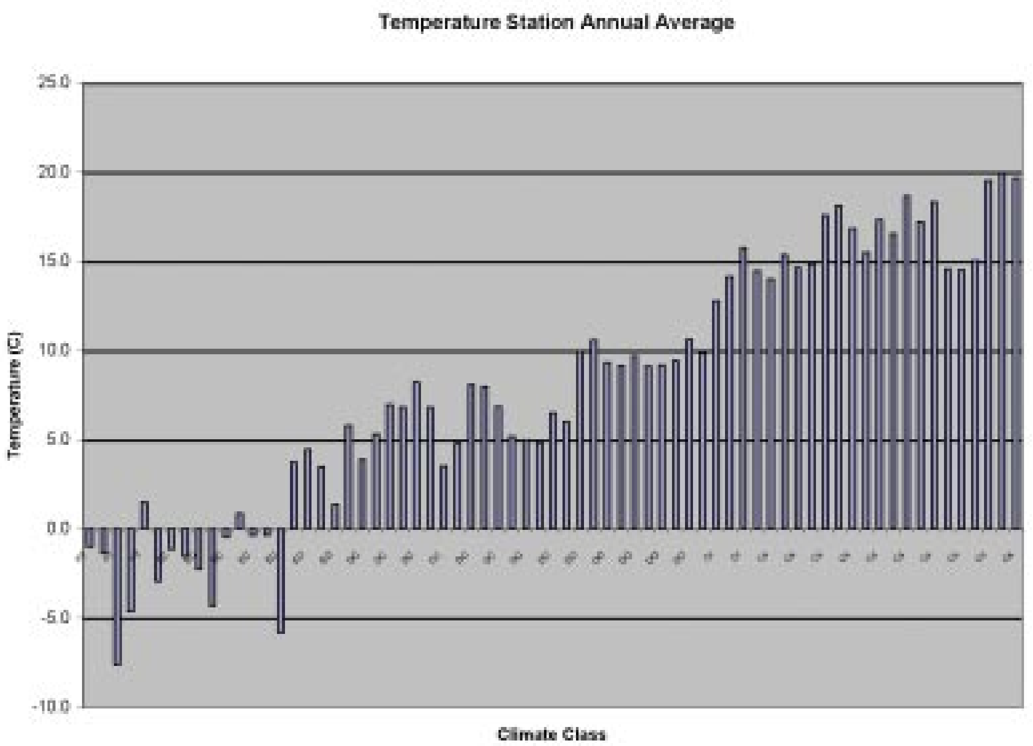

Figure 4 : *Mean annual temperature for the analogue stations selected for Central England ordered by climate class.*

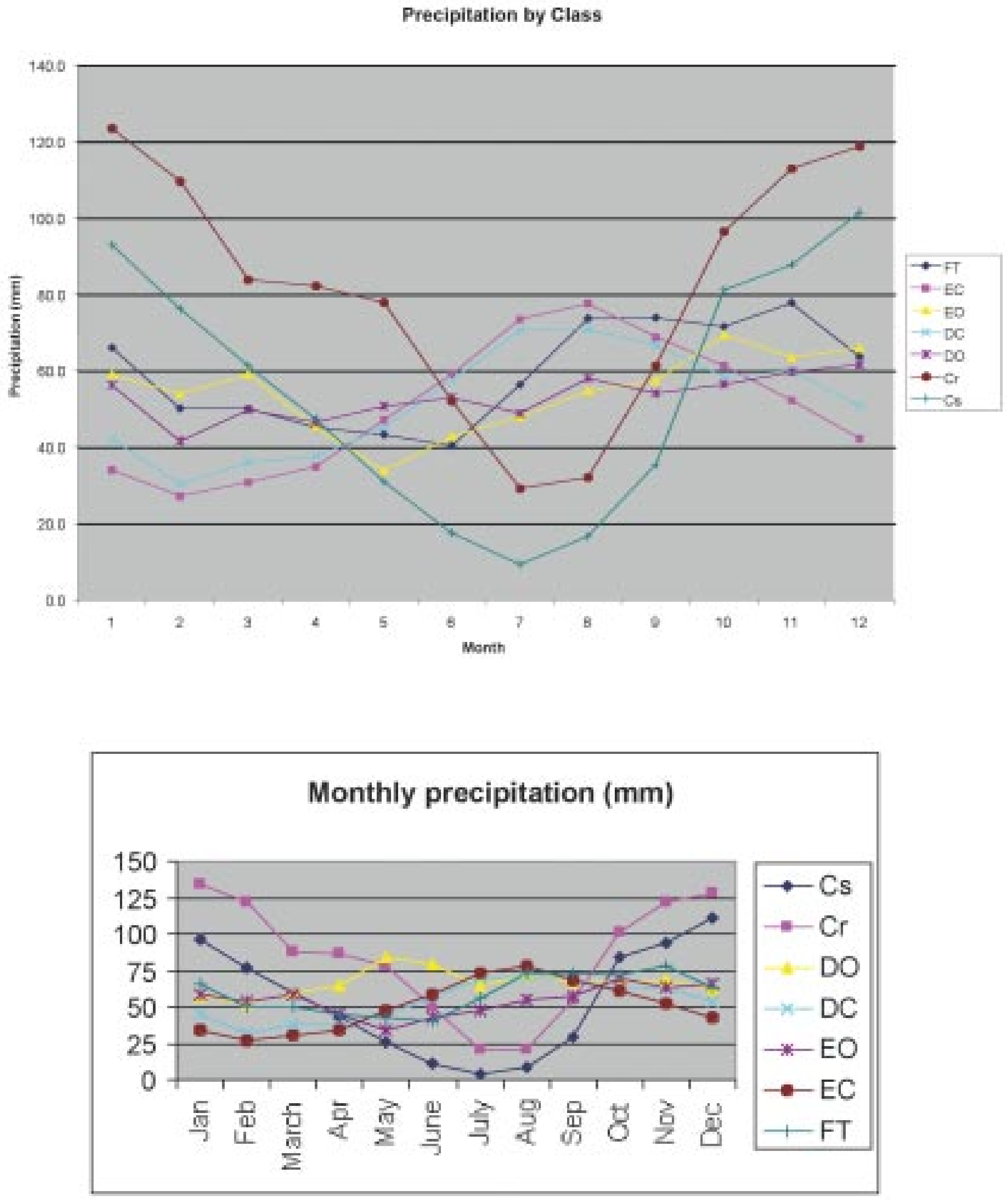

Figure 5 : *Mean monthly precipitation climate class averages for analogue stations selected for (a) Central England and (b) Northeast France.*

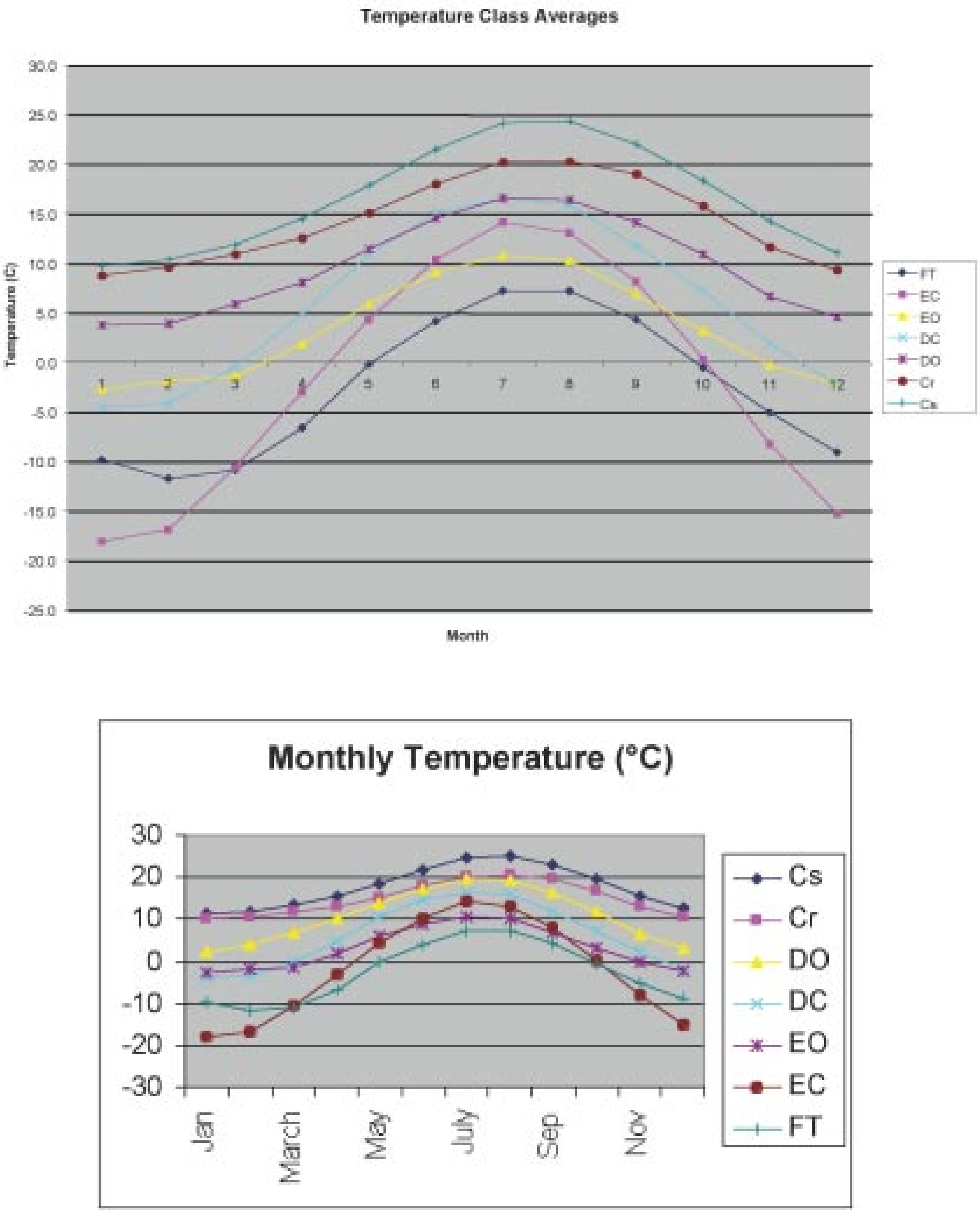

Figure 6 : *Mean monthly temperature climate class averages for analogue stations selected for (a) Central England and (b) Northeast France.*

2.5. - Step 5: Selection of appropriate MoBidiC simulations and variables for the identification of downscaling rules/thresholds

The rule-based downscaling methodology has been developed for application to output from the MoBidiC simulations of the next 200 ka carried out for BIOCLIM (described in detail in Ref.1). Output from simulations for the future incorporating anthropogenic CO_2 forcing is needed in order to identify rules and thresholds for the enhanced warming state (which did not occur over the last climatic cycle), whereas output from a simulation of the last climatic cycle is needed for the identification of downscaling rules/thresholds for all other climate classes/states.

Thus output from the following MoBidiC simulations (all of which incorporate orbital forcing) has been used to identify the downscaling rules/thresholds (described in Section 2.6):

- Transient simulation of the last glacial-interglacial cycle (see Ref.1, Section 3.2.3)
  - 126 – 0 ka BP
  - CO_2 as reconstructed from the Vostok ice core [Ref.17]
  - Ice sheets: as in LLN 2-D NH at 126 ka BP and then computed by the model

- Simulation B3 (see Ref.1, Section 4.3)
  - 0-200 ka AP
  - Anthropogenic CO_2: 'low' anthropogenic scenario B3 from Deliverable D3 (maximum anthropogenic contribution of 850 ppmv at 325 yr AP; see Ref.18, Figure 5)
  - Natural CO_2: Paillard's model B3a (see Ref.18, Figure 5)
  - Ice sheets: present-day value for the present, computed by the model for the future

- Simulation B4 (see Ref.1, Section 4.4)
  - 0-200 ka AP
  - Anthropogenic CO_2: 'high' anthropogenic scenario B4 from Deliverable D3 (maximum anthropogenic contribution of 1350 ppmv at 325 yr AP; see Ref.18, Figure 5)
  - Natural CO_2: Paillard's model B4a (see Ref.18, Figure 5)
  - Ice sheets: present-day value for the present, computed by the model for the future

Having identified the MoBidiC simulations to use, appropriate variables then had to be identified. MoBidiC is a zonally-averaged model. The energy balance of the surface is computed for each 5° latitudinal band, with a distinction between snow-free, snow-covered and ice-covered surfaces over the continents (Eurasia, Africa and America in the Northern Hemisphere) and ice-free and ice-covered surfaces over the oceans (the Atlantic, Pacific and Indian Oceans) (see Ref.1, Section 2).

For most of the thresholds between climate classes it was considered appropriate to use the most regionally-specific information available from MoBidiC, i.e., sectoral averages: 50-55°N for Central England and Northeast France and 35-45°N for Central Spain. Zonally-averaged precipitation in MoBidiC is computed from zonally-averaged evaporation and the vertically integrated water vapour meridional transport and then distributed over the continents and oceans using ratios derived from present-day statistics, with some corrections over the ice sheets [Ref.19 ; Ref.20]. Temperature is considered to be more reliably simulated than precipitation. Confidence in the temperature palaeodata underlying the sequences of the last climatic cycle (see Section 2.1) is also higher than for precipitation and the Køppen/Trewartha classification is primarily temperature based (see Appendix 1). Thus, there are a number of reasons why it was decided to use temperature as the basis of the rules/thresholds.

MoBidiC has a single Eurasian continental sector with no longitudinal variability. This large continental sector is unlikely to be fully representative of western Europe where the BIOCLIM case-study regions are located.

Thus, initially it was proposed to use temperature averaged across the Eurasian continental and Atlantic oceanic sectors for Central England and Northeast France. However, abrupt temperature events occur at 100 and 10 ka BP in the high northern latitudes of the Atlantic Ocean in the transient simulation of the last glacial-interglacial cycle which are also evident in Atlantic ocean sector temperature at 50-55°N (see Ref.1, Section 3.2.3). These events are considered to be comparable to the Younger Dryas. However, there are discrepancies in the timing and magnitude of the 10 ka BP MoBidiC event and the palaeoclimate record for the Younger Dryas, so use of a model output that emphasised this simulated event gave poorer agreement with the palaeoclimatic record than model output that de-emphasised it. Thus, it was decided to use Eurasian continental sector temperature for Central England and Northeast France. Further justification for the decision to use continental sector temperature is the palaeoclimate evidence that ice sheets reached, but did not cover, Central England during the Last Glacial Maximum.

The two abrupt events in MoBidiC output are less evident in the Atlantic ocean sector further south, so it was decided to use Atlantic ocean temperature at 35-45°N for Central Spain as it is located on the western edge of the Eurasian continent. This may seem somewhat counter-intuitive, given the argument above, because Central Spain is more continental than Central England. However, the characteristics of the MoBidiC sectors rather than real-world geography are a more important consideration in the choice of suitable variables. It should also be noted that the analogue stations selected for Central Spain (see Section 2.3) reflect the continentality of this region.

Where possible, it was decided to use annual temperature only, however, monthly temperature output was also obtained for use if necessary (see Section 2.6).

Although it was considered possible to distinguish boundaries between the tundra (FT), subarctic (E) and temperate (D) climate classes in terms of annual temperature, a surrogate of continentality was considered necessary to define the continental/oceanic (i.e., EC/EO and DC/DO) thresholds for Central England and Northeast France. The most obvious variable to use is sea level. This could be estimated from global ice volume using the Marsiat and Berger [Ref.21] relationship. However, because this relationship is linear, it is more straightforward to use ice volume which is a direct output of MoBidiC. Antarctic ice volume varies very little over the transient simulation of the last glacial-interglacial cycle (see Ref.1, Section 3.2.), so it was decided to use Northern Hemisphere ice volume for the oceanic/continental threshold.

Clearly it is not possible to validate MoBidiC performance for the next 200 ka. However, Section 3 of Deliverable D7 [Ref.1] describes a number of experiments performed for validation and evaluation purposes, including an equilibrium control experiment for the present day and the transient simulation of the last glacial-interglacial cycle (listed above). The latter experiment is of particular interest here. The implications of identified biases in this simulation, such as the underestimation of the maximum of continental ice in the Northern Hemisphere at the Last Glacial Maximum (18 ka BP), are discussed in Sections 2.6 and 2.7. However, it is worth stressing here that the MoBidiC variables are treated more as ‘indices’ rather than as absolute temperature/ice volume estimates, i.e., scaling and multiplication factors are used to identify appropriate threshold values (see Section 2.6). In the latter case, this helps to counter the potential criticism that oceanic sector averages may not be representative of Central Spain. In all cases, however, the selection of variables (and their threshold values, see Section 2.6), involves subjective decisions which may need revisiting, for example, in the light of new palaeoclimatic data (Section 4).

In summary, it was decided to use the following MoBidiC variables for the identification of downscaling rules/thresholds:

- Central England and Northeastern France
    - Mean annual (and, if necessary, monthly) temperature for the Eurasian continental sector 50-55°N
    - Northern Hemisphere ice volume

- Central Spain
  - Mean annual (and, if necessary, monthly) temperature for the Atlantic oceanic sector 35-45°N

Time series plots of these variables for the three MoBidiC simulations listed above are shown in Appendix 7. For completeness, output for the natural scenario – A4 – simulation of the next 200 ka is also shown in the Appendix. This simulation (with natural CO_2 forcing derived from Paillard's A4a model, see Ref.18, Figure 5) is described in Deliverable D7 [Ref.1], Section 4.2. It was not used for the identification of downscaling rules/thresholds, although the downscaling methodology was applied to output from this simulation (see Section 2.8). The future simulations with anthropogenic CO_2 forcing (B3 and B4) were only used for the identification of rules/thresholds for the enhanced warming state which did not occur over the last glacial-interglacial cycle.

2.6. - Step 6: Identification of objective rules/thresholds for defining climate classes in MoBidiC output

Step 6 is the identification of objective rules and thresholds for defining climate classes in MoBidiC output. These rules and thresholds were identified using output for the last glacial-interglacial cycle, although output from future simulations was also required to define the enhanced warming state which did not occur over the last climatic cycle. Appropriate MoBidiC simulations and variables for the three study regions are identified in Section 2.5.

When applied to MoBidiC simulations of the last glacial-interglacial cycle, the rules and thresholds should allow the climate sequences shown in Tables 1 and 3 and Figures 1 to 3 (see Section 2.1) to be reproduced. They need to be region specific (i.e., Central England, Northeast France and Central Spain) and as objective as possible. In order to test the rules and thresholds empirically (i.e., in the Excel spread sheets devised by Mike Thorne and Clare Goodess), the Køppen/Trewartha climate classes were assigned index values as shown in Table 7.

The most likely ranges of simulated mean annual sectoral temperature-based threshold values for the:
- tundra/subarctic (FT/E) boundary (parameter t1); and,
- temperate/subarctic (D/E) boundary (parameter t2)

for Central England and Northeast France were identified based on examination of MoBidiC output for the 50-55° Eurasian continental sector for the sub-periods identified in Table 1 and comparison with the regional palaeoclimate temperature estimates given for these sub-periods in Deliverable D2 Tables 5.4 [Ref.8] and 3.1/3.2 (reproduced here in Appendix 2).

The most likely range of simulated mean annual sectoral temperature-based threshold values for the:
- temperate/subtropical (D/Cr) boundary (parameter t3)

was selected by identifying the maximum 50-55° Eurasian continental sector temperature simulated by MoBidiC over the last glacial-interglacial cycle and taking a slightly higher value (based on the argument that the Cr climate class did not occur over this period).

The most likely range of simulated mean annual sectoral temperature-based threshold values for the:
- Cr/Cs boundary, i.e., reflecting a greater degree of anthropogenic enhanced warming (parameter t4)

was identified by comparing the regional palaeoclimate estimates (see Ref.8 Tables 5.4 and 3.1/3.2 which are reproduced here in Appendix 2) and the simulated range of variability for 50-55° Eurasian continental sector temperature over the last glacial-interglacial cycle (about 20°C and 3° respectively) and scaling the simulated temperature change by a factor of 7 (20/3 approximates to 7) to estimate the simulated sectoral temperature equivalent of an observed regional warming of about 3°C above the D/Cr boundary (3°C/7 approximates to 0.4°C, thus if t3 = 1.7°C, t4 = 2.1°C). Given the proximity of Central England and Northeast France, it was decided to use the same threshold values for the t3 and t4 parameters in both study regions (though different analogue stations are selected for the Cr and Cs climate classes in the two study regions, see Section 2.3).

Finally, the most likely range of simulated Northern Hemisphere ice volume threshold values for the:

- continental/oceanic EC/EO and DC/DO boundary (parameter Ice)

was identified by comparing simulated Northern Hemisphere ice volumes with the climate sequences in Table 1.

The most likely MoBidiC threshold ranges identified for parameters t1, t2 and Ice (i.e., those applicable to the MoBidiC simulation of the last glacial-interglacial cycle) were then tested in the Excel spread sheets constructed by Mike Thorne and Clare Goodess (and which were available for use by BIOCLIM participants on the Business Collaborator work space).

A concordance index was devised to evaluate performance: scoring 1 whenever the same climate class appears in both the observed sequence (i.e., in Table 1) and the downscaled sequence and 0 when the classes are different. Allowance was made for periods where two classes are equally possible, for example, a score of 1 is achieved if the downscaling estimates EC or FT conditions for Central England during the period 28-41 ka BP. The concordance index sum is calculated together with the percentage of correct scores (out of a maximum of 252). Results are summarised in Table 8. Recommended MoBidiC threshold values are given in the table. For some parameters, a range of threshold values gives the same concordance index sum. Thus, the range of threshold values over which results are stable is also indicated in the table. In cases with a relatively large stable range, selection of the recommended threshold value was largely a matter of subjective judgement. Time series plots of the concordance indices for Central England and Northeast France are shown in Figures 7 and 9 respectively, and the downscaled indices (plotted using the empirical index values given in Table 7) are shown in Figures 8 and 10.

Table 8 indicates that the identified rules/thresholds work slightly better for Central England, with a concordance index sum of 71%, compared with 65% for Northeast France. There are two periods when the downscaling performs poorly in both regions. Firstly, from about 119-111 ka BP, when the downscaling indicates EO conditions in both regions rather than DO or EC as indicated by the observed sequences (Table 1). This suggests that MoBidiC has problems reproducing the observed OIS 5e to 5d transition. Secondly, the performance of the downscaling is considerably worse from 15-0 ka BP. Initially, the downscaling indicates EC rather than FT conditions from 15-13.5 ka BP, i.e., not sufficiently cold. Thereafter, however, the downscaling indicates conditions that are systematically too cold, i.e., EC rather than DC from 13-11.5 ka BP and EC or DC rather than DO from 10-0 ka BP. The latter period includes an abrupt cooling event in MoBidiC output which is not observed in the palaeoclimate record at this time (see Section 2.5), but it is also evident that MoBidiC is too cold and simulates too much Northern Hemisphere ice throughout the Holocene.

The downscaling also performs poorly for Central England from 70-60.5 ka BP, when EC rather than the FT conditions indicated in Table 1 are estimated. However, the climate classification for this period is uncertain. Similarly, EC rather than FT conditions are estimated for Northeast France from 76-70.5 ka BP and 51-47 ka BP: again periods when the classification is uncertain (Table 1). There are also discrepancies in the downscaling for Northeast France from 42.5-32.5 ka BP: which is again indicated as EC rather than FT as observed. The French observed sequence may, however, reflect a regional oscillation, as the Central England sequence for this period indicates EC conditions (Table 1). The general tendency for the downscaling to produce EC rather than FT conditions may also be a reflection of MoBidiC's tendency to underestimate ice volume at the Last Glacial Maximum (Ref.1, Section 3.2.3).

In general, therefore, the causes of discrepancies in the downscaled and observed sequences can be identified

The selected MoBidiC predictor variable for Spain is annual Atlantic surface temperature for the 35-45N sector. Initial inspection of the MoBidiC data did not reveal any clear threshold ranges for the sub-periods in Table 3. Thus a slightly different approach was taken than for Central England and Northeast France.

For the MoBidiC simulation of the last glacial-interglacial cycle, simulated Atlantic annual average temperature for the 35-45N sector ranges from 17.3°C to 15.7°C (i.e., a range of only 1.6°C) compared with regional palaeoclimate estimates of 18°C to < 3°C (i.e., a range of at least 15°C) in the Spanish classification (Table 2). This gives a multiplication factor of 15/1.6, i.e., about 9. So the following rough approximation was used to convert observed (i.e., palaeoclimate) threshold values (O) to the equivalent simulated values (S):

$$S = ((O - 10.5)/9) + 16.5,$$
where 10.5 = (18+3)/2, and 16.5 = (17.3+15.7)/2

Observed regional threshold values were identified from Table 2 for the last glacial-interglacial cycle and from Lomba et al., 2003 for future warm periods and converted to MoBidiC equivalent sectoral values using the above equation. A problem was found, however, with the BSk and BWk threshold values. Table 2 indicates that the observed palaeoclimate temperature range of these classes is large and almost exactly the same, i.e., 3-11°C. The main distinguishing feature is that periods classified as BWk are drier than BSk periods, i.e., with less than 200 mm annual precipitation (Table 2). However, MoBidiC precipitation is considered less reliable than temperature and unsuitable as a predictor variable (see Section 2.4). On the assumption that colder periods will be drier, the BWk/BSk boundary was defined as 16.2°C in MoBidiC 35-45N Atlantic sector output, i.e., mid-way between the FT/B and B/Csb boundaries. The threshold values and rules thus obtained for all the boundaries are shown in Table 9.

The MoBidiC rules/thresholds listed in Table 9, together with threshold values either side of those listed, were tested in an Excel spreadsheet and the concordance index calculated in the same way as for Central England and Northeast France. The only improvement to the original values occurred with t3, slightly better results are obtained with an observed threshold value of 16.8°C rather than 16.9°C. However, even the ‘best’ thresholds and rules give a concordance index sum of only 55%. This concordance index is shown in Figure 11a and the downscaled index in Figure 12.

Figure 11a indicates three periods when the downscaling performs consistently badly: 82-64 ka BP (Csb rather than Csa, then BSk rather than Csa and BWk rather than Csa); 61-55 ka BP (BSk rather than BWk) and 31-19 ka BP (BWk rather than BSk). The discrepancies during the latter two periods suggest a problem with the somewhat arbitrarily chosen BWk/BSk threshold value, although there are longer periods when the downscaling correctly distinguishes between BWk and BSk conditions (e.g., 96-87 ka BP and 54-39 ka BP). These problems with the BWk/BSk boundary reflect the difficulty of trying to define a moisture-related threshold using temperature. Distinguishing between these two classes in the palaeoclimate record is also difficult, and it could be argued that they should be treated as a single climate class (Recreo, personal correspondence). If this is done, the concordance index increases to 77% (Figure 11b). The discrepancies at 61-55 ka BP and 31-19 ka BP are removed, leaving the discrepancy at 82-64 ka BP when downscaled classes are not sufficiently warm. In this case, downscaled index values of 10 and 15 in Figure 12 can be considered as a single class. Although this increases the apparent skill of the downscaling, the downscaled index now does little more than identify two states (i.e., subtropical interglacial periods and dry glacial periods).

Compared with Central England and Northeast France, the downscaling for Central Spain performs well for 15-0 ka BP, which is somewhat surprising, given the tendency for MoBidiC to be too cool and to simulate too much Northern Hemisphere ice over the Holocene. However, the downscaled index does not indicate more periods as warm as the present-day (i.e., Csa conditions) than are observed in the Table 3 sequence. The downscaled index (Figure 12) indicates Csa conditions during OIS 5e and 5c. Although the observed sequence does not extend back to this period, the downscaled classification for this period appears reasonable.

The MoBidiC threshold values listed in Table 9 are all based on annual mean Atlantic surface temperature for the 35-45N sector. Examination of winter (DJF) and summer (JJA) means for this variable indicates periods when summer temperature appears to be in phase opposition to winter temperature (Figure 13). Winter temperature appears to more closely reflect observed patterns of change. Thus an attempt was made to use winter temperature for downscaling. However, the MoBidiC simulated winter temperature range over the last glacial-interglacial cycle is only 0.6°C. Choosing threshold values from within this restricted range gave extremely poor results and the attempt to use winter rather than annual temperature was therefore abandoned It may, however, be worth exploring this approach further using continental sector temperature as the temperature range could be larger than for the oceanic sector.

Winter and summer means of MoBidiC Atlantic sector 35-45N temperature were also used to explore whether a rule is required to define the As, tropical climate class. Lomba et al., [Ref.14] consider that this climate class could occur in the future. Compared with the BWh/BSh classes which are used to represent enhanced warming for Central Spain, the main distinguishing feature of the As class is a much weaker seasonal temperature cycle (Appendix 1). However, plots of summer minus winter temperature output indicate that this does not occur in the B3 and B4 MoBidiC simulations with anthropogenic CO_2 forcing. Thus rules for identifying the As class are not given.

There are clearly a number of problems with the performance of the rule-based downscaling scheme for Central Spain and it seems that rule-based downscaling is less successful for Spain than for Central England and Northeast France. In part, this is due to problems with the underlying classification (Table 2):

- the classification for the last glacial/interglacial cycle only starts at 104 ka BP;

- the classification has two periods of uncertainty: Stage 5c (96-104 ka BP) and the Younger Dryas to Oldest Dryas (10-13.3 ka BP). The Stage 5c uncertainty could be eliminated by obtaining dates for St Germain Ia to Ic, but there is no reason to expect that MoBidiC would be able to capture such events; and

- it is difficult to distinguish between BSk and BWk conditions.

The latter problem is related to the fact that the palaeoclimate record for Central Spain over the last glacial-interglacial cycle is more strongly influenced by regional precipitation changes than are the records for Central England and Northeast France (see Ref.8). However, the main reason for the poorer performance of the rule-based downscaling for Central Spain, is the inherent problem of trying to use MoBidiC temperature output to classify 'dry' climate classes, which is discussed further in Section 4.

Index value	Climate class in the Central England and Northeast France sequences	Climate class in the Central Spain sequence
0	FT	FT
10	EC	BWk
15	EO	BSk
20	DC	CSb
25	DO	Csa
30	Cr	BSh
35	Cs	BWh

Table 8: *MoBidiC threshold values and rules for Central England and Northeast France. t1-t4 are defined using MoBidiC average annual temperature for the 50-55°N Eurasian continental sector. Ice is defined using MoBidiC Northern Hemisphere ice volume.*

Parameter and units	Boundary and rule	Central England: Recommended MoBidiC threshold value	Northeast France: Recommended MoBidiC threshold value	Central England: Stable range	Northeast France: Stable range
t1 °C	FT/EC < t1 = FT	-1.1	-0.9	-1.1	-0.9
t2 °C	D/E > t2 = D	0.35	0.27	0.31 to 0.70	0.26 to 0.27
t3 °C	D/Cr > t3 = Cr	1.7	1.7	*	*
t4 °C	Cr/Cs > t4 = Cs	2.1	2.1	*	*
Ice 10^6 km^3	EC/EO DC/DO > Ice = EC/DC	11.0	10.2	10.4 to 11.1 11.4 to 11.6	10.2
Concordance index sum: **N** %		180 71%	163 65%	180 71%	163 65%

**Can't be evaluated. In the case of D/Cr, this is because of MoBidiC cold bias at the end of the simulation.*

Table 9: *MoBidiC threshold values and rules for Central Spain. t1-t6 are defined using MoBidiC average annual temperature for the 35-45°N Atlantic oceanic sector. Observed thresholds are defined using palaeoclimate estimates from Table 2.*

Parameter	Rule	Observed threshold	MoBidiC threshold
t1	< t1 = FT > t1 = BWk	3°C	15.7°C
t2	>t2 = BSk	7°C	16.2°C
t3	>t3 = CSb	11°C	16.6°C
t4	> t4 = CSa	14°C	16.9 (16.8) °C
t5	> t5 = BSh	20°C	17.6°C
t6	> t6 = BWh	30°C	18.7°C
Concordance index sum: N	114* 161**		
%	55%* 77%**		

**Results when BWk and BSk are treated as two separate climate classes.*

*** Results when BWk and BSk are treated as a single climate class.*

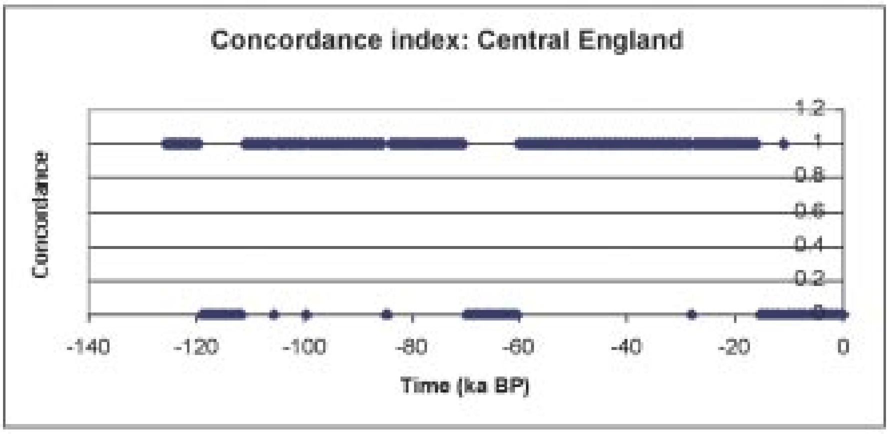

Figure 7 : *Concordance index for Central England.*

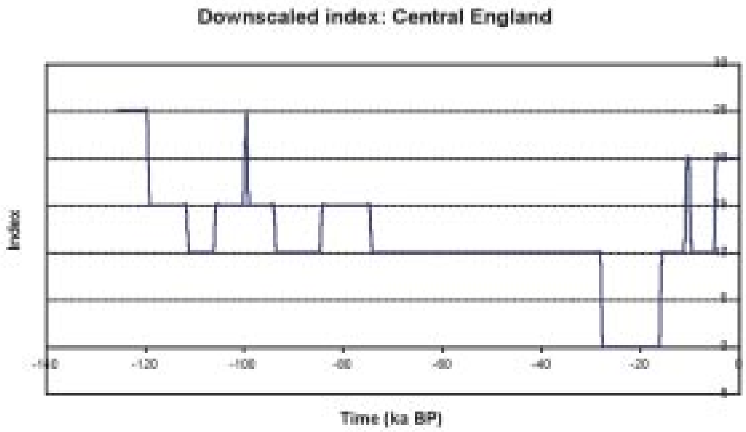

Figure 8 : *Downscaled index for the last glacial-interglacial cycle for Central England.*

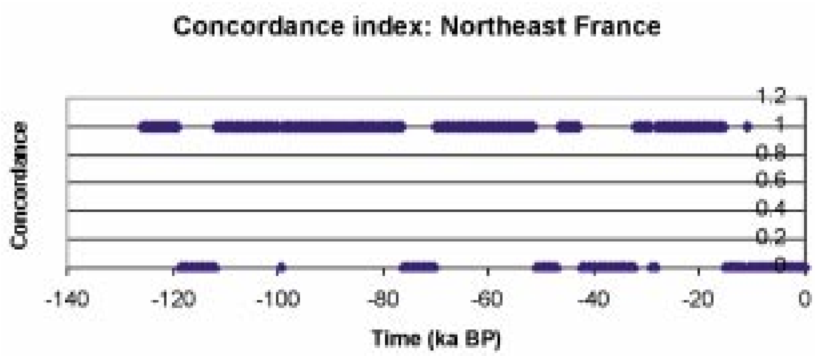

Figure 9 : *Concordance index for Northeast France.*

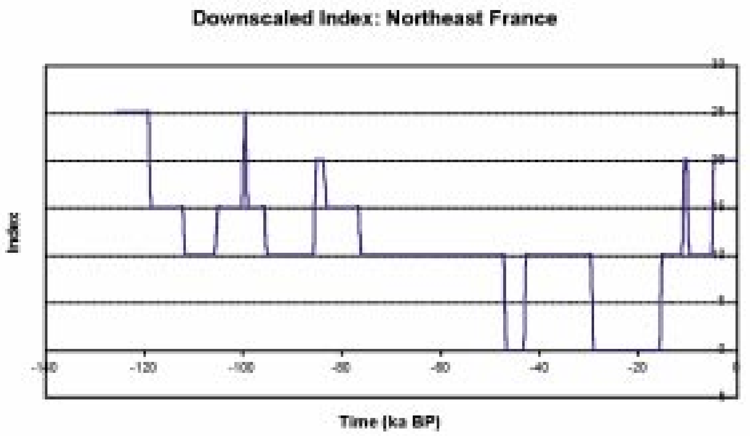

Figure 10 : Downscaled index for the last glacial-interglacial cycle for Northeast France.

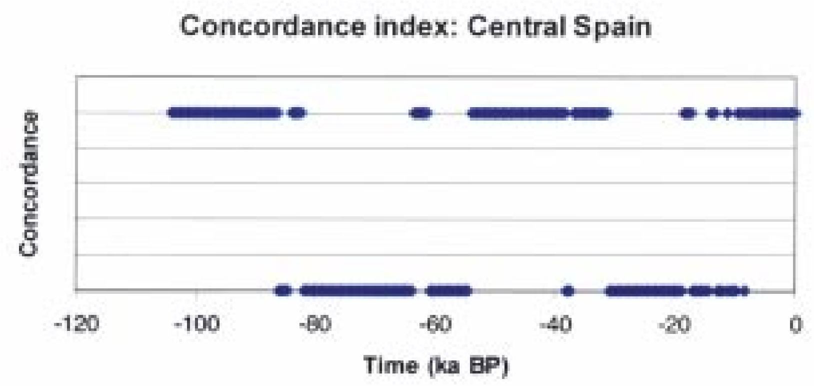

Figure 11a : Concordance index for Central Spain: BWk and BSk are treated as two separate climate classes.

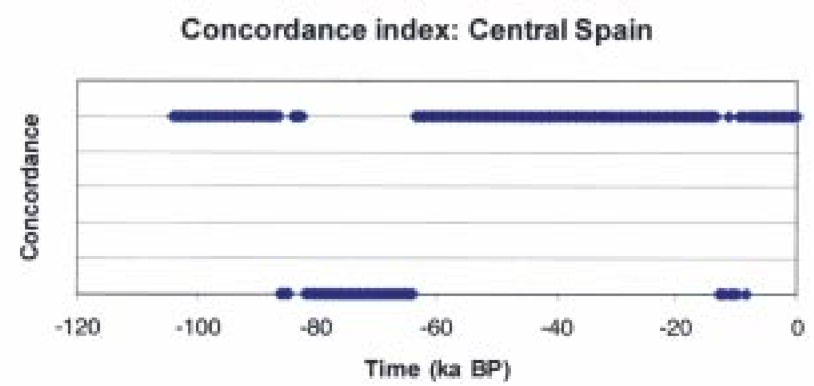

Figure 11b : Concordance index for Central Spain: BWk and BSk are treated as a single climate class.

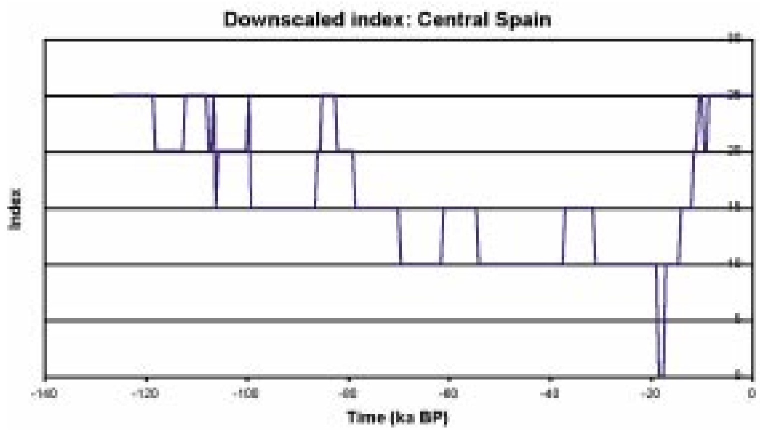

Figure 12 : *Downscaled index for the last glacial-interglacial cycle for Central Spain. Note that index values of 10 (BWk) and 15 (BSk) could be considered as a single climate class.*

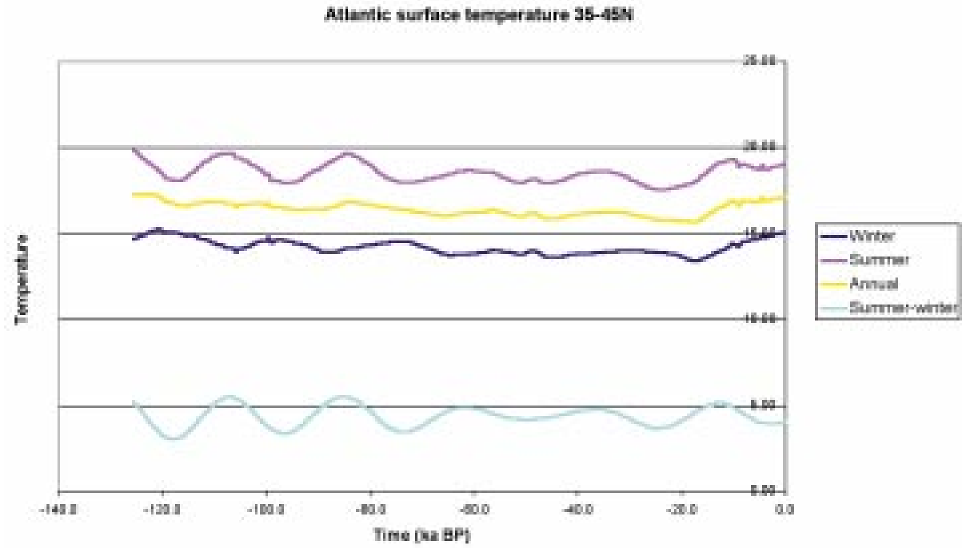

Figure 13 : *Atlantic surface temperature 35-45N simulated by MoBidiC for the last glacial-interglacial cycle.*

2.7. - Step 7: Evaluation of the rule-based downscaling methodology for the last climatic cycle

The concordance index presented in Section 2.6 provides a method for assessing the relative performance of different rules and thresholds. The rules and thresholds have been selected in order to overcome some of the known biases of MoBidiC. Simulated temperature rather than precipitation is used, for example, and is scaled to compensate for the relatively low range of simulated variability over the last glacial-interglacial cycle. Similarly, the simulated Northern Hemisphere ice volume threshold values used to distinguish EC/EO and DC/DO conditions for Central England and Northeast France in MoBidiC output are likely to be lower than the actual values, because of the tendency of MoBidiC to underestimate ice volume and extent during the last glacial. The rules and thresholds cannot, however, compensate for some biases, such as the tendency for MoBidiC to be too cool during the Holocene.

There is, however, a concern that we are liable to get into circular arguments in evaluating the performance of the rule-based downscaling methodology (see Section 4). In the case of Central England, a wide range of data have been used to provide the palaeoclimatic classification over the period 127 ka BP to the present day (see Section 5 of Ref.8). These data included palaeobotanical, coleopteran and periglacial data from a wide range of sites across northwest Europe, interpreting them in a more local context. The main restriction on the analysis was that it was based on a comparison of palaeoclimatic reconstructions made by others, rather than being a fresh interpretation of the primary data. However, as the interpretations used were recent and comprehensive, it is unlikely that a re-examination of the primary data would reveal major new insights.

As the rule-based downscaling makes use of Köppen-Trewartha climate classes defined on the basis of this palaeoclimatic analysis, application of the rules to the MoBidiC simulation of the last glacial-interglacial cycle should do no more than recover the climate classes that went into development of the rules, provided that the rules are correctly defined. (The extent to which this is the case is quantified by the concordance index.) Therefore, it is rather misleading to consider validating the rules against palaeodata. However, the rule-based scheme can legitimately be applied to this period to investigate the degree to which the rule-based scheme degrades the quality of information relative to the palaeodata on which it is based. For example, the rule-based scheme can be used to reconstruct January and July temperatures for the Herning Stadial and then the results compared with the palaeoclimate temperature estimates of Aalbersberg and Litt [Ref.22] that went into the analysis.

The rule-based downscaling scheme for Central England incorrectly indicates EO rather than EC conditions during the earlier part of the Herning Stadial, 116-111.5 ka BP, but correctly indicates EC conditions during the more recent part, 111-106 ka BP. Temperature estimates from Aalbersberg and Litt [Ref.22] for the Herning Stadial are therefore compared with values calculated from the EC analogue stations selected for Central England (see Appendix 5) in Table 10.

	January	July
Aalbersberg and Litt [Ref.22] Mean minimum temperature	-19 to -28°C	8 to 11°C
Mean of the EC analogue stations	-18°C	14.1°C
Maximum of the EC analogue stations	-9.6°C	18.6°C
Minimum of the EC analogue stations	-23.8°C	10.9°C

Table 10: *Comparison of downscaled and palaeodata estimates of Central England temperature for the Herning Stadial.*

Bearing in mind that the palaeodata estimates in Table 10 are minimum estimates, the agreement with downscaled values is relatively good. However, it should be noted that the palaeodata estimates are based on coleopteran data from only one site in Central England (Chelford) [Ref.22].

While rigorous validation is not possible for the reasons outlined above (unless new independent palaeodata become available), some further evaluation analyses, focusing on the Last Glacial Maximum and Holocene thermal optimum, could be undertaken using General Circulation Model data (e.g., from the Palaoeclimate Modelling Intercomparison Project: http://www-lsce.cea.fr/pmip and see Ref.23). One other possibility is to use the rule-based method to compute quantities, such as the depth of penetration of permafrost, that depend on the climate history rather than the climate at a particular time. The difficulty with this is that it tests a combination of the climate reconstruction, the model used for permafrost development and the, often equivocal, evidence used to determine permafrost depth and period of occurrence.

The inter-comparisons of the different downscaling methodologies used in BIOCLIM (see Section 1) described in Section 3.4 of Deliverable D10-12 [Ref.6] also provide some insight into the performance of the rule-based downscaling methodology described here.

2.8. - Step 8: Application of the rule-based downscaling methodology to MoBidiC output for future time periods

The final methodological step is to apply the threshold values and rules given in Tables 8 and 9 to MoBidiC output for the next 200 ka for the two anthropogenic scenarios (B3 and B4) and the natural scenario (A4). These simulations are outlined in Section 2.5 and described in detail in Deliverable D7 [Ref.1], Section 4. Time series plots of the variables used in downscaling are shown in Appendix 7.

The downscaled indices for Central England, Northeast France and Central Spain are shown in Figures 14, 15 and 16 respectively. It is stressed that the future changes indicated by these indices are driven only by changes in the variables used to identify the thresholds and rules (see Sections 2.5 and 2.6), i.e., annual average temperature for the 50-55°N Eurasian continental sector and Northern Hemisphere ice volume in the case of Central England and Northeast France and annual average temperature for the 35-45°N Atlantic oceanic sector in the case of Central Spain.

The main feature of the results for the anthropogenic scenarios B3 and B4 is the persistence of conditions warmer than the present day. For Central England and Northeast France the Cs class persists until 73.5 ka AP for the low CO_2 scenario (B3) and, apart from a couple of minor cooling events, until 165.5 ka AP in the high CO_2 scenario (B4). The DO class (i.e., the class experienced in both regions at the present day) does not reappear until 93 ka AP or 168.5 ka AP for the B3 and B4 scenarios respectively. For Central Spain, the BWh class persists until 7.5 ka AP or 16 ka AP for the B3 and B4 scenarios respectively, and today's Csa conditions do not reappear until 70 ka AP or 97 ka AP. The most extreme conditions encountered in Central England and Northeast France over the next 200 ka are EO for the low CO_2 B3 scenario and DO for the high CO_2 B4 scenario. For Central Spain, the most extreme conditions are Csb for B3 and Csa for B4.

Even in the natural A4 scenario, conditions as warm as the present day persist for a considerable time: to 53 ka AP for Central England and Northeast France and to 54.5 ka AP for Central Spain. The most severe conditions encountered in Central Spain are four BWk episodes. Central England and Northeast France experience a brief period of FT conditions just after 100 ka AP, as does Northeast France for one time step towards the end of the simulation. Both Central England and Northeast France show brief 'no-analogue' periods, scored as 5 in the indices. These are periods when it is cold enough to be classified as FT, but there is insufficient Northern Hemisphere ice for conditions to be classified as continental.

The results shown in Figures 14-16 have been used by the country teams in Workpackage 4 to develop narratives of climatic and environmental change for the specific regions of interest over the next 200 ka (see Ref.6, Section 5).

Finally, as an illustration of some of the uncertainties, i.e., those associated with the identification of MoBidiC threshold values, a number of different threshold values from the stable ranges identified in Table 8 were used to explore the sensitivity of the downscaled indices for Central England using the low CO_2 B3 scenario. Eight sensitivity tests were carried out using the following simulated threshold values (with all others held at the recommended value):

- Ice = 11.5; 10.5
- t2 = 0.31; 0.5; 0.7
- t3 = 1.5, t4 = 1.9; t3 = 1.8, t4 = 2.2; t3 = 2.0, t4 = 2.4

Results are shown in Appendix 8. Although some minor variations are evident, the major patterns of change outlined above remain constant.

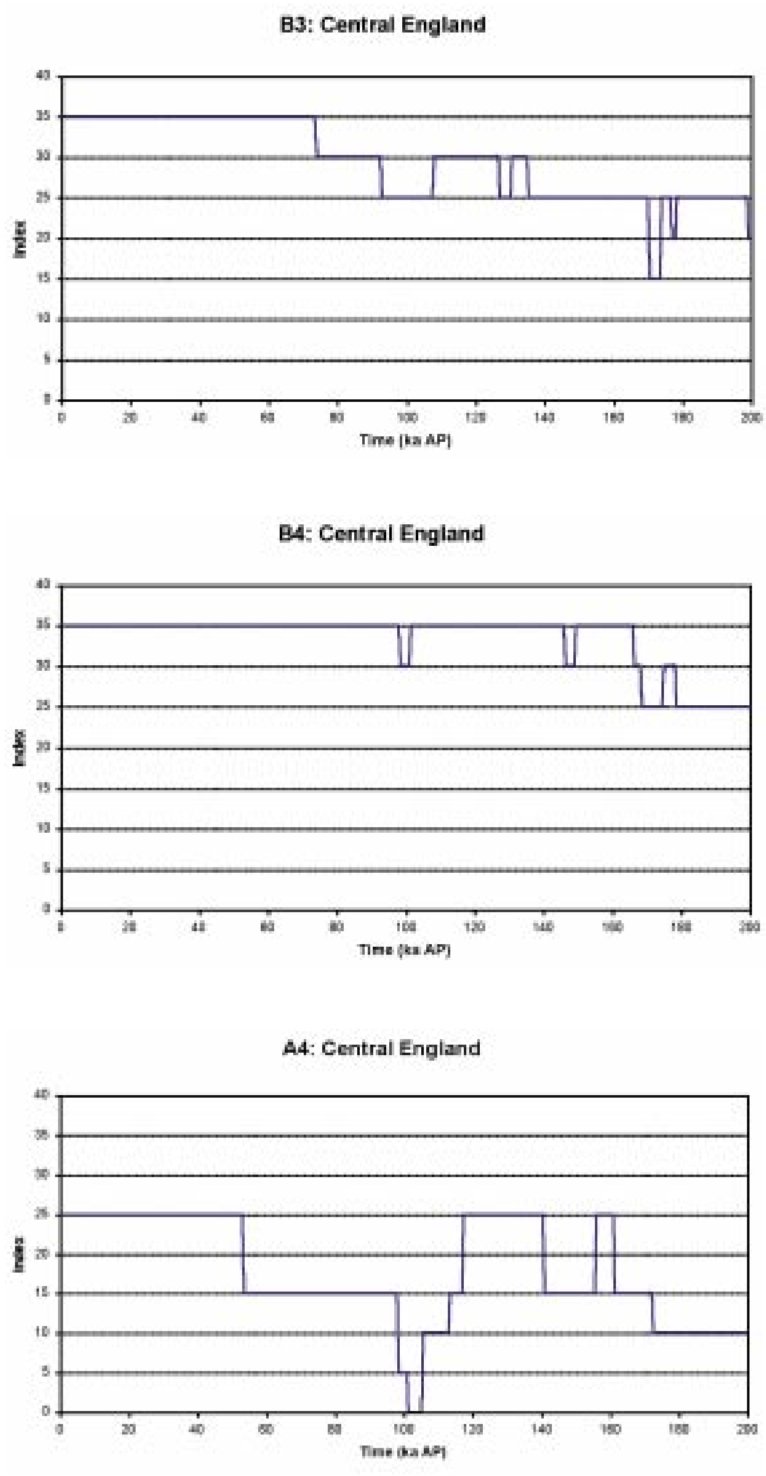

Figure 14: *Downscaled indices for Central England over the next 200 ka derived from MoBidiC output for the low anthropogenic B3, high anthropogenic B4 and natural A4* CO_2 *scenarios.*

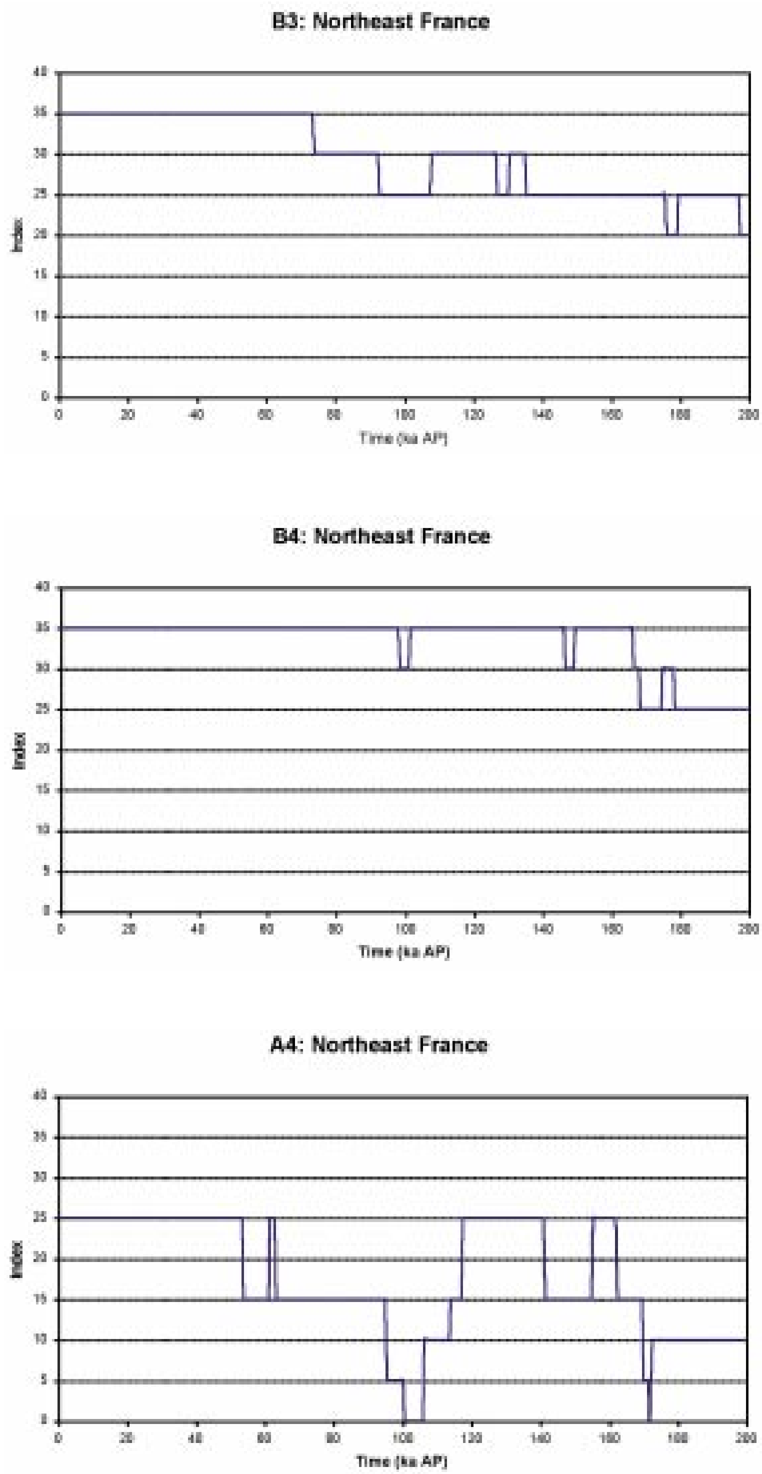

Figure 15: *Downscaled indices for Northeast France over the next 200 ka derived from MoBidiC output for the low anthropogenic B3, high anthropogenic B4 and natural A4 CO_2 scenarios.*

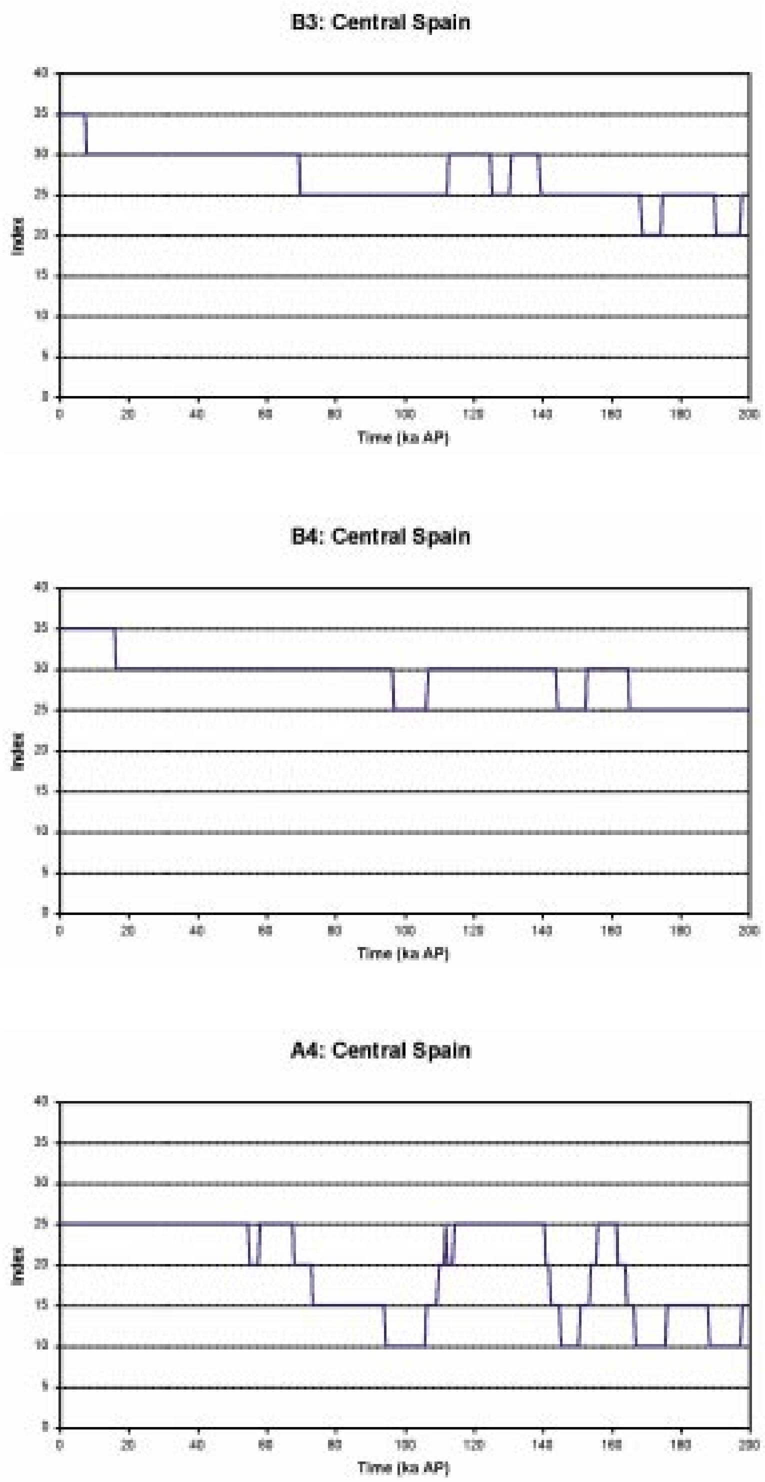

Figure 16: *Downscaled indices for Central Spain over the next 200 ka derived from MoBidiC output for the low anthropogenic B3, high anthropogenic B4 and natural A4 CO_2 scenarios.*

3. Application of the rule-based downscaling methodology to LLN 2-D NH output

As described in Section 1, it became apparent that the rule-based downscaling methodology could be applied to output from the LLN 2-D NH simulations carried out for Work Package 2 (see Ref.18). This has two advantages. First, the simulations of the future are longer (one Myr) than for MoBidiC (200 ka) and, second, downscaled indices derived from MoBidiC and LLN 2-D NH output can be compared. The same sequences for the last glacial-interglacial cycle (Table 1) and analogue stations (see Appendices 5 and 6) are used for downscaling from both climate models, thus it is primarily the relative performance of the two models that can be compared.

For MoBidiC, the rule-based downscaling was considered to be less reliable for Central Spain, primarily because of the greater importance of precipitation variability in this region (see Sections 2.6 and 4), hence LLN 2-D NH output was only downscaled for Central England and Northeast France initially. It may be possible to improve the MoBidiC rule-based downscaling for Central Spain, for example, by using different variables (see Section 4), in which case the method could also be applied to LLN 2-D NH output. However, if the desire is to use precipitation-related variables, these may be less representative of the study region in LLN 2-D NH which only has one continental sector than in MoBidiC which has three continental sectors. In the meantime, inspection of LLN 2-D NH output (available from UCL/ASTR) could be used to make qualitative inferences about the next one Myr for Central Spain.

Simulated continental surface temperature for the latitude band 50-55°N and Northern Hemisphere ice volume were again used as predictor variables for Central England and Northeast France, although, as noted above, there is only one continental sector in LLN 2-D NH, as opposed to three, including Eurasia, in MoBidiC. Output for these two variables from a simulation of the last 400 ka is shown in Figures 17 and 18. Although the simulation was run for 400 ka, only output for the last 127 ka was used, i.e., for the period of the sequences shown in Table 1.

The same downscaling rules were used as shown in Table 8, together with the same approach to identifying simulated threshold values as described for Central England and Northeast France using MoBidiC output in Section 2.6. The recommended threshold values identified for LLN 2-D NH are listed in Table 11. The concordance indices for Central England and Northern France are shown in Figures 19 and 20 respectively, and the downscaled indices in Figures 21 and 22.

Performance is again better for Central England (with a concordance sum of 76%) than for Northeast France (62%). Note that there are only 126 data points in this case, because LLN 2-D NH has a time step of 1 ka, compared with 500 a for MoBidiC. The periods when the downscaling performs poorly (Figures 19 and 20) are very similar to those for MoBidiC (Figures 7 and 9). Like MoBidiC, for example, LLN 2-D NH is too cold towards the end of the simulation.

The rules and threshold values shown in Table 11 were applied to output from LLN 2-D NH simulations for the next 1 Ma using the B3, B4 and A4 scenarios as for MoBidiC (see Section 2.8). Time series of the continental temperature and Northern Hemisphere ice volume output used in the downscaling are shown in Figures 23 and 24 respectively. Downscaled indices for Central England and Northern France are shown in Figures 25 and 26.

The LLN 2-D NH downscaled results for the next 200 ka are inter-compared with those obtained for MoBidiC and the other downscaling methods used in BIOCLIM as part of the work reported in Deliverable D10-12 [Ref.6]. However, a visual inspection of Figures 25 and 26 again indicates the persistence of warm conditions over the next 100 ka or so.

During the next 1 Ma, FT conditions are only indicated at one time step in Central England for the B3 scenario (Figure 25), and for five very brief periods in Northeast France (Figure 26). For the high CO2 B4 scenario, only two very brief FT periods occur in the index for Northeast France and none for Central England.

As for MoBidiC, conditions as warm as the present day persist for some time at the start of the A4 simulation. There are a number of brief periods of FT conditions over the next 1 Ma (eight in Central England and 15 in Northeast France). However, it is only over the second half of the A4 simulation, particularly for Central England, that relatively strong DO-FT (i.e., glacial-interglacial) oscillations occur.

Parameter and units	Boundary and rule	Central England: Recommended LLN 2-D NH threshold value	Northeast France: Recommended LLN 2-D NH threshold value
t1 °C	FT/EC < t1 = FT	-0.4	-0.2
t2 °C	D/E > t2 = D	2	2
t3 °C	D/Cr > t3 = Cr	3	3
t4 °C	Cr/Cs > t4 = Cs	4	4
Ice 106 km^3	EC/EO DC/DO > Ice = EC/DC	8	5
Concordance index sum: N		96	78
%		76%	62%

Table 11: *Simulated thresholds and rules for downscaling LLN 2-D NH output to Central England and Northeast France. t1-t4 are defined using LLN 2-D NH average annual temperature for the 50-55°N continental sector. Ice is defined using LLN 2-D NH Northern Hemisphere ice volume.*

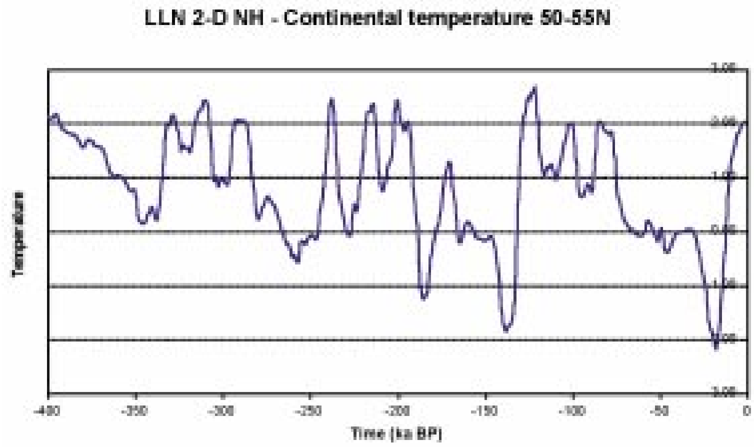

Figure 17 : *LLN 2-D NH annual temperature for the last glacial-interglacial cycle.*

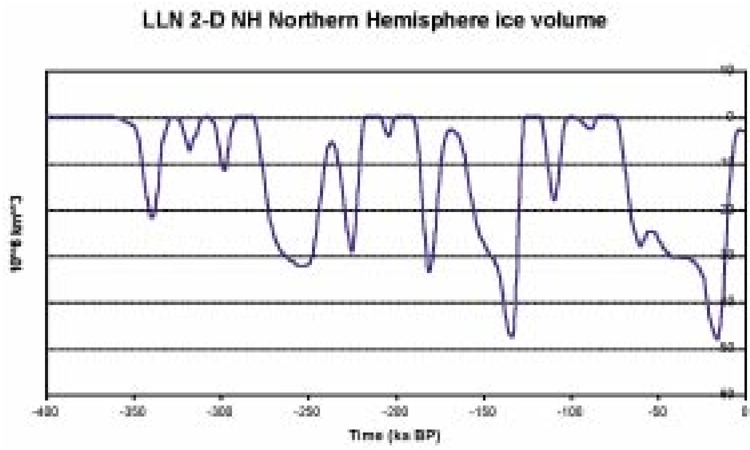

Figure 18 : *LLN 2-D NH Northern Hemisphere ice volume for the last glacial-interglacial cycle.*

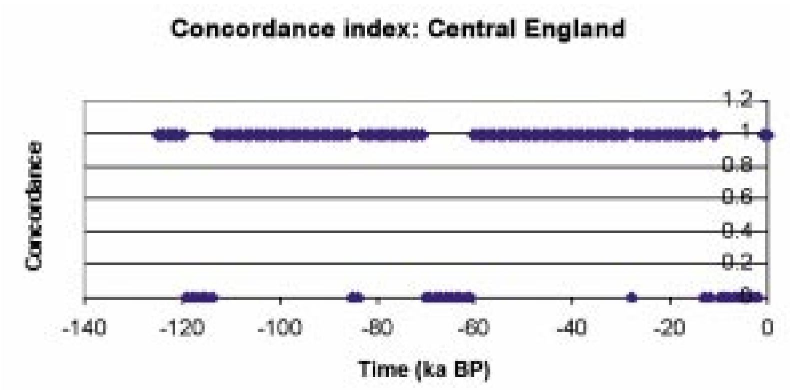

Figure 19 : *Concordance index for Central England – LLN 2-D NH output.*

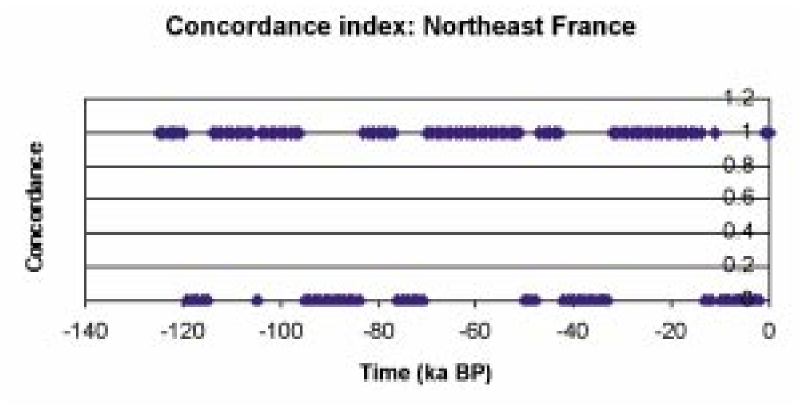

Figure 20: *Concordance index for Northeast France – LLN 2-D NH output.*

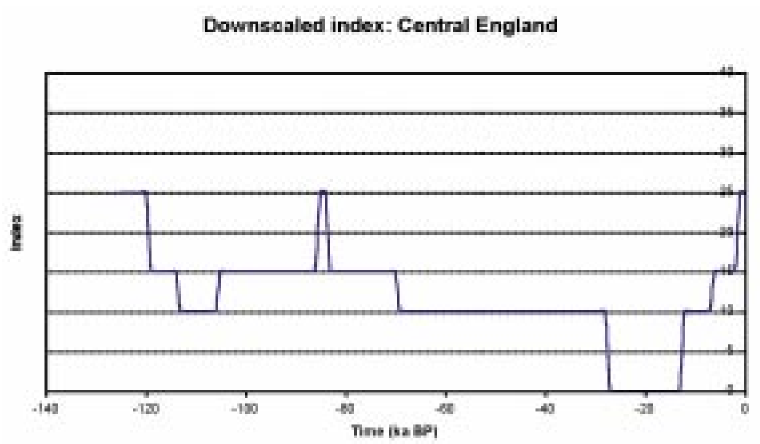

Figure 21: *Downscaled index for the last glacial-interglacial cycle for Central England – LLN 2-D NH output.*

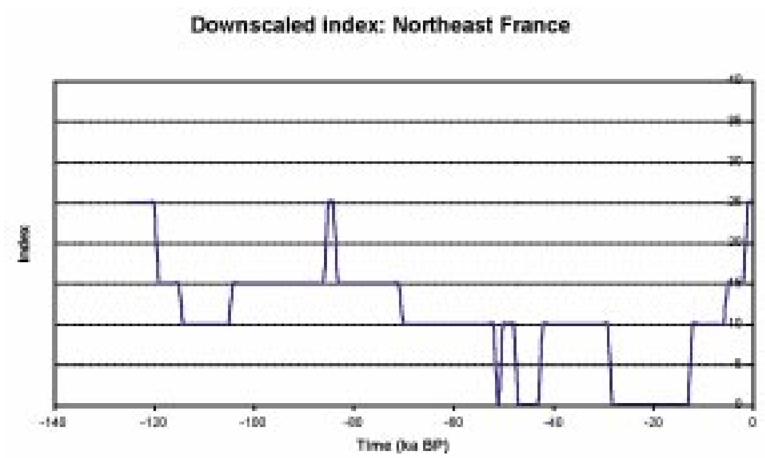

Figure 22: *Downscaled index for the last glacial-interglacial cycle for Northeast France – LLN 2-D NH output.*

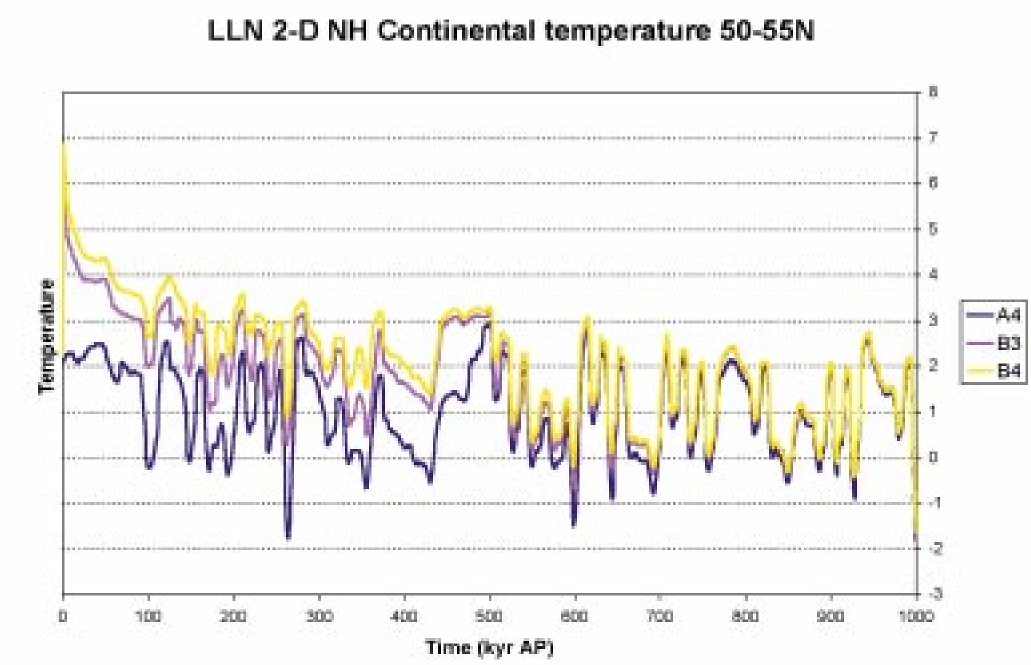

Figure 23: *LLN 2-D NH annual continental temperature 50-55N for the next 1 Ma for the low anthropogenic B3, high anthropogenic B4 and natural A4 CO_2 scenarios.*

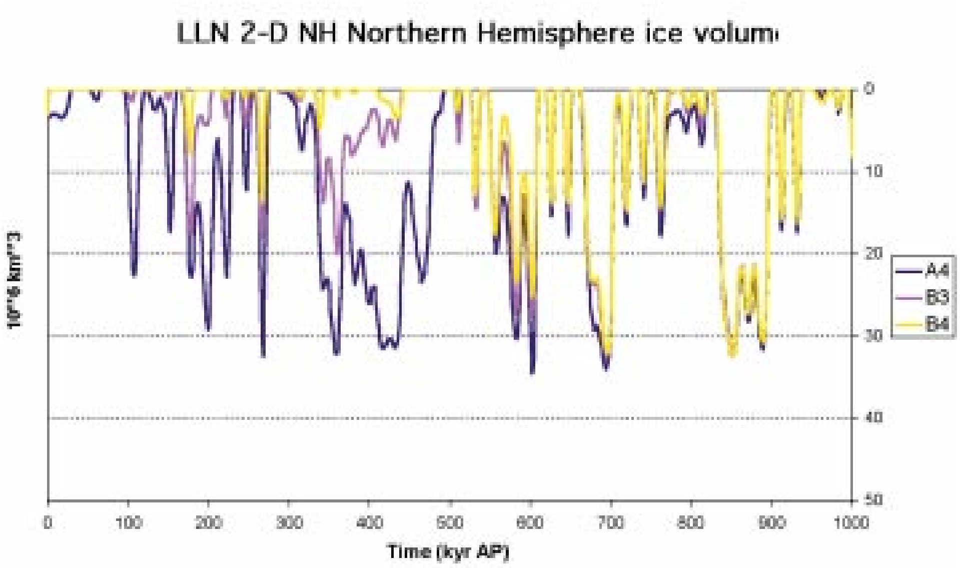

Figure 24: *LLN 2-D NH Northern Hemisphere ice volume for the next 1 Ma for the low anthropogenic B3, high anthropogenic B4 and natural A4 CO_2 scenarios.*

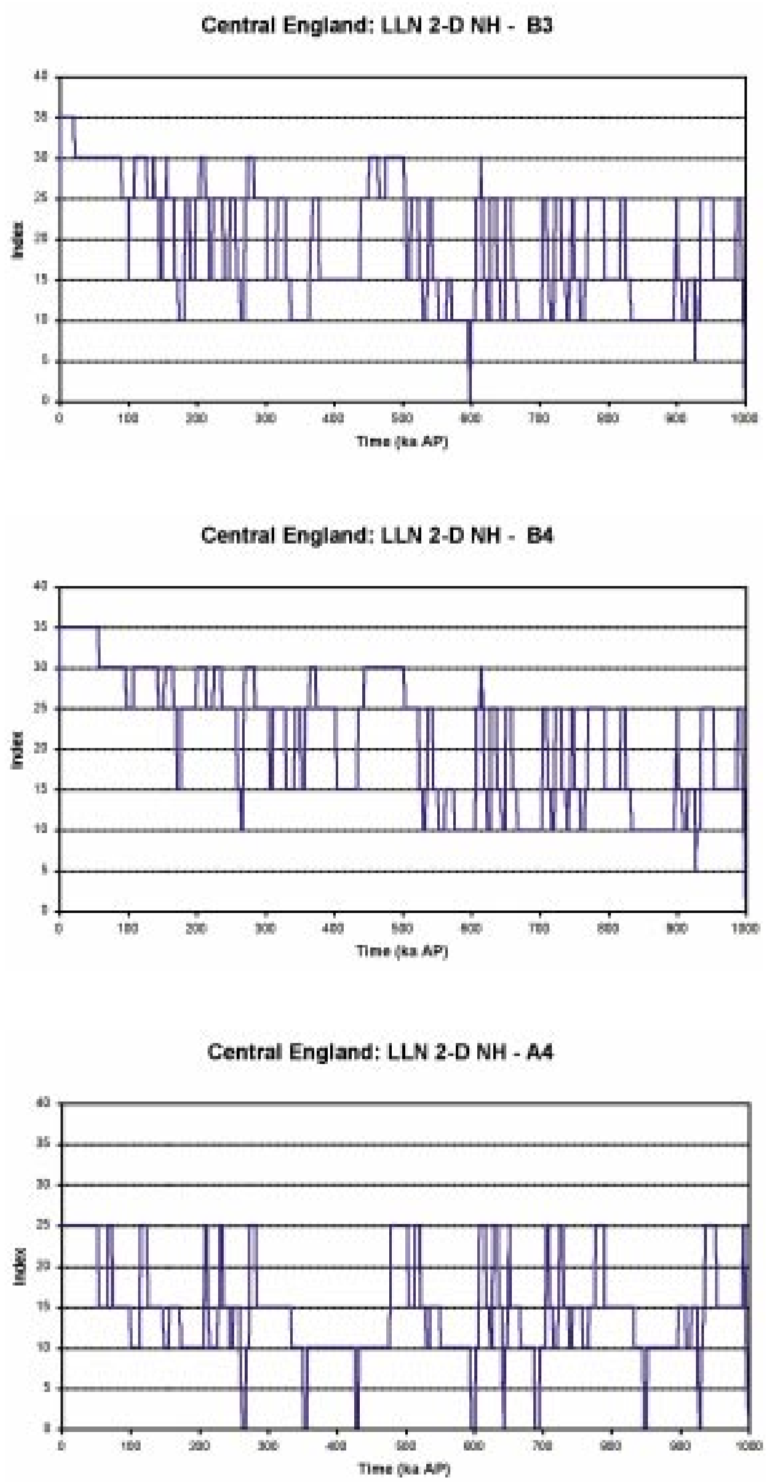

Figure 25: *Downscaled indices for Central Spain over the next 200 ka derived from MoBidiC output for the low anthropogenic B3, high anthropogenic B4 and natural A4 CO_2 scenarios.*

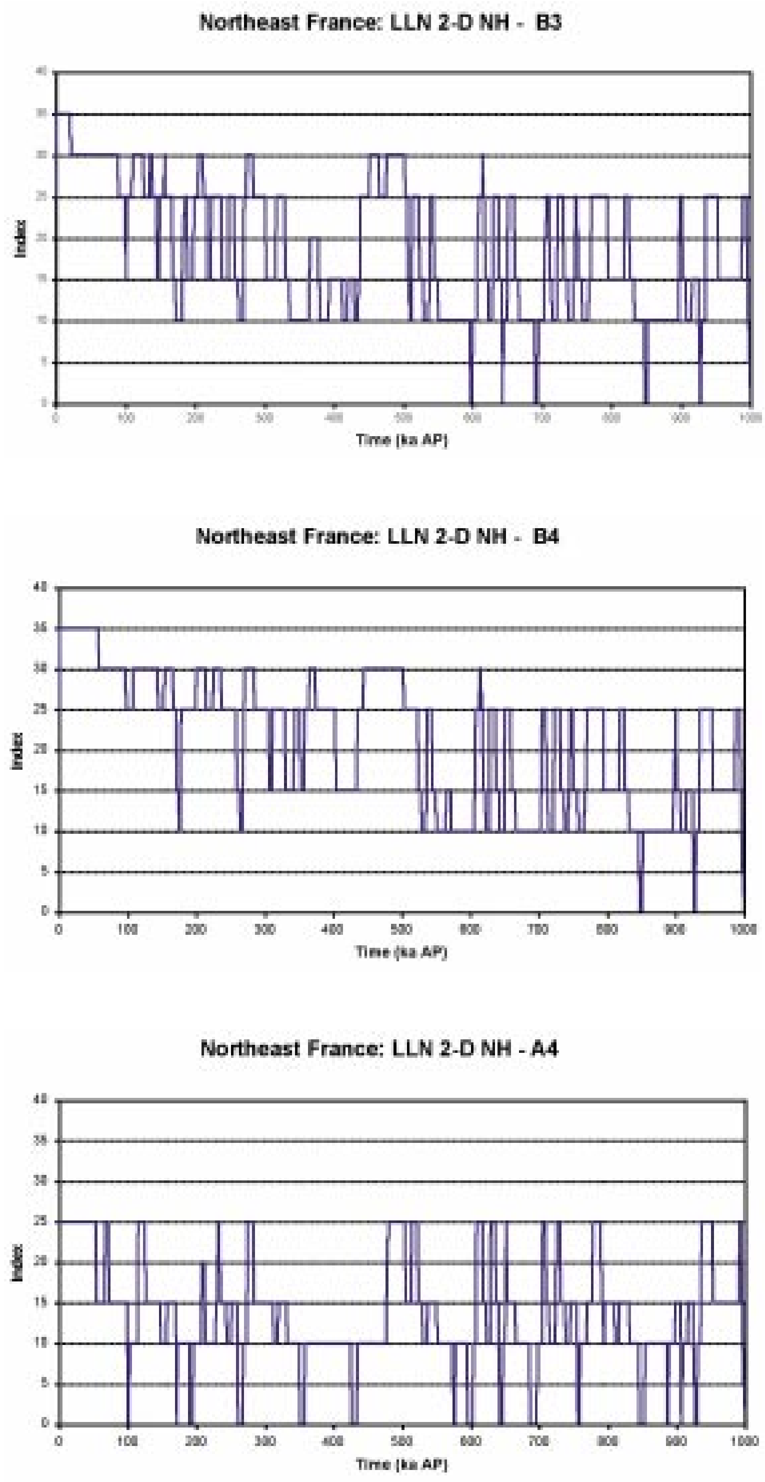

Figure 26: *Downscaled indices for Northeast France over the next 1 Ma derived from LLN 2-D NH output for the low anthropogenic B3, high anthropogenic B4 and natural A4 CO_2 scenarios.*

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4. Concluding remakes

The eight steps required to develop and implement the rule-based downscaling methodology are described in this deliverable, with many additional technical details provided in the appendices, and references included to supporting BIOCLIM deliverables and technical notes. Thus, although a degree of subjectivity is involved in the methodology, the results presented here are reproducible and transparent.

In addition, all the observed and simulated data sets used to develop the rule-based downscaling methodology, including the Excel spreadsheets used to identify objective rules/thresholds for defining climate classes and to construct the concordance indices (see Section 2.6) and downscaled indices (see Section 2.8), can be downloaded from the BIOCLIM Business Collaborator work space. Thus BIOCLIM participants will be able to further develop and refine the methodology, in the light of new palaeoclimatic data, for example. This would be particularly beneficial for Central Spain where the methodology performs less well than for Central England and Northeast France (Section 2.6).

It was not originally the intention to apply the methodology to the German and Czech Republic BIOCLIM case-study regions. However, the teams from these countries have undertaken many of the steps for their own regions (see Ref.6) and have followed the development of the methodology over the course of the project. They also have access to the Excel spreadsheets (see above), which could be modified relatively easily for application to these additional regions. Thus it should be a fairly straightforward task to extend all the steps of the rule-based downscaling methodology to these regions in the future if desired.

It would also be desirable to re-visit the application of the methodology to Central Spain. One option, for example, would be to determine whether better results are obtained using continental rather than oceanic sector temperature, or an average (possibly weighted) of the two sectors. Further consideration should be given to the use of moisture-related variables rather than temperature as the basis for downscaling and the use of multiple variables could also be explored. The use of temperature to define moisture-related thresholds (i.e., the BWk/BSk boundary) is considered to be the major cause of the relatively poor performance of the downscaling methodology in Central Spain (see Section 2.6). However, further review of the palaeoclimatic evidence, the characteristics of potential analogue stations and palaeo-model simulations (e.g., from PMIP), may also help to address these problems. Future work for Central Spain could also involve application of the methodology to LLN-2D NH output (which can be obtained from UCL-ASTR).

Some of the sources of uncertainty and difficulty involved in the rule-based downscaling methodology have been discussed in earlier sections of this deliverable. These sources, together with a number not previously discussed, are summarised below:

- an element of subjective judgement is involved, particularly in Steps 1, 3, 5 and 6;
- it has to be assumed that the rules/thresholds apply in the future;
- the validity of the latter assumption cannot be tested;
- independent validation for past periods is difficult;
- there is a danger of circularity of argument in identifying rules/thresholds and evaluating the method, also in identifying rules/thresholds for enhanced warming states from future simulations, which are then used to downscale the same simulations;
- it is not possible to isolate and quantify the main sources of error, i.e.,
  - errors in the underlying climate classifications (shown in Section 2.1);
  - errors in the definition of rules/thresholds (see Section 2.6); and,
  - errors in the climate model simulations (discussed for MoBidiC in Section 2.6).
- thus it is not possible to quantify all the uncertainties or to provide error bars on the downscaled results;

- only single variables are used to define each threshold, whereas the use of multiple variables may give improved results;
- the use of temperature to define a moisture-related threshold is not desirable;
- a binary concordance index is used, i.e., correct (1) or incorrect (0), whereas some sort of weighted index could be used, e.g., to deal with periods of ambiguous classification and/or to reflect the severity of any mis-match;
- although the analogue stations are carefully selected for each case-study region, it must be acknowledged that there is no such thing as a 'perfect analogue' and 'no analogue' periods can occur; and,
- the analogue station data come from the latter part of the 20th century, typically 1961-1990, and hence all these series are likely to incorporate some element of global warming.

While this list of problems may appear rather daunting, the rule-based downscaling methodology is considered to have two major advantages so far as the aims and objectives of BIOCLIM are concerned:

- it is computationally undemanding (compared with running general circulation or regional climate models, for example); and,
- the use of climate classes and states is consistent with the BIOMASS methodology.

In addition, the outputs are sufficiently flexible (see Section 2.4, for example) that they can be used both qualitatively and quantitatively for performance assessment (see Ref.6). The Køppen/Trewartha classification scheme is considered the most appropriate for BIOCLIM (see Section 1) and has the advantage of being empirical. It is also flexible: classifications at the two, three and four-letter levels have been used to develop the rule-based downscaling methodology. This classification has also provided a useful basis for inter-comparisons with results from the other downscaling methods used in BIOCLIM. These inter-comparisons are presented in Section 3.4 of Deliverable D10-12, which also discusses some of the broader uncertainties associated with construction of the BIOCLIM scenarios, e.g., those related to inter-emissions scenario and inter-model variability.

The downscaled climate indices and accompanying analogue data presented here provide useful qualitative and quantitative input to performance assessment. The development of the methodology draws strongly on the consolidating work of the country teams involved in BIOCLIM (see Ref.8) and the UCL-ASTR climate modelling group (see Ref.1). The country teams have also been closely involved in many of the methodological steps described here. Thus the process of developing the methodology has provided a valuable opportunity for BIOCLIM partners from different disciplines to work together and has provided ongoing input into the Work Package 4 work on exploring and evaluating the potential effects of climate change on the nature of biosphere systems.

5. References

Ref. 1: BIOCLIM Report D7. Continuous Climate Evolution Scenarios Over Western Europe (1000km Scale).

Ref. 2: Burgess, P.E. 1998: Future Climatic and Cryospheric Change on Millennial Timescales: An Assessment using Two-Dimensional Climate Modelling Studies. PhD Thesis, University of East Anglia, Norwich, UK.

Ref. 3: BIOCLIM Report D8b. Development of the Physical/Statistical Downscaling Methodology and Application to Climate Model CLIMBER for BIOCLIM Work Package 3.

Ref. 4: BIOCLIM Report D4/5. Global Climatic Characteristics, Including Vegetation and Seasonal Cycles Over Europe, for Snapshots Over the Next 200,000 Years

Ref. 5: BIOCLIM Report D6a. Regional Climate Characteristics for the European Region at Specific Sites: The Dynamical Downscaling.

Ref. 6: BIOCLIM Report D10 - 12. Development and Application of a Methodology for Taking Climate-Driven Environmental Change into Account in Performance Assessments.

Ref. 7: Rudloff, W., 1981: World-Climates, Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart, 632pp.

Ref. 8: BIOCLIM Report D2. Site-specific and Palaeo Environmental Data.

Ref. 9: Walter, H., 1984: Vegetation of the Earth and Ecological Systems of the Geo-biosphere. 3rd edition, Springer Verlag.

Ref. 10: Lomba, L., Recreo, F. and Ruiz, C., 2002: Preliminary Identification of Meteorological Stations as Potential Climate Analogues.

Ref. 11: Goodess, C.M., Palutikof, J.P. and Davies, T.D., 1992: The Nature and Causes of Climate Change: Assessing the Long-term Future. Belhaven Press, London.

Ref. 12: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dal, X., Maskell, K. and Johnson, C.A. (eds), 2001: Climate Change 2001: The Scientific Basis. Cambridge University Press.

Ref. 13: Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassel, D., Boorman, P., McDonald, R. and Hill, S., 2002: Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK, 120pp.`

Ref. 14: Lomba, L., Recreo, F. and Ruiz, C., 2003: Preliminary Identification of Meteorological Stations as Potential Warm Climate Analogues.

Ref. 15: Recreo, F., 2003: Preliminary Analysis of the Meteorological Stations as Analogue Climate Stations.

Ref. 16: Shaw, E.M., 1983: Hydrology in Practice. Van Nostrand Reinhold, UK.

Ref. 17: Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.-M., Basile, I., Benders, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V., Legrand, M., Lipenkov, V.Y., Lorius, C., Pépin, L., Ritz, C., Saltzman, E. and Stievenard, M., 1999: Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, Nature, 399, 429-436.

Ref. 18: BIOCLIM Report D3. Global Climatic Features Over the Next Million Years and Recommendation for Specific Situations to be Considered.

Ref. 19: Gallée, H., van Ypersele, J.P., Fichefet, T., Tricot, C. and Berger, A., 1991: Simulation of the last glacial cycle by a coupled sectorially averaged climate-ice sheet model. Part I: The climate model, Journal of Geophysical Research, 96, 13139-13161.

Ref. 20: Crucifix, M., Loutre, M.F., Tulkens, P., Fichefet, T. and Berger, A., 2002: Climate evolution during the Holocene: A study with an Earth system model of intermediate complexity, Climate Dynamics, 19, 417-433.

Ref. 21: Marsiat, I. and Berger, A., 1990: On the relationship between ice volume and sea level over the last glacial cycle, Climate Dynamics, 4, 81-84.

Ref. 22: Aalbersberg, G. and Litt, T., 1998: Multiproxy climate reconstructions for the Eemian and Early Weichselian, Journal of Quaternary Science, 13, 367-390.

Ref. 23: Thorne, M.C., 2003: Extraction of Climatic Gradients.

Ref. 24: FARJANEL G., RAZIN P. and COURBOULEIX S. (1991) – Histoire du Würm et de l'Holocène en France. Rapport ANDRA 620 RP BRG 91-011.

Ref. 25: WOILLARD G. (1980) – The pollen record of Grande Pile (NE France) and the climatic chronology through the last interglacial-glacial cycle. Suppl. au Bulletin de l'AFEQ, n° Spéc. 1, p. 95-103.

Ref. 26: HULME, M (2001) – Gradients of Temperature and Precipitation across the British Isles in the Instrumental Record, CRU Research Paper Number 2 (Second Series), Climate Research Unit, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, May 2001.

Ref. 27: JONES P.D. (2001) – Instrumental and Palaeoclimatic Records for the last Millenium: Sensitivity to Natural and Anthropogenic Forcing, CRU Research Paper Number 1 (Second Series), Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK.

Ref. 28: PRENTICE I.C., GUIOT J., HUNTLEY B., JOLLY D. and CHEDDADI R. (1996) – Reconstructing biomes from palaeoecological data: a general method and its application to European pollen data at 0 and 6 ka, Climate Dynamics, 12, 185-194.

Ref. 29: COOPE G.R., LEMDAHL G., LOWE J.J. and WALKING A. (1998) – Temperature gradients in northern Europe during the last glacial-Holocene transition (14-9 14C kyr BP) interpreted from coleopteran assemblages, Journal of Quaternary Science, 13, 419-433.

Ref. 30: HUIJZER A.S. and ISARIN R.F.B. (1997) – The reconstruction of past climates using multi-proxy evidence: an example of the Weichselian Pleniglacial in Northwest and central Europe, Quaternary Science Reviews, 16, 513-533.

Ref. 31: LOWE I.J., AMMANN B., BIRKS H.H., BJÖRCK S., COOPE G.R., CWYNAR L., DE BEAULIEU J-L., MOTT R.J., PETEET D.M. and WALKER M.J.C. (1994) – Climatic changes in areas adjacent to the North Atlantic during the last glacial-interglacial transition (14-9 ka BP): a contribution to IGCP-253, Journal of Quaternary Science, 9, 185-198.

Ref. 32: PEYRON O., GUIOT J., CHEDDADI R., TARASOV P., REILLE M., DE BEAULIEU J-L., BOTTEMA S. and ANDRIEU V. (1998) – Climatic reconstruction in Europe for 18,000 yr B.P. from pollen data, Quaternary Research, 49, 183-196.

Ref. 33: ATKINSON T.C., BRIFFA K.R. AND COOPE G.R. (1987) – Seasonal temperatures in Britain during the past 22,000 years, reconstructed using beetle remains, Nature, 325, 587-592.

Appendix 1: the køppen/trewartha climate classification scheme

A tropical climates:	over 17°C in all months	Ar tropical rain Am tropical monsoonal rain Aw tropical summer rain As tropical winter rain
C subtropical climates:	over 9°C 8-12 months	Cr subtropical rain Cw subtropical summer rain Cs subtropical winter rain
D temperate climates:	over 9°C 4-7 months	DO temperate oceanic DC temperate continental
E subarctic climates:	over 9°C 1-3 months	EO subarctic oceanic EC subarctic continental
F polar climates:	over 9° no month	FT tundra FI ice
B dry climates:	evaporation > precipitation	BS steppe BW desert BM marine desert

The rules for Køppen/Trewartha climate classification shown below are taken from pages 84-85 of Rudloff [ref.7]. Within BIOCLIM, they are applied to long-term averages of monthly temperature and precipitation from potential analogue stations as part of the rule-based downscaling methodology (see Section 2.3). They have also been applied to monthly temperature and precipitation averages from the General Circulation Model and Regional Climate Model used in BIOCLIM Work Package 2 (see Ref.4 and Ref.5) in order to inter-compare the various downscaling methods used in BIOCLIM (see Section 3.4 of Deliverable D10-12).

The following variables must be calculated in order to classify each station or model gridbox:

Tann = mean annual temperature

Rann = mean annual precipitation

Rsum = mean precipitation in summer (April-September)

Rwin = mean precipitation in winter (October to March)

RW = desert limit of precipitation = 10(*Tann*-10) + 300 *Rsum/Rann*

rmin = mean monthly precipitation of the driest month

R' = 25(100-*rmin*)

First of all, one has to ask whether annual precipitation is lower than the desert limit:

- *The climate is BW* if *Rann* < *RW.*
- *The climate is BM* if *Rann* < *RW* and the place is near the coast and has a high air humidity.
- *The climate is BS* if *Rann* < *2 RW.*
- *The class is not B* if *Rann* ≥ *2 RW.*

Secondly, one has to ask how many months are > 17°C:

- If all months are, *the climate is A.*

Then one has to ask how many months have > 59 mm precipitation:

- *The climate is Ar* if more than 9 months do.
- *The climate is Am* if *Rann* ≥ than *R'*: otherwise
- *The climate is Aw* if *Rwin* < *Rsum*, and
- *The climate is As* if *Rsum* < *Rwin*.

If not all months, or none, are > 17°C, we have to ask how many months are > 9°C:

- *The climate class is F* is there are no months > 9°C,
- *the climate class is E* if there are 1-3 months > 9°C,
- *the climate class is D* if there are 4-7 months > 9°C, and
- *the climate class is C* if there are more than 7 months > 9°C.
- *The climate is Cr* is the class is C and the driest month of summer has > 29 mm precipitation.
- *The climate is Cs* if rmin is in summer with < 30 mm precipitation and is exceeded at least three times by the wettest month in winter, and *Rann* < 890 mm; otherwise
- *the climate is Cr.*
- *The climate is Cw* if *rmin* is in winter and is exceeded at least ten times by the wettest month in summer; otherwise
- *the climate is Cr.*

(The foregoing procedure can also be applied to characterise D climates by means of r, s and w. s and w can also be applied without restriction to B, E and F climates. However, this was not done within BIOCLIM)

The next question is how many months there are < 0°C:

- *The climate is FI* if the class is F and all months < 0°C; otherwise *the climate is FT.*
- *The climate is DO* if the class is D and no month < 0°C; otherwise *the climate is DC.*
- *The climate is EO* if the class is E and no month < –9°C; otherwise *the climate is EC.*

The classifications are prefixed by a G if the height of the place is between 500 m and below 2500 m, by an H if it is 2500 m or more. In addition to this all classifications can be expanded by two code letters of the thermal standard scale indicating the warmth of summer and the cold of winter corresponding to the maximum and minimum of the mean monthly air temperature.

Universal Thermal Scale:

35°C	to …	severely hot	i
28°C	to 34°C	very hot	h
23°C	to 27°C	hot	a
18°C	to 22°C	warm	b
10°C	to 17°C	mild	l
0°C	to 9°C	cool	k
-9°C	to –1°C	cold	o
-24°C	to –10°C	very cold	c
-39°C	to –25°C	severely cold	d
…	to –40°C	excessively cold	e

Appendix 2: regional climatic sequences - tables from deliverable D2

***Table 3.1 from Deliverable D2:** Situations and Parameters selected for the Climatic Scenario at the Meuse/Haute-Marne site during last glacial cycle.*

Climatic evolution			Calendar Age (ka BP)	Estimated Duration (ka) including transition durations	Temperature (°C) annual thermal value	
OIS	*SELECTED EVENTS* N° *	Name			"Warm" Scenario	"Cold" Scenario
1	13	Holocene	0 – 10	10	+10°	+ 10°
2	12	Younger Dryas	10 – 11	1	- 1°	- 3°
	11	Late glacial	11 – 15	4	+ 4°	+ 2°
3	10	Maxi glacial	15 – 26	11	- 6°	- 12,5°
	9	Interstade	26 – 32	6	+ 2°	+ 1°
	8	Cold glacial	32 – 51	19	- 5°	- 10°
	7	Temperate glacial	51 – 70	19	0°	- 2°
4	6	Early glacial	70 – 76	6	- 4°	- 8°
5	5	St Germain II	76 – 85	9	+ 5°	+ 2°
	4	Melisey II	85 – 91	6	- 3°	- 5°
	3	St Germain I	91 – 100	9	+ 6°	+ 3°
	2	Melisey I	100 – 106	6	0°	- 2°
	1	Eemian	106 – 126	20	+ 11°	+ 11°

** these thirteen climatic events (stages) are arbitrarily numbered in their natural succession, from the oldest to the most recent.*

***Table 3.2 from Deliverable D2:** Climatic Parameter Values and Time Uncertainties from the Grande Pile Analysis.*

Grande-Pile stratigraphy (1)		OIS	T (°C) (estimated)		Proposed Climatic Scenario (2)			Grande-Pile climatic reconstruction (pollen & beetles) (3)		
Age (ka BP)	Local name		Summer	Winter	Stage	Age (ka BP)	Name	Name	Age (ka BP)	T°C(r)
0 - 10.2	Holocene	1			13	0 - 10	Holocene	Holocene	0 - 11	10
10.2 - 10.7	Recent Dryas	2			12	10 - 11	Recent Dryas	Recent Dryas	11 - 13.5	3
10.7 - 29	Lanterne III				11	11 - 15	Late glacial	Late glacial	13.5 - 18.5	5
		3			10	15 - 26	Maxi glacial	Maxi glacial	18.5 - 29	0
					9	26 - 32	Interstade	Glacial	29 - 73	2
29 - 70	Lanterne II				8	32 - 51	Cold glacial			
		4			7	51 - 70	Temperate glacial			
70 - 75	Ognon – Lanterne I				6	70 - 76	Early glacial			
75 - 85	St Germain II	5a	15.5	-1	5	76 - 85	St Germain II	St Germain II	73 - 88	9
85 - 95	Melisey II	5b			4	85 - 91	Melisey II	Melisey II	88 - 94	4
95 - 105	St Germain I	5c	15.5	-1	3	91 - 100	St Germain I	St Germain I	94 - 103	8
105 - 115	Melisey I	5d			2	100 - 106	Melisey I	Melisey I	103 - 109	3
115 - 127	Eemian	5e	15.5	-1	1	106 - 120	Eemian	Pre Melisey	109 - 116	5
							Eemian	116 - 129	9	

(1) from [Ref. 24]
(2) from Table 3.1
(3) from [Ref. 25]

Table 4.5 from Deliverable D2: *Characterisation of Climate States Sequences for Southern Spain during the last Climatic Cycle.*

Calendar Age (ka PB)	OIS	Local Name for southern Spain reconstruction	Mean Annual Temperature (°C)	Mean Annual Precipitation (mm)	Climate Class			Comments
					Køppen-Trewartha	Walter	Rivas Martinez	
0 - 5.4	1	Subboreal	13-17 to 17-19	<600-1000	Cs	ZB IV	Mesomediterranean to thermomediterranean, dry to subhumid	More uncertainty and climatic variability, with marked pluvial fluctuations and drier tendency. Slight deterioration of climatic conditions.
5.4 - 6.3	1	Atlantic	17-19	600-1000	Aw	ZB II	Thermomediterranean, subhumid	Thermal Optimum
6.3 - 7.9	1	Atlantic/Boreal	-	-	Cs	ZB IV	Mesomediterranean, subhumid	Maximum of deciduous Quercus curve.
7.9 - 8.2	1	Boreal	17-19	600-1000	Cs	ZB IV	Thermomediterranean, subhumid	-
8.2 - 10.3	1	Preboreal/Boreal	13-17	350-600	Cs	ZB IV	Mesomediterranean, dry	-
10.3/10.0 - 11/10.7	1	Younger Dryas	4-8	200-350	BSk	ZB III/IV	Oromediterranean, arid to semiarid	Rapid climatic deterioration. Arid but as cold as the Oldest Dryas, or even the Final Würm / Middle Würm.
11.0/10.7 - 13.3/12	2	Bølling-Allerød Late Glacial Interstadial	8-13 to 13-17	200-600 to 600-1000	Cf	ZB VI	Supramediterranean to mesomediterranean, semiarid or dry to subhumid	Specific climatic amelioration toward 13 Ka BP (at 10 ka BP for the rest of Europe). Vegetation recovery, especially oak forests, *Quercus* ilex and deciduous *Quercus*. Both then dominate the arboreal stratum to the present time.
13.3/12.8 - 15.2	2	Oldest Dryas	4-8 to 8-13	350-650 to 200-350	BSk	ZB III/IV	Oromediterranean to supramediterranean, dry to semiarid	-
15.2 - 19.8	2	Final Würm	<4	<200-350	EC-FT	ZB VIII/IX	Cryomediterranean, dry	Last Glacial Maximum toward 18 Ka BP. Steppe and semidesert conditions alternate.
19.8 - 23.6	2	Final Würm/ Middle Würm	4-8 or <4	<200-350	EO-EC	ZB VIII	Oromediterranean or cryomediterranean, arid	Cold and arid, semidesert. Minimum average temperature of coldest month below –7ºC. Around 19.8 ka BP more becomes more like semidesert.
24 - 38	3	Middle Würm	8-13 to 4-8	200-350 to 350-600	DCa-DCb	ZB VI/VIII	Supramediterranean to oromediterranean, semiarid to dry	Slightly arid environmental conditions. Poorly marked climatic episodes due to varied climatic gradations. Little climatic fluctuation.
>38	3		-	-	-	-	-	No data at Padul for this period. Palynology indicates very arid vegetation.
<63.5	4	Eowürm	4-8	<200	BSk	ZB III/IV	Oromediterranean, arid	Cold and extremely arid episode.
>63.5 - 84	5a	St. Germain II	13-17	>200 to 650-1000	Cs	ZB IV	Mesomediterranean	General thermal recovery, although it includes the early part of the regression to the colder and arid OIS 4 period.
84 - 96	5b	Mélisey II	8-13	350-600 to 200-350	BSk	ZB III/IV	Supramediterranean, dry to semiarid	-
96 - 104	5c	St. Germain Ic	13-17	650-1000	DO	ZBVI	Mesomediterranean, subhumid	-
	5c	St. Germain Ib	13-17	600-1000	DO	ZBVI	Mesomediterranean, subhumid	-
	5c	St. Germain Ia	8-13	200-350	DO - DC	ZBVI	Supramediterranean semiarid	Slight climatic deterioration.
	5c	-	17-19	350-650	Cs	ZBIV	Thermomediterranean, dry	-

Calendar Age (ka PB)	OIS	Local Name for Central England reconstruction	Description	Mean Annual Temperature (°C)		Køppen Trewartha Climate Class	Basis	Refs.
				Best Estimate	Uncertainty			
0 - 5	1	Recent Holocene	Within range of current UK climate, as characterised by the instrumental record and confirmed by longer-term palaeodata. Vegetational characteristics similar to those at the present day.	+10	±2	DO	Direct observation	[Ref. 26] [Ref. 27]
5 - 7	1	Holocene Thermal Optimum		+12	±2	DO	Increase in temperature of about 2oC across much of Europe.	[Ref. 28]
7 - 10	1	Early Holocene		+10	±3	DO	By 9.6 ka BP temperatures in the British Isles were as warm, or even warmer than, at the present day	[Ref. 29]
10 - 10.5 10.5 - 11	1 1	Late Younger Dryas Early Younger Dryas	A period of intense cold associated with the formation of corrie glaciers in he British uplands	-8 +0	±6 ±6	EC EC	Ensures that the rapid temperature fall at the beginning of the Younger Dryas is in accord with observations from Britain and the Netherlands and that both periods are consistent with Atkinson et al. Climate classification recognises warm summers and extremely cold winters.	[Ref. 30] [Ref. 31]
11 - 13	1 or 2	Windermere interstadial		+8	±3	DC	Coldest month a little below 0°C and warmest around 16°C, based on individual fauna.	[Ref. 30]
13 - 18	2	Late Glacial		-10	-14 to +2	FT	No indication of significant warming during ice retreat	[Ref. 30]
18 - 22	2	Last Glacial Maximum	Ice-sheets covered most of Northern Britain. Southern Britain was periglacial in character.	-10	-14 to +2	FT	Coleopteran reconstruction from [Ref.33] suggests a mean annual temperature of –4oC, but the results for individual fauna reported in their paper suggest a lower value, more in accord with the work of Peyron et al. The upper bound of the uncertainty range is supported by Atkinson et al., but not by Peyron et al. The lower bound is consistent in both reports.	[Ref. 30] [Ref. 32]
22 - 38	2 or 3		Not characterised.	-	-	-	-	-
38 - 41	3	Middle Weichselian pleniglacial	Brief period of exceptionally cold conditions	-9	±2	FT, possibly EC	Sites from Central England. Uncertainty is based on variability between these sites	[Ref. 30]
41 - 77	3 or 4		Generally cooling relative to the Oddrade interstadial	-	-	-	-	-
77 - 91	5a	Oddrade interstadial	For vegetational associations and a general description of conditions, see the main text.	+3 [Ref. 117]	±3	EO	Similar in northwest Europe to the Brørup interstadial	[Ref. 22]
91 - 97	5b	Rederstall stadial		0	±3	EC or EO	Based on general northwest European data, but no specific British data. Difficult to select EC or EO, as coldest month was around –10°C.	[Ref. 22]
97 - 104	5c	Brørup interstadial		+3	±3	EO	Based on time slice 5 of Aalbersberg and Litt. Small temperature amplitude indicates oceanic climate.	[Ref. 22]
104 - 116	5d	Herning stadial		-7	±3	EC	Based on time slice 4 of Aalbersberg and Litt, but for only one British site; uncertainty based on time slice 5	[Ref. 22]
116 - 131	5e	Eemian		+10	±2	DO	Based on time slices 1 to 3 of Aalbersberg and Litt	[Ref. 22]

Table 5.4 from Deliverable D2: *Characterisation of Climate States Sequences for Central England during the last Climatic Cycle.*

Appendix 3: finalisation of the last climatic cycle sequences for central england and northeast France

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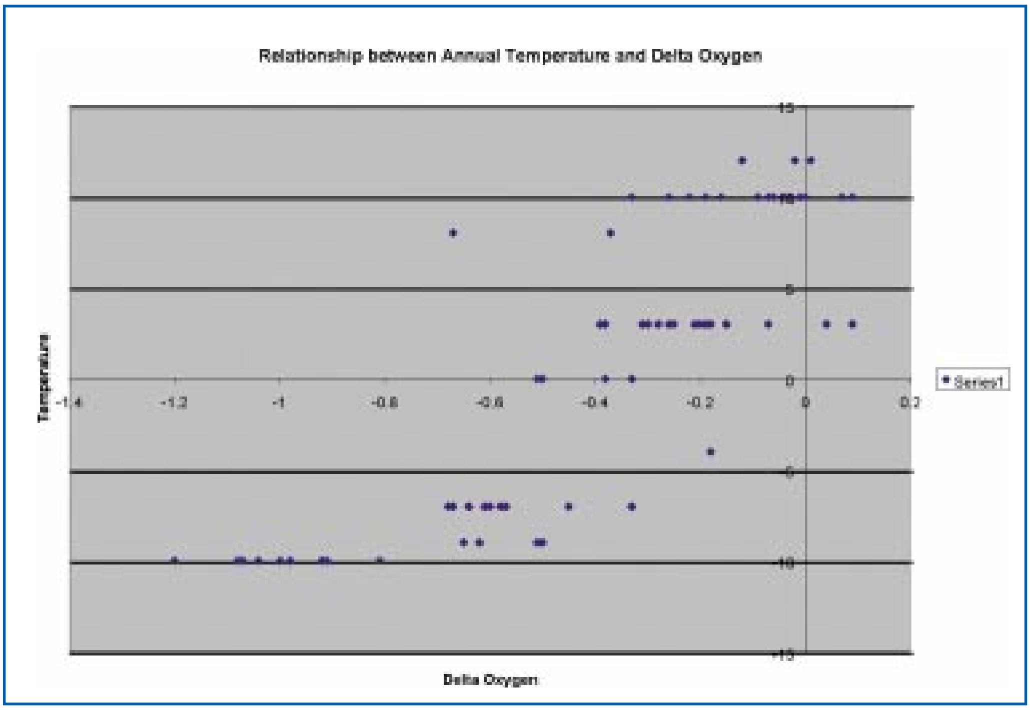
External Memorandum

Thursday, April 18, 2002

From: M C Thorne
To: C M Goodess
Copies: P Degnan, B M Watkins, D Texier
Subject: Assignment of Climate Classes

Clare

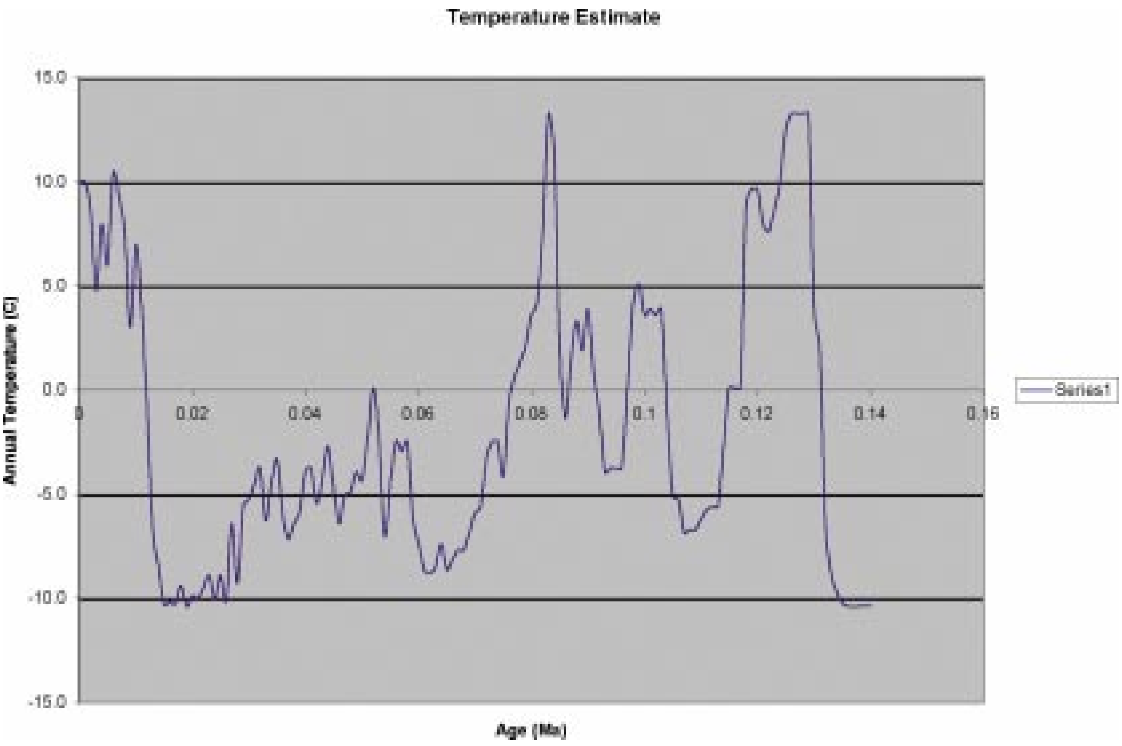
Under actions TA4/8 and TA4/11, I have given further consideration to the Köppen-Trewartha Climate Classes in Table 5-4 (D2, page 98), as reproduced in the Appendix to your discussion document prepared for BIOCLIM ME4. I think that the only outstanding issue is the association of climate classes with the periods 22-38 ka BP and 41-77 ka BP. To do this, I have taken the SPECMAP oxygen isotope ratios over the last 131 ka and related them to my best estimates of Central England mean annual temperature. Results are shown in the following figure.



The two, slightly odd points at +8°C relate to the Windermere Interstadial and should not be given undue weight. Excluding these points, the data are well fitted by:

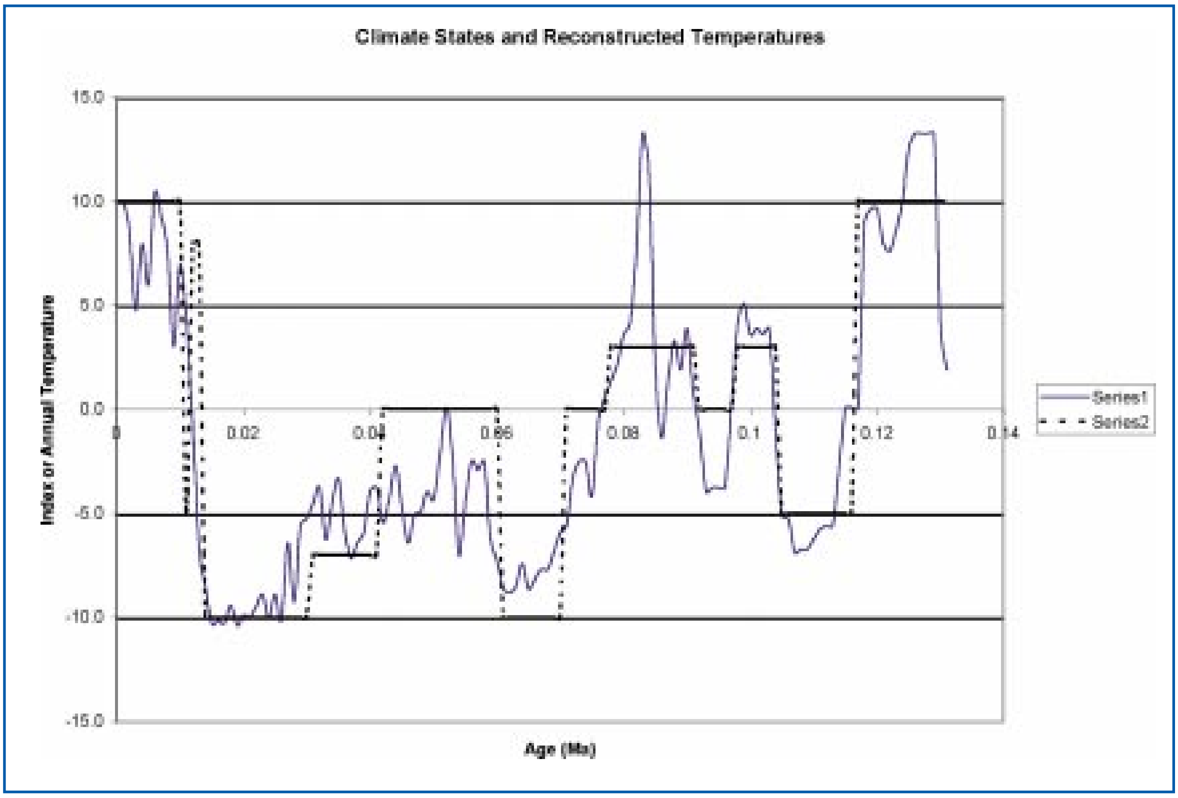
$$T = 10 + 35\Delta + 15\Delta^2$$

Where T (oC) is the mean annual temperature and Δ is the $\delta^{18}O$ value. Applying this relationship, I reconstruct mean annual temperatures as shown in the following figure.



This shows that mean annual temperatures over the period 38 to 22 ka BP declined rapidly. As I assign 41-38 ka BP to FT, possibly EC, I think that this classification should be extended to around 30 ka BP. Between 30 ka BP and 22 ka BP, I think that we can reasonably conclude that FT applies. The period from 77 to 41 ka BP is best split into 77 to 70 ka BP, 70 to 60 ka BP and 60 to 41 ka BP. The period from 70 to 60 ka BP is more extreme than the Herning Stadial (EC) and approaches the LGM in severity (FT). Overall, my inclination would be to treat OIS 4 as a full glacial and assign this period to FT. The period from 60 to 41 ka BP is probably a little warmer than the Middle Weichselian pleniglacial (FT possibly EC) and appears similar to the Rederstall stadial (EC or EO). It is definitely warmer than the Herning stadial (EC). Overall, EC or EO seems the most reasonable attribution. The period from 77 to 70 ka BP is similar to the Rederstall stadial and is classified EC or EO. The following figure shows my reconstructed annual temperature estimates plotted against climate type. To bring these onto a common scale, I have used the following convention.

Class	Index Value (Similar to Annual Average Temperature)
DO	10
DC	8
EO	3
EO/EC	0
EC	-5
EC/FT	-7
FT	-10



This attribution of states seems reasonable. However, it is emphasised that the attribution of states to the mid-Devensian remains difficult and that the whole period from 30 to 60 ka BP could reasonably be characterised as EC.

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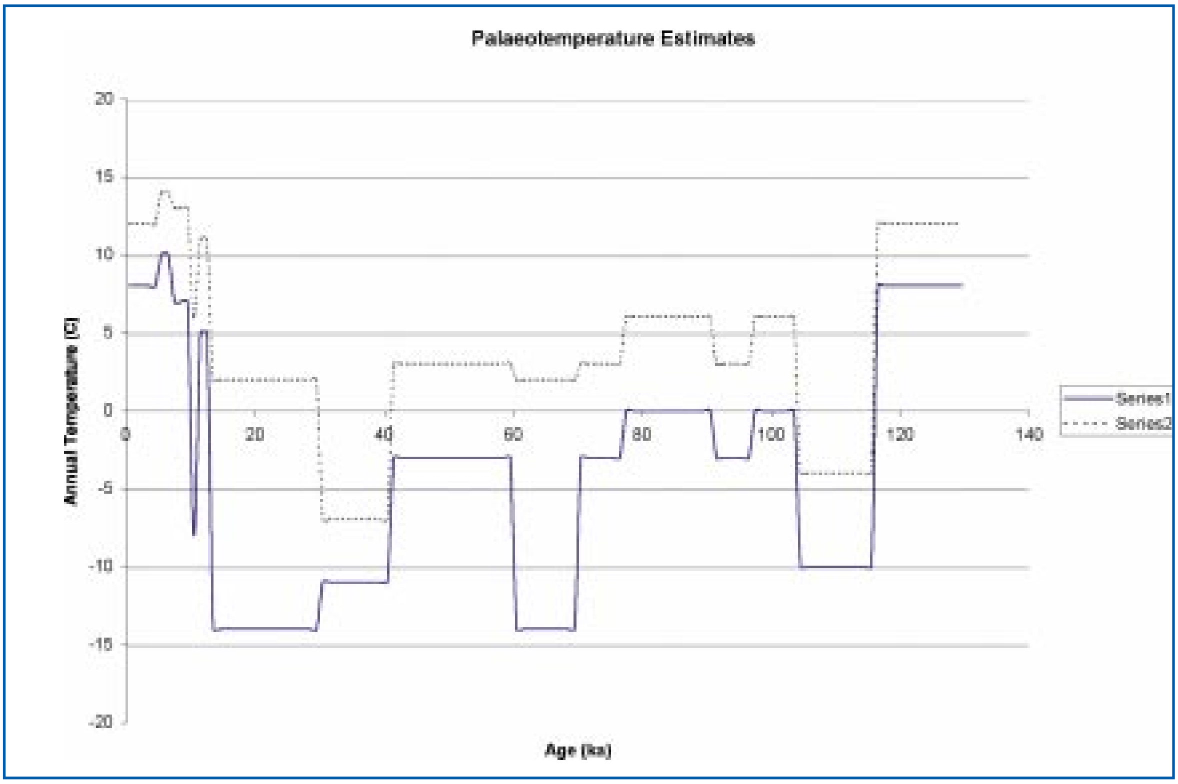
External Memorandum

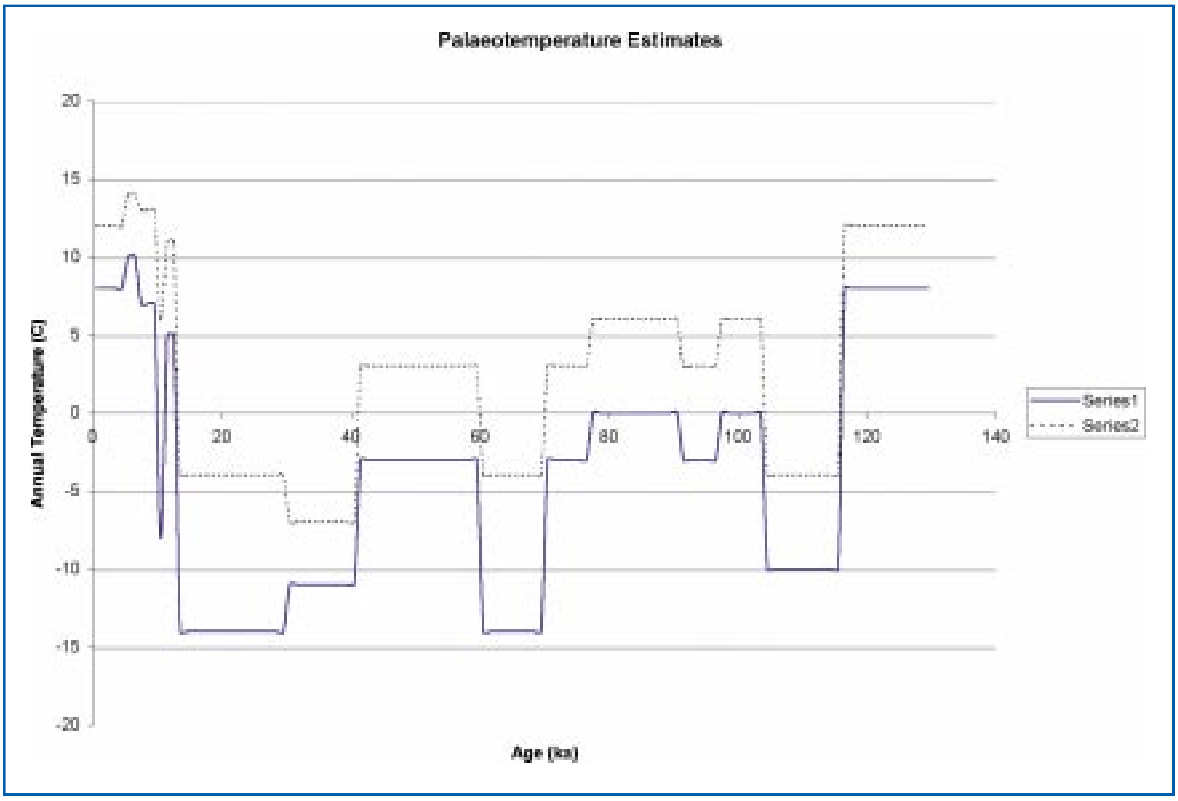
Tuesday, May 7, 2002

From: M C Thorne
To: C M Goodess, P Degnan, D Texier, B M Watkins
Copies:
Subject: Climate Uncertainties

I have been giving a bit more consideration to uncertainties in the past climate of Central England in the context of BIOCLIM action TA4/11. In my memo of Thursday 18th April, I assigned Köppen-Trewartha climate classes to the periods 22-38 ka BP and 41-77 ka BP and made some remarks on the likely nature of the climate over those intervals. I thought that it would also be useful to produce a figure showing estimates of mean annual temperature over the last 131,000 years based on D2, Table 5-4 and my memo. This information is shown in the following figure, with the broken line being the upper limit and the full line the lower limit.



Personally, I think that the upper limits of the ranges assigned to glacial episodes are rather high. I would be tempted to set them down from +2°C to the value of –4°C adopted for the Herning stadial at 116 to 104 ka BP. If this is done, as in the following figure, reasonably tight constraints on annual temperature are obtained.



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External Memorandum

Saturday, July 6, 2002

From: M C Thorne
To: D Texier, C Goodess, P Degnan
Copies:
Subject: French Climate Classification

Dear All

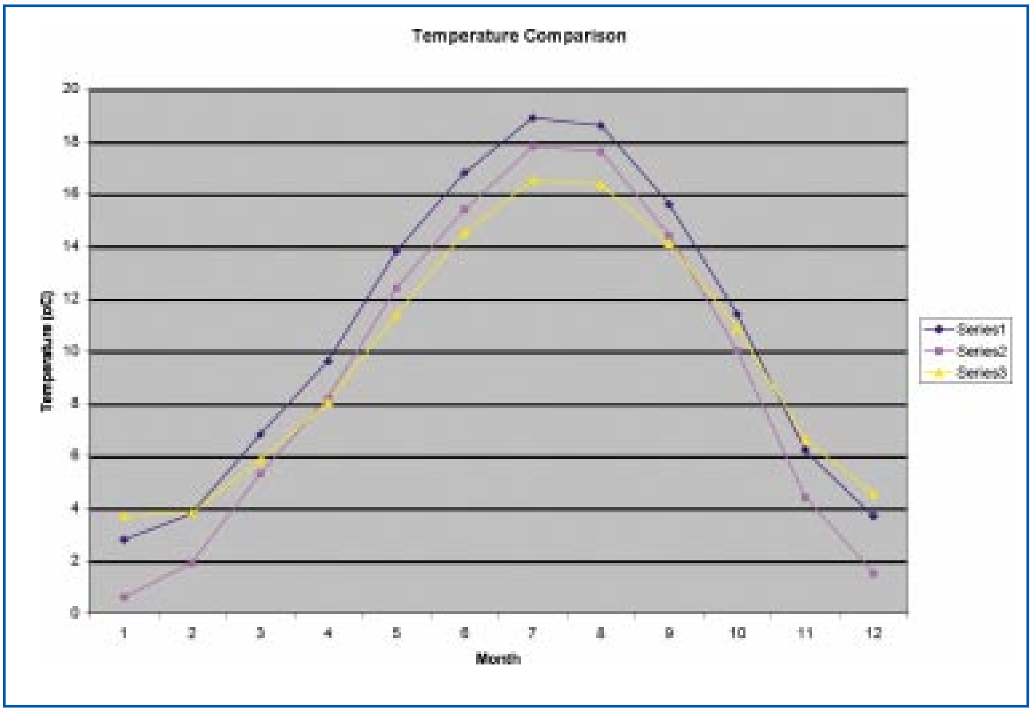
At the request of Delphine, I have been looking at the climate classification for Northeast France for the last glacial-interglacial cycle, to ensure that a consistent approach is adopted to the one that I have used for Central England. Various memoranda have been exchanged on this topic and I think that I am now in a position to offer a fairly definitive view.

The first matter to establish is appropriate time boundaries for the various characteristic intervals of the last 130 ka. In Deliverable D2, we have two French classifications, listed and compared in Table 3-2. The British classification is given in Table 5-4. We also have the Quaternary stratigraphic nomenclature given at Table 1-1 of that report.

Here, I deal with each of the periods in sequence, starting from the youngest.

Holocene (0-10 ka BP)

There is little dispute about the date of the beginning of the Holocene. Tables 1-1, 3-2 and 5-4 place it at 10 ka BP (except for the Grande Pile climate reconstruction which places it at 11 ka BP – this date is not adopted because the Grande Pile stratigraphy places it at 10.2 ka BP). Tables 1-1 and 5-4 divide it into sub-stages, but this is over-elaborate for climate classification. In Central England, the mean annual temperature at the Holocene thermal optimum was about 2°C warmer than at the present day (Table 5-4). Based on modern instrumental climate records, a classification of DO is appropriate and this classification would not be altered by a 2°C rise in mean annual temperature. For the French site, I have examined instrumental data from Saint-Dizier and Langres. Both of these should currently be classified as DO. I have compared the mean monthly temperatures for these two sites with the average of the climate stations selected to be representative of Central England. Results of this comparison are shown in the following figure.



Series 1 is Saint-Dizier, Series 2 is Langres and Series 3 is the mean of the Central England analogue stations. Although both Saint-Dizier and Langres exhibit slightly more seasonality than the mean UK station, no months are below 0°C, so they cannot be classified as DC. Furthermore, a comparison of the temperature cycle with that for Cr stations (not shown) demonstrates that this would be a highly inappropriate classification.

One point to note is that the French stations are somewhat wetter than the typical UK DO analogue station. The annual precipitation values are 830 and 893 mm at Saint Dizier and Langres, respectively, with the precipitation distributed reasonably uniformly throughout the year. The UK analogue stations also have precipitation distributed fairly uniformly throughout the year, with annual totals ranging from 553 to 869 mm (mean 635 mm). Therefore, in respect of precipitation, the French stations are no more continental than the UK analogues.

Younger Dryas (10-11ka BP)

Table 1-1, defines the Younger Dryas to cover the interval 10-11 ka BP. Table 3-2 uses the term Recent Dryas and gives age ranges of 10.2-10.7, 10-11 and 11-13.5 ka BP, respectively. It would generally be agreed that a duration of 2.5 ka for the Younger Dryas is too long. Table 5-4 distinguishes 10-10.5 and 10.5-11 ka BP as the Late Younger Dryas and Early Younger Dryas, respectively. However, this temporal resolution is considered unduly fine for the current application. Here, the conventional interval of 10-11 ka BP is adopted.

For Central England, the Late Younger Dryas was assigned a mean annual temperature of -8±6°C. This is almost as cold as full glacial conditions. However, the Early Younger Dryas was assigned a mean annual temperature of 0±6°C (Table 5-4). Overall, a reasonable compromise is to assign the Younger Dryas to EC. For Northeast France, the warm and cold mean annual temperature estimates are –1°C and –3°C. With a climate range of a little more than 16°C, as at the present day, this suggests that at least one month would have been colder than –9°C. Therefore, EC is marginally preferred.

Late Glacial (11-18ka BP)

For Central England, this period is distinguished into the Windermere Interstadial (11-13 ka BP) and the Late Glacial (13-18 ka BP). The Windermere Interstadial is assigned a mean annual temperature of 8±3°C, whereas the Late Glacial is assigned a mean annual temperature of –14 to 2 (best estimate –10) °C. Based on geomorphological evidence, the upper end of this range is thought to be unduly warm. As the Windermere Interstadial is rather cooler than the Holocene and would have been expected to exhibit winter temperatures below 0°C, it is classified as DC. The Late Glacial is assessed as being as cold as the Last Glacial Maximum (see below) and is, therefore, assigned to FT (no month over 9°C, but some months above 0°C).

At Grande Pile, the Late Glacial is defined as the whole period from the end of the Maxi glacial (Last Glacial Maximum) to the beginning of the Recent (Younger Dryas). It is assigned a mean annual temperature of 2, 4 or 5°C. However, regional data (Ref.8, Section 3.2.2) make a distinction between the cold Ancient Dryas early in the period and the later Bølling and Allerød episodes. These episodes were associated with a rise in temperature, colonisation of the steppe by shrubs and eventual development of boreal forest (Ref.8, Section 3.2.2).

Overall, it is difficult to distinguish the pattern of climate change between Northeast France and Central England. Therefore, the following joint scheme is proposed:

Windermere Interstadial/ Bølling-Allerød (11-13 ka BP): DC
Late Glacial/ Ancient Dryas (13-18 ka BP): FT

It is likely that a brief transition through EC/EO occurred late in the Ancient Dryas, as summer temperatures rose (F has no months over 9°C, E has 1-3 such months and D has 4-7). However, the regional data in both France and the UK suggest that the transition was very rapid, so it would be overcomplicating the description to introduce these additional states.

Last Glacial Maximum (18-28 ka BP)

During the period 18-22 ka BP, ice sheets covered most of Northern Britain and Southern Britain was periglacial in character. This is the period defined as the Last Glacial in Table 5-4. The mean annual temperature is estimated as about –10°C (Table 5-4). Unless, the regime was highly continental, this strongly suggests that no months had temperatures above 9°C. Therefore, FT is assigned. Even if the mean annual temperature was a few degrees higher, it would remain more likely than not that no months had temperatures above 9°C.

For Northeast France, the Maxi glacial is defined from 15 to 26 or 18.5 to 29 ka BP. The relatively late date for the end of the Maxi glacial in the former of these may reflect incorporation of the early (coldest) part of the Late Glacial. The extension to earlier dates is consistent with the interpretation of British Data. In an earlier memorandum, when assigning climate classes to Central England for periods for which directly relevant data are non-existent, I wrote:

Mean annual temperatures over the period 38 to 22 ka BP declined rapidly. As I assign 41-38 ka BP to FT, possibly EC, I think that this classification should be extended to around 30 ka BP. Between 30 ka BP and 22 ka BP, I think that we can reasonably conclude that FT applies. The period from 77 to 41 ka BP is best split into 77 to 70 ka BP, 70 to 60 ka BP and 60 to 41 ka BP. The period from 70 to 60 ka BP is more extreme than the Herning Stadial (EC) and approaches the LGM in severity (FT). Overall, my inclination would be to treat OIS 4 as a full glacial and assign this period to FT. The period from 60 to 41 ka BP is probably a little warmer than the Middle Weichselian pleniglacial (FT possibly EC) and appears similar to the Rederstall stadial (EC or EO). It is definitely warmer than the Herning stadial (EC). Overall, EC or EO seems the most reasonable attribution. The period from 77 to 70 ka BP is similar to the Rederstall stadial and is classified EC or EO.

On this basis, the whole period from 18-30 ka BP was assigned to FT. As I also assigned the period from 41-30 ka BP to EC/FT, it is fairly arbitrary as to where we define the beginning of the Maxi glacial/ Last Glacial Maximum. I propose, therefore, that we define the Last Glacial Maximum as the period 18-28 ka BP. French mean annual temperature estimates for this period are –6°C (warm) and –12.5°C (cold) (D2, Table 3-1). These are consistent with Central England estimates, so, by the same arguments, FT applies.

Early Glacial (28-41 ka BP)

As argued in the extract above, based on data for the Middle Weichselian pleniglacial at 41-38 ka BP, the whole of this period is characterised as EC/FT for Central England. However, in Table 3.1, the French distinguish an interstadial from 26 to 32 ka BP (mean annual temperature 1 or 2°C and, therefore, reasonably assigned to E) and a cold glacial from 32 to 51 ka BP, mean annual temperature –5 or –10°C, so properly assigned to FT).

Putting these two sets of data together, we have the following consistent picture:

Period (ka BP)	Central England	Northeast France
28-32	EC/FT	EC
32-41	EC/FT	FT

The period 28-32 ka BP has been assigned EC rather than EO for Northeast France solely on the basis of consistency with the Central England classification.

The Mid-Devensian (41-76 ka BP)

In Table 5-4, the Climate of Central England was described as generally cooling relative to the preceding Oddrade interstadial (OIS 5a – see below) over the period 77-41 ka BP. Subsequently (see above), I distinguished three periods 77-70 ka BP (EO/EC), 70-60 ka BP (FT) and 60-41 ka BP (EO/EC). The last of these periods is the Upton Warren interstadial, now dated at around 57 ka BP. However, it is not clear that it persisted through to 41 ka BP.

In Table 3-1, the period 76-70 ka BP is termed the Early glacial and is assigned a mean annual temperature of –4 or –8°C. As discussed for the Last Glacial Maximum, this implies a classification of FT. The period from 70-51 ka BP is described as Temperate glacial and is assigned a mean annual temperature of 0 or –2°C. The date of the Upton Warren interstadial falls within this interval. It seems most likely that this interval was EC, with at least one winter month below –9°C. As discussed above, the interval from 51-41 ka BP is classified as FT.

Overall, it seems appropriate to align the chronologies as set out in the following table:

Period (ka BP)	Central England	Northeast France
41-51	EO/EC	FT
51-60	EO/EC	EC
60-70	FT	EC
70-76	EO/EC	FT

It is emphasised that this interval is difficult to characterise. Evidence of palaeoclimatic conditions is limited and dates are difficult to establish. It is known that a number of climate oscillations occurred over the period and it is quite likely that the above classifications are biased because of the small number of sites studied. There is some suggestion that the climate in Northeast France was generally somewhat colder than in Central England, but a general classification of EC for the whole period in both countries would be plausible.

Oxygen Isotope Stage 5 (76-127 ka BP)

There is no debate about the sequence of events, with both the French and Central England classifications recognising OIS stages 5a-5e. The local names used are summarised below.

OIS	French Period Name	UK Period Name
5a	St Germain II	Oddrade Interstadial
5b	Melisey II	Rederstall Stadial
5c	St Germain I	Brørup Interstadial
5d	Melisey I	Herning Stadial
5e	Eemian	Eemian

However, there are some differences in dates. These are summarised below.

OIS	Dates (ka BP)					
	Table 1-1	Table 3-2: Grande Pile Stratigraphy	Table 3-2: Proposed Climate Scenario	Table 3-2: Grande Pile Climatic Reconstruction	Table 5-4	620 RP BRG 91-011
5a	77-91	75-85	76-85	73-88	77-91	75-85
5b	91-97	85-95	85-91	88-94	91-97	85-95
5c	97-104	95-105	91-100	94-103	97-104	95-105
5d	104-116	105-115	100-106	103-109/116	104-116	105-115
5e	116-131	115-127	106-120	109/116-129	116-131	115-130

The ambiguity under Table 3-2: Grande Pile Climatic Reconstruction arises because it is not clear whether the Pre-Melisey I should be assigned with Melisey I or the Eemian. The 620 RP BRG 91-011 data have been supplied more recently. Overall, it will be seen that the original climate scenario dates are anomalous. These have not been used and the following simplified system has been developed.

OIS	Period (ka BP)
5a	76-85
5b	85-95
5c	95-105
5d	105-117
5e	117-127

This is based on the orbitally tuned data given by R S Bradley, Palaeoclimatology, Academic Press, 1999, at Table 6.2, Column D. It is generally consistent with both the British and French schemes.

For Central England, I classified the Eemian as identical to the Holocene and this seems appropriate also for Northeast France. This and the other classifications for Central England are given in Table 5-4. For Northeast France, Melisey I is assigned a mean annual temperature of 0 or –2°C. As with the Temperate glacial (see above), this is most reasonably assigned to EC. St Germain I is appropriately somewhat warmer at 6 or 3°C. This seems best characterised as either EO or DC. It is likely to be close to the boundary of these two classes, with 3 or 4 months above 9°C. Melisey II is significantly colder than Melisey I at –3 or –5°C. It is not certain that there would have been any summer months over 9°C, so the best classification is EC or FT. St Germain II is assigned a mean annual temperature of 5 or 2°C, as with St Germain I either EO or DC seems plausible. Thus, the final classifications for OIS 5 are as listed below.

OIS	Period (ka BP)	Central England	Northeast France
5a	76-85	EO	DC/EO
5b	85-95	EO/EC	*EC/FT*
5c	95-105	EO	DC/EO
5d	105-117	EC	EC
5e	117-127	DO	DO

The two sets of classifications are highly consistent.

Summary

Overall, the following summary table is provided for use in the remainder of the project.

Period (ka BP)	Central England	Northeast France
0-10	DO	DO
10-11	EC	EC
11-13	DC	DC
13-18	FT	FT
18-28	FT	FT
28-32	EC/FT	EC
32-41	EC/FT	FT
41-51	*EO/EC*	*FT*
51-60	*EO/EC*	*EC*
60-70	*FT*	*EC*
70-76	*EO/EC*	*FT*
76-85	EO	DC/EO
85-95	EO/EC	*EC/FT*
95-105	EO	DC/EO
105-117	EC	EC
117-127	DO	DO

Less certain attributions are shown in italics.

Comments on the climate classification scheme for Northeast France from Paul Degnan (Nirex) to Mike Thorne - 9 July 2002

Thanks for Climate classification note. Just a couple of points.

When Delphine asked for a 'consistent approach' was it really to rationalise the time frames for the two regions into a single set, as shown in the summary table in your note? Or rather was it to ensure that the climate state shown for one region was consistent with the inferred climate state in the other at broadly the same time?

Given that there will some diachroneity in the transitions between one climate state and another (both in reality and hence also within the context of the Koppen-Trewartha classification scheme), one would not necessarily expect there to be an exact match in the timing of any transitions between the two areas. I believe that we would therefore be open to the criticism that we are ignoring local information (for both NE France and C England) that provides more precise age determinations for the transitions between climate states. You have provided very strong reasoning to support the single set of time frames, but it is nevertheless 'forcing' published ageing recommendations derived by the acknowledged experts into a more 'artificial' set of time frames.

If there is a good reason for it, then I would support the rationalisation you have provided in the summary table. However, I am not clear what is the use that would be made of a single set of times for the transitions in NW Europe

If Delphine was asking her question to ensure consistency in the climate state attributions (e.g. DO in C England should not occur at the same time as FT in NE France), or in the directions of movement between climate states, I can see that this would be a useful check between the published datasets, and your note usefully fulfils this. Perhaps Delphine could clarify her intention? The information you provided does however, raise a question about the published climate states, as follows:

Accepting (but ignoring) diachroneity, I would have though that whenever you had a given climate state in C England, it would correspond to the same climate state or one removed in NE France. For example, EO or EC in C England would be EC or FT in NE France, and you show that this is the case in all time periods. What I am less clear about is how you can have the different climate states in the two regions at the same time, but when you look at another time period you can reverse the order of the states during a given time frame. e.g. at 41-51 and 70-76 you show FT in NE France and EO/EC in C England (this sounds reasonable as 'relatively near' oceanic effects would warm the UK relative to the continental position of NE France). But for 60-70 ka BP you have FT in C England, while EC in NE France. In terms of expected climate distributions for western continents this doesn't seem right and also it reverses the positions of the climate states at the 41-51 and 70-76 time periods.

Another minor point. For the Last Glacial Maximum (page 4), you propose a time frame of 18-28 ka BP. However, I recall Geoff Boulton mentioning that the FennoScandian ice sheet bridged across the North Sea to the UK ice sheet at exactly this time. Therefore the inference is that FT conditions must have been established in C England prior to this time (at least 30 ka BP?). I am not certain if Geoff based his time assignment on geological or modelling evidence. If the latter, then I am happy to leave the LGM at 18-28 ka BP. If it is based on geological evidence however, and I think it is, then the time frame should extend further back.

Response from Mike Thorne to Paul Degnan, 9 July 2002

Thanks for your comments. My responses are given below.

a) I did not start out with a presumption of perfect chronological correlation. However, there does not seem to be any good evidence of diachronicity. For example, the Late Glacial through Younger Dryas through Holocene changes line up within a few hundred years at worst (this is considering the individual pollen zones, as well as the grosser climate periods that I have discussed). Leads and lags of a few hundred years would be expected in a perfectly synchronous system because of vegetational response times, e.g. advance from refuges. Similarly, the Grande Pile stratigraphy from OIS 5 is almost in exact temporal agreement with the general Quaternary stratigraphy from ocean sediment records (to within about 2000 years, which is approximately the resolution of those records). Correlations for OIS 2-4 are not be be relied on to the same degree, because of greater uncertainties in dating.

b) The single set of timings are not necessary for downscaling, rather they emerge naturally from the data. The earlier confusion arose because somewhat inappropriate times had been assigned to the French temperature scenario.

c) I agree that, in general, I would expect the French area to be more continental than Central England. However, at the present day, this distinction is small, as discussed in my note. It would, therefore, require only minor perturbations to distort this picture. Both locations are 'ice marginal' at times of maximum glaciation and details of margin fluctuations may have differed in the two areas. Therefore, the relation between the climate states in the two areas may not have been constant. Having said this, I think that the agreement is remarkably good. In the period 0-28 ka BP, there are no distinctions. At 28-32 ka BP, we may have the early extensive phase of the Fennoscandian ice over Britain (if Geoff is right), so the UK climate may have been depressed by being ice marginal. At

32-41 ka BP we may not be able to distinguish the states, but, if anything, Northeast France is more extreme. The distinctions between 41 and 76 ka BP are limited and probably reflect the paucity of data. The reversal at 60-70 ka BP is anomalous, but could reflect moderately extensive preferential ice development in Britain toward the end of OIS 4, so I would not rule it out. However, as I comment in the note, I would be happy to assign the whole period from 41 to 76 ka BP to EC in both areas. OIS 5 is interesting. If anything, the oscillations are more extreme in NE France than in Central England. This could reflect a bias with the French temperature estimates, but it could also reflect a bias in my Central England data with an emphasis on information from the Netherlands. However, I have preferred to go along with the material presented in D2, only adjusting the timings to remove the artificial anomalies that existed previously.

d) I hesitated over the date for the beginning of the LGM. My earlier judgement was that FT applied back to at least 30 ka BP in Central England. I still think that this is likely. However, given uncertainties in timing, my suggestion is that we can be fairly sure of FT back to 28 ka BP and then the climate could be either EC or FT back to 41 ka BP. Recall that when we train the rule-based downscaling, either EC or FT for this period will be recorded as correct. Therefore, if we are uncertain, we do not have to choose between them. I think that Geoff's date was based on geological evidence. However, it reflects a merging of the ice sheets somewhere between Norway and Scotland and does not necessarily imply that ice had pushed south into England. The relative growth of the Fennoscandian and British ice sheets at this time would have been strongly conditioned by the depression of ELA over Scotland and we do not have a good handle on this. In summary, we run out of data for Central England over this period and our knowledge of the size of the British ice sheet at this time is very limited. If anything, the oddity in the early glaciation is FT for NE France at 32-41 ka BP. This could be the result of overemphasis of the very cold period at 38-41 ka BP. However, in general terms, both records agree that FT (with oscillations to EC) is a good description of the period 41-13 ka BP.

Reply from Paul Degnan to Mike Thorne, 9 July 2002

Thanks for the comprehensive response Mike. The only outstanding questions are: 'is it necessary to have the rationalised timeframes used in the project (and for what exactly)?' and if they are used, is the need strong enough to counter criticism from external researchers about the rationale you have used to create the single set of time frames (as opposed to published determinations for the transitions)? This latter question only arises if the answer to the first part of the first question is 'yes' and depends perhaps on a 'political' decision.

Reply from Mike Thorne to Paul Degnan, 9 July 2002

I think that we only use timeframes for convenience. What we shall aim to do is develop downscaling rules to recover the past climate states. We can place different weights on the individual states to determine how important it is to match them and/or how confident we are in the class that we have assigned. The timeframes and weights can be different for different locations. Similarly, for future projections, the timing and duration of the states will be whatever they are predicted to be. They will not have to be reported as a single synchronous set across sites.

Appendix 4: selection of climate stations for central england

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External Memorandum

18 June 2002

From: M C Thorne
To: C M Goodess
Copies: D Texier, B M Watkins, P Degnan
Subject: Selection of Climate Stations

Clare

I have been through the data on available climate stations that you posted on the COBWEB site. You required selection of stations for use in downscaling. I have made a first pass at this for Central England, as described below.

As we have discussed previously, the relevant classes for this area are FT, EC, EO, DC, DO, Cr and Cs. Both warming and cooling transitions would be expected to proceed along this series, though sometimes the transitions would be so fast, e.g. in periods similar to the Late Glacial following the Last Glacial Maximum, that some states might appear to be omitted.

My general rules for selection are described below. Class specific rules are then given together with details on the climate stations that conform to all the rules.

Altitude

Central England generally lies at an altitude of less than 200 m, though ridge crests can reach 300 m. I have, therefore, selected stations with altitudes in the range 0 to 200 m.

Length of Record

Clearly, a good record for 1961-90 is fundamental. Therefore, climate normals with 100%, or close to 100%, coverage are important. However, high percentages are generally achieved when long time series are held. In order to study longer-term trends, it is desirable to include longer records. I, therefore, imposed a further requirement. This was that the first and last years of the CRU temperature and precipitation series should each span an interval of at least 50 years, and should also include the whole period 1961-90. This seemed likely to yield useful long records and also would tend to select stations for which the data would be of good quality. I made an exception from this rule for DO, as discussed below.

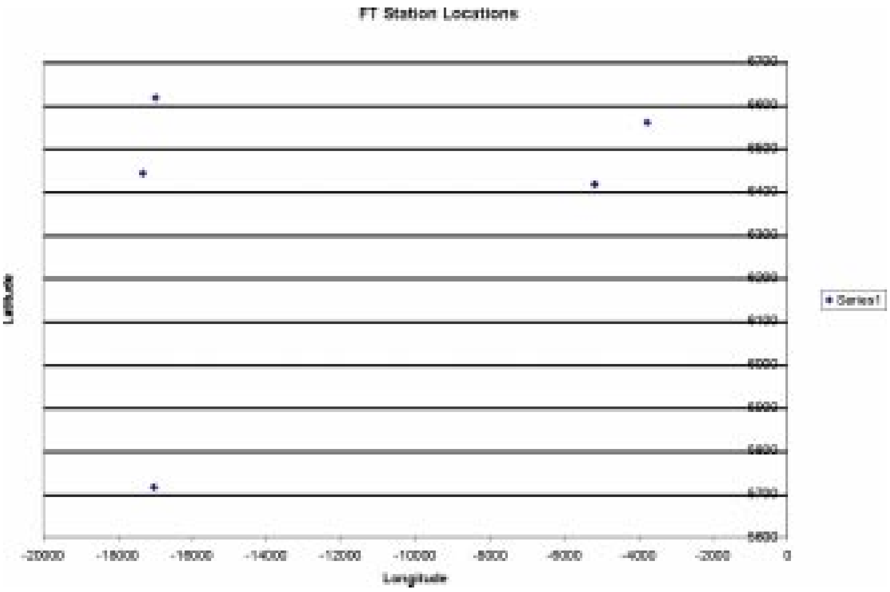
Analysis by Class

FT

From the palaeodata, I have assessed the mean annual temperature of Central England during FT as –14°C to –4°C. All FT stations have a summer temperature classification of k (0 to 9°C). Therefore, to achieve the specified mean annual temperature range, the classifications ko or kc seem appropriate. Winters classed as severely cold (d) or excessively cold (e) would seem much more characteristic of high northern latitudes in deep continental interiors. They were, therefore, excluded from further consideration.

In addition, many FT stations are in very high northern latitudes. To exclude those with photoperiods grossly different from Central England, I included only stations south of 67°N.

On this basis, I identified five stations, as listed in the Appendix to this memorandum. The locations of these five stations are shown in the following figure.

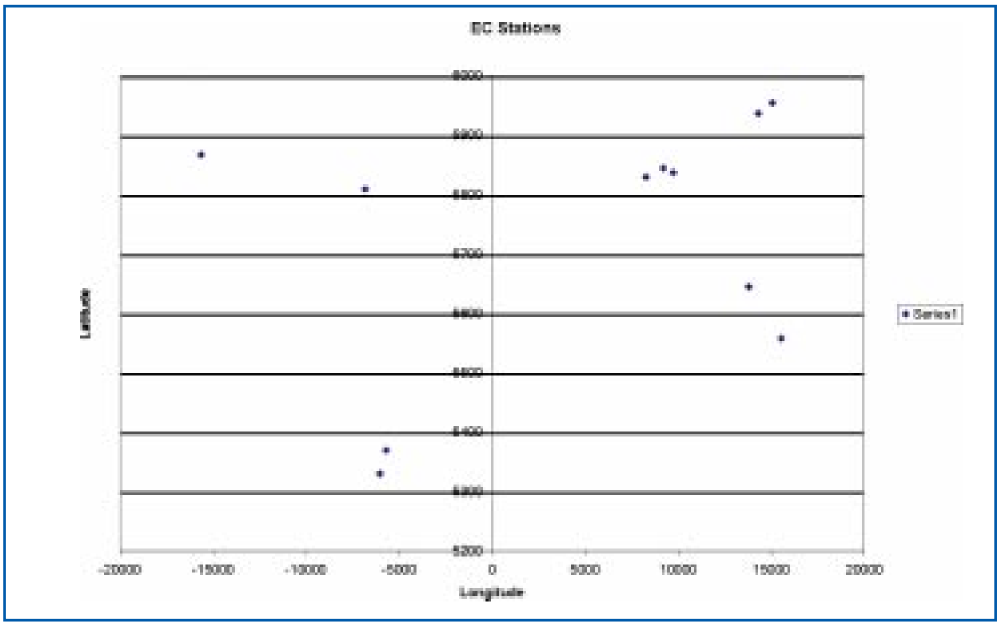


The two westmost stations are Godthaab and Ammasalik in Greenland. Of the three eastmost stations, the two northern ones are Mys Uelen and Buhta Provide in the Russian Federation, whereas the southern one is St Paul in Alaska.

EC

From the palaeodata, I give mean annual temperature ranges for EC in Central England of either –10 to –4°C, or –8 to 6°C. However, the upper end of the latter range is determined by the Early Younger Dryas only, and it may be that this is an artefact of trying to adopt a single climate class of the whole of the Younger Dryas. The earlier part of this episode probably reflects a rapid cooling from the preceding Windermere Interstadial.

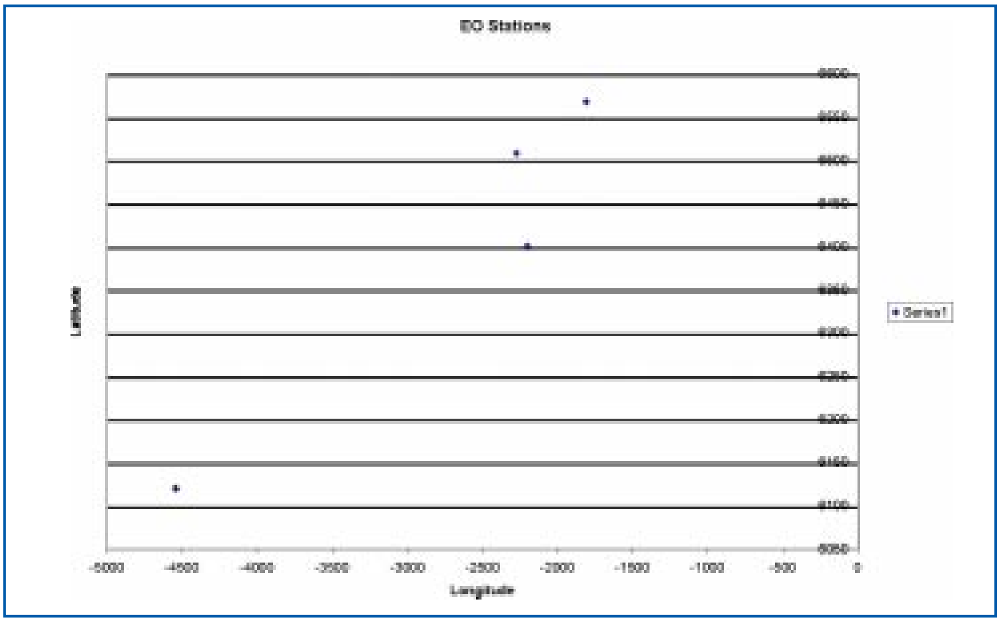
I, therefore, consider that a sub-zero mean annual temperature is appropriate and also reject extreme continentality, as for FT. This suggests cool, mild or warm summers in combination with cold or very cold winters, leading to classes lo, lc, bc and kc. In this case, there are stations at more southerly latitudes than for FT, so I could impose the requirement that selected stations were south of 60°N. The selected stations are listed in the Appendix and are shown on the following figure.



Stations in both the USA and the Russian Federation are included.

EO

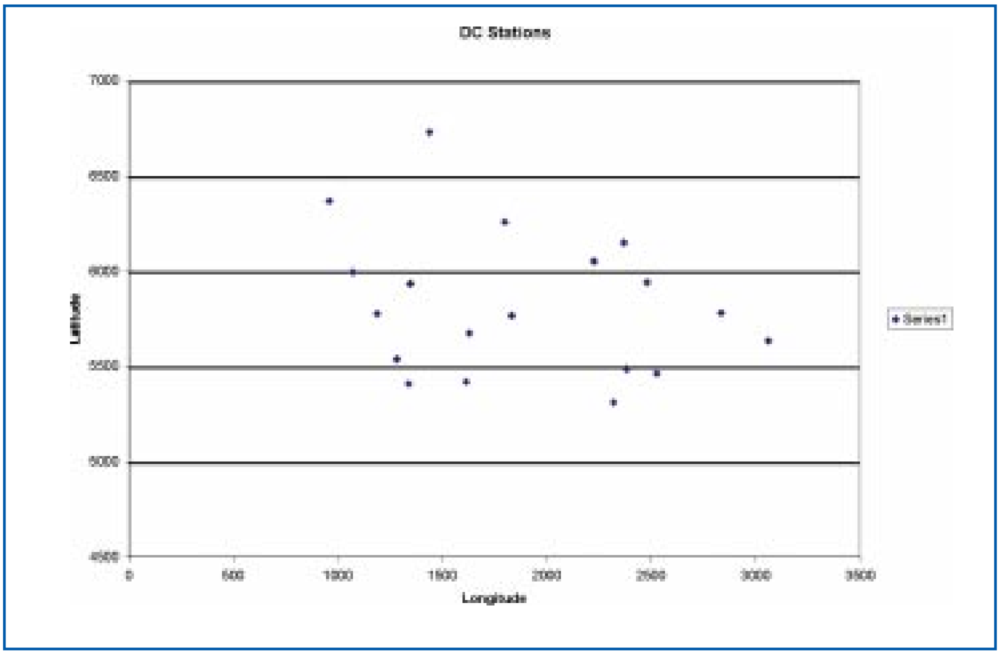
EO stations were provided for 'Greater' Europe only. All stations were classified as lo, ko, kk and lk. The combination lk gives mean annual temperatures that are typically around 9°C. In Central England, such temperatures would normally be associated with DO rather than EO. In fact, the combination lk occurs only in Iceland, so I suspect that the associated stations have only just crept into the category, as various other Icelandic stations are ko, lo and kk. Because of the limited number of stations available, I imposed a latitude cut off at 67°N, as for FT. The 4 stations selected are listed in the Appendix and shown in the following figure.



Three of these stations are in Iceland (the eastern cluster). The fourth (Ivigtut/Narsarsuaq) in Greenland will be interesting for comparison, but may be somewhat less appropriate as an analogue.

DC

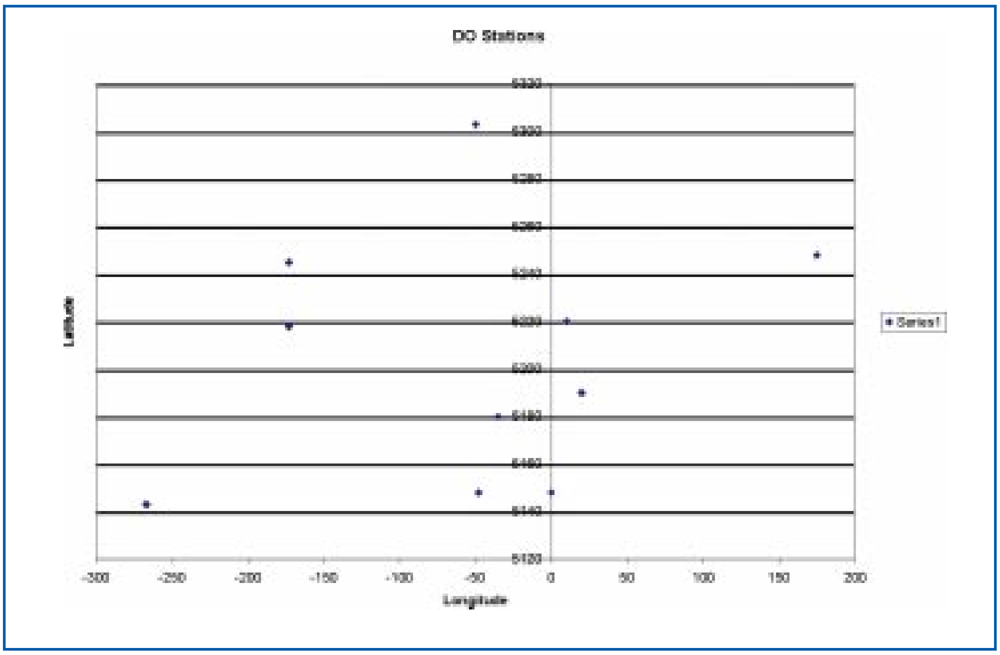
DC stations were also provided only for 'Greater' Europe. However, this provides ample scope for selection. From the paleodata, DC is recorded only during the Late Glacial, which I take to be characterised by cool or mild summers and cool or cold winters. In practice, selection of l or k for summer and k or o for winter was not a strong criterion. Based on these criteria, 19 stations were selected, as listed in the Appendix and shown on the following figure.



A general trend is readily apparent, with a decrease in latitude occurring for the more eastern stations. This partly reflects the fact that the DC/DO distinction (at least one month below 0°C for DC) reflects an interplay between mean annual temperature and degree of continentality. Northern stations will typically be rather colder than their southern counterparts, but will also tend to be less continental. Bearing in mind the location of Central England, it is suggested that stations west of 20°E are preferred as analogues. This leaves a group of 10. If the cutoff were moved to 15°E, there would still be a group of 6 that could be used.

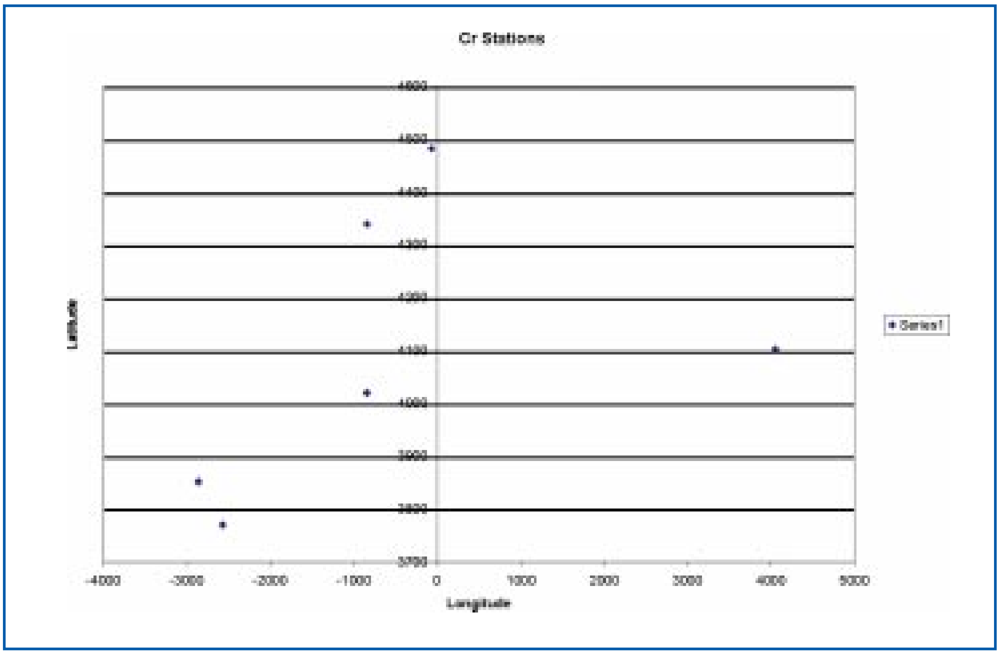
DO

For DO, I take the climate of the Holocene as a model. I have estimated that mean annual temperatures throughout the Holocene were within ±2°C of those at the present day. This degree of variation is similar to that seen across 'Lowland Britain' at the present day. I have, therefore, selected stations from this area. As very few long records are held by CRU, I have selected some stations that are connected with agricultural research or are used for agricultural purposes (e.g. MORECS), so that a tie in with collateral data will be possible. I have then selected others to provide full geographical coverage of the area of interest. My choices are Long Ashton, Heathrow, Stratford-on-Avon, Rothamsted, Lowestoft, Cranwell, Birmingham Airport, Stansted Airport, Greenwich and Cambridge. Details are given in the Appendix and they are shown on the following figure.



Cr

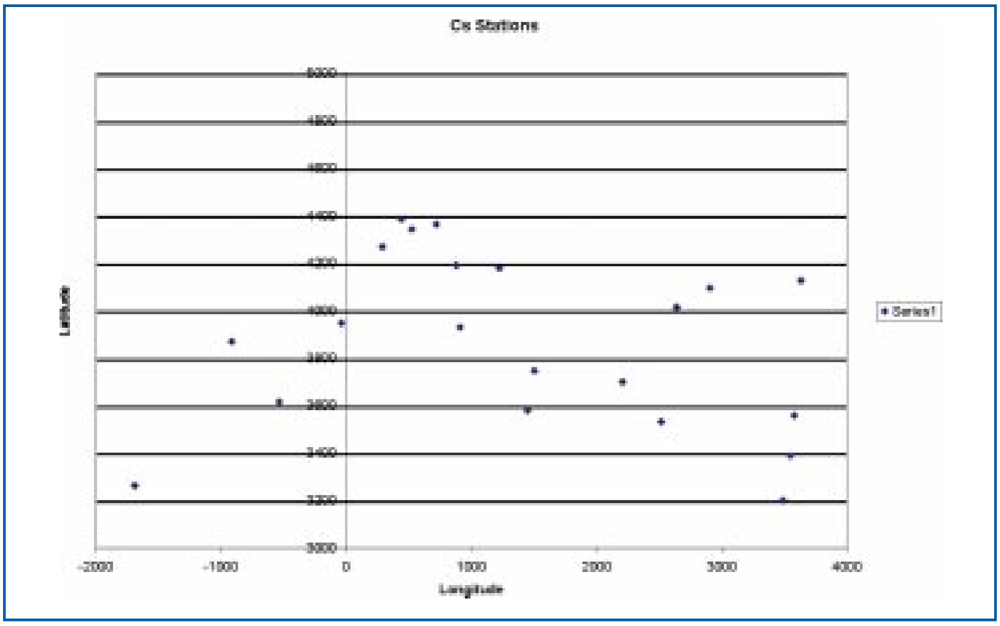
Selection of C stations is not constrained by the paleoclimatic record. However, I have taken the view that an oceanic climate should be adopted. For Cr, this implies mild or warm summers and mild or cool winters. This gives l or b for summer and l or k for winter. Six stations satisfied these criteria. These are listed in the Appendix and shown on the following figure.



I have some doubts as to the applicability of the easternmost station (Rize, Turkey) and we may wish to undertake variant analyses in which it is excluded from consideration.

Cs

Cs is more extreme than Cr, but I take the position that it should be on a continuing trend, again with limited continentality. Thus, summers would be warm or hot (b or a) and winters would be mild or cool (l or k). This yields 21 stations, listed in the Appendix and shown on the following figure.



It is debatable whether Eastern Mediterranean stations beyond 20°E should be included, so variant analyses, excluding these stations may be undertaken.

The Next Step

It would be useful if I could examine mean monthly temperature and precipitation data for the identified stations, so that I can begin some sensitivity analyses on variations in hydrology as an input to WP4.

Appendix: Selected Climate Stations

Stn-ID	is the (i7) WMO or pseudo-WMO station number
Station name	is the (a20) station name (may be truncated)
Lat.	is the (i5) latitude in (degrees decimal)*100
Long.	is the (i6) longitude in (degrees decimal)*100
Elev.	is the (i5) elevation in meters
Country	is the (a13) country (may be 3-letter abbrev.)
smr	is the (a1) thermal summer classification
wtr	is the (a1) thermal winter classification
L/G	is the (a1) elevation 'flag' – "L" indicates less than 500 m and "G" indicates 500-2499 m
tyr1	is the (i4) first year of any CRU temperature time series
tyr2	is the (i4) last year of any CRU temperature time series
pyr1	is the (i4) first year of any CRU precipitation time series
pyr2	is the (i4) last year of any CRU precipitation time series
tnorm	is the (i4) period of temperature normals calculation
t%	is the (i3) %-presence of temperature values in tnorm
pnorm	is the (i4) period of precipitation normals calculation
p%	is the (i3) %-presence of precipitation values in pnorm

FT STATIONS: NORTHERN HEMISPHERE

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
425000	GODTHAAB	6417	-5175	70	GRE	k	o	L	1866	2001	1874	2000	6190	100	6190	100
436000	AMMASALIK	6560	-3763	52	GRE	k	o	L	1894	2001	1897	2000	6190	100	6190	100
2539900	MYS UELEN	6617	-16983	7	RUSSIAN FEDE	k	c	L	1918	2001	1928	2000	6190	100	6190	100
2559400	BUHTA PROVIDE	6442	-17323	17	RUSSIAN-FEDE	k	c	L	1936	1990	1934	1993	6190	97	6190	100
7030800	ST. PAUL	5715	-17022	9	UNITED STATE	k	o	L	1916	2001	1915	2000	6190	100	6190	100

EC STATIONS: NORTHERN HEMISPHERE

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
2591300	MAGADAN	5955	15078	118	RUSSIAN FEDE	l	c	L	1930	1990	1930	1993	6189	96	6190	100
2923100	KOLPASEV	5830	8290	76	RUSSIA	b	c	L	1925	2001	1936	2000	6189	96	6190	100
2926300	ENISEJSK	5845	9215	79	RUSSIAN FEDE	b	c	L	1871	2001	1881	2000	6189	96	6190	100
2928200	BOGUCANY	5838	9745	134	RUSSIAN FEDE	b	c	L	1930	2001	1913	2000	6189	96	6190	100
3108800	OHOTSK	5937	14320	8	RUSSIAN FEDE	l	c	L	1890	2001	1891	2000	6189	96	6190	100
3116800	AJAN	5645	13815	9	RUSSIAN FEDE	l	c	L	1891	2001	1892	2000	6189	96	6190	100
3241100	ICA	5558	15558	10	RUSSIAN FEDE	l	c	L	1935	2001	1935	2000	6189	92	6190	100
7032600	KING SALMON	5868	-15665	15	UNITED STATE	l	c	L	1917	2001	1918	2000	6190	100	6190	100
7181600	GOOSE	5330	-6040	49	CANADA	l	c	L	1941	2001	1942	1998	4190	167	6190	100
7181800	CARTWRIGHT	5370	-5700	14	CANADA	l	c	L	1934	2001	1935	1998	6190	100	6190	100
7190600	FORT CHIMO	5810	-6840	37	CANADA	l	c	L	1942	2001	1948	1998	4790	147	6190	100

EO STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
401300	STYKKISHOLMUR	6508	-2273	17	ICE	l	o	L	1823	1999	1857	1998	6190	100	6190	100
403000	REYKJAVIK	6400	-2200	61	ICELAND	l	o	L	1870	2001	1829	2000	6190	100	6190	100
406300	AKUREYRI	6568	-1808	27	ICE	l	o	L	1882	2001	1928	2000	6190	100	6190	100
427000	IVIGTUT/ NARSARSUAQ	6120	-4542	32	GRE	l	o	L	1875	1990	1875	1990	6190	100	6190	100

DC STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
115200	BODO	6730	1440	13	NOR	l	o	L	1868	2001	1869	2000	6190	100	6190	100
124100	ORLAND	6370	960	10	NOR	l	o	L	1951	2001	1951	2000	6190	100	6190	100
149200	OSLO BLINDERN	5995	1072	96	NORWAY	l	o	L	1816	2001	1866	2000	6190	99	6190	100
236100	HARNOSAND	6260	1800	8	SWEDEN	l	o	L	1859	2000	1860	1993	6190	100	6190	97
241800	KARLSTAD	5935	1347	55	SWE	l	o	L	1859	2001	1861	2000	6190	100	6190	100
251200	GOETEBORG/ GAVE	5777	1188	53	SWEDEN	l	o	L	1860	2000	1890	2000	6190	100	6190	100
259000	VISBY AIRPORT	5767	1833	51	SWE	l	o	L	1859	2001	1861	2000	6190	100	6190	100
261600	FALSTERBO	5538	1282	5	SWEDEN	l	k	L	1879	2000	1890	1990	6190	100	6190	100
267200	KALMAR	5673	1630	15	SWE	l	o	L	1859	2000	1861	1990	6190	100	6190	100
294300	TAMPERE	6150	2370	85	FINLAND	l	o	L	1890	1999	1890	1990	6170	33	6190	100
297200	TURKU	6052	2227	59	FINLAND	l	o	L	1890	2001	1909	2000	6190	100	6190	100
1018400	GREIFSWALD	5410	1340	6	GERMANY	l	o	L	1951	2001	1951	2000	6190	99	6190	97
1210500	KOSZALIN	5420	1615	34	POLAND	l	o	L	1848	1990	1861	1993	6690	83	6190	100
1229500	BIALYSTOK	5310	2320	151	POL	l	o	L	1951	2001	1951	2000	6690	83	6190	93
2603800	TALLIN	5942	2480	44	EST	l	o	L	1806	2001	1845	2000	6190	100	6190	100
2625800	PSKOV	5783	2835	45	RUS	l	o	L	1883	1990	1891	1995	6190	97	6190	100
2647700	VELIKIE LUKI	5635	3062	106	RUSSIAN FEDE	l	o	L	1881	2001	1881	2000	6190	97	6190	100
2662900	KAUNAS	5488	2383	77	LITHUANIA	l	o	L	1922	2001	1892	2000	6190	100	6190	100
2673000	VIL'NJUS	5463	2528	189	LIT	l	o	L	1777	1990	1881	2000	6190	97	6190	100

DO STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
-386780	LONG ASHTON	5143	-267	51	UK	l	k	L	*	*	1920	1999	6190	100	6190	100
-351130	HEATHROW	5148	-48	25	UK	b	k	L	*	*	*	*	6190	100	6190	100
-344320	STRATFORD ON AVON	5218	-173	49	UK	l	k	L	*	*	1961	1999	6190	100	6190	100
-335370	ROTHAMSTED	5180	-35	128	UK	l	k	L	*	*	1961	1999	6190	100	6190	100
-331970	LOWESTOFT	5248	175	25	UK	l	k	L	*	*	1961	1999	6190	100	6190	99
-324320	CRANWELL	5303	-50	62	UK	l	k	L	*	*	1961	1995	6190	100	6190	100
353400	BIRMINGHAM AIRPORT	5245	-173	99	UK	l	k	L	1951	1997	1949	1999	6190	100	6190	100
368300	STANSTED AIRPORT	5190	20	106	UK	l	k	L	*	*	1950	1997	6190	100	6190	100
378370	GREENWICH	5148	0	7	UK	b	k	L	*	*	1820	1994	6190	100	6190	70
389960	CAMBRIDGE	5220	10	12	UK	l	k	L	1871	1969	1848	1999	6190	100	6190	100

Cr STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
751000	BORDEAUX MERIGNAC	4483	-68	61	FRANCE	b	k	L	1851	2001	1842	2000	6190	100	6190	100
800100	LA CORUNA	4340	-840	67	SPAIN	b	l	L	1951	2001	1877	2000	6190	100	6190	100
850600	HORTA (ACORES)	3852	-2863	62	PORTUGAL	b	l	L	1920	1996	1902	1996	6190	100	6190	100
851300	PONTA DELG. (AZORES)	3770	-2570	67	PORTUGAL	b	l	L	1865	1996	1865	1996	6190	100	6190	100
854900	COIMBRA	4020	-842	141	POR	b	l	L	1866	1991	1866	1996	6190	100	6190	100
1704000	RIZE	4103	4052	9	TUR	b	k	L	1929	2001	1929	2000	6190	100	6190	100

Cs STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
764500	NIMES COURBESSAC	4387 4387	440 440	62 62	FRANCE FRANCE	a a	k k	L L	1951 1951	1995 1995	1951 1951	1995 1995	6190 6190	100 100	6190 6190	100 100
765000	MARIGNANE	4345	523	36	FRANCE	a	k	L	1838	2001	1749	2000	6190	99	6190	97
769000	NICE	4365	720	28	FRANCE	a	k	L	1951	2001	1951	2000	6190	100	6190	100
774700	PERPIGNAN	4270	290	48	FRANCE	a	k	L	1836	2001	1850	2000	6190	99	6190	97
776100	AJACCIO	4192	880	9	FRANCE	b	k	L	1951	2001	1855	2000	6190	100	6190	100
828500	VALENCIA	3948	-38	11	SPAIN	a	l	L	1900	1994	1859	2000	6190	100	6190	100
849500	GIBRALTAR	3615	-535	5	GIBRALTAR	a	l	L	1951	2001	1852	2000	6190	100	6190	100
852200	FUNCHAL	3263	1690	56	MADEIRA	b	l	L	1900	2001	1880	2000	6190	100	6190	100
853500	LISBOA	3872	-915	95	POR	a	l	L	1864	2001	1836	2000	6190	100	6190	100
1624200	ROMA FIUMICINO	4180	1223	3	ITALY	a	k	L	1811	1996	1871	1996	6190	100	6190	93
1646000	CATANIA/FONTA	3747	1505	17	ITALY	a	l	L	1892	1992	1892	1992	6190	100	6190	83
1656000	CAGLIARI ELMAS	3930	910	5	ITA	a	l	L	1951	2001	1942	2000	6190	100	6190	100
1659700	LUQA	3580	1450	91	MAL	a	l	L	1853	2001	1841	2000	6190	100	6190	100
1672600	KALAMATA	3700	2210	11	GREECE	a	l	L	1951	2001	1951	2000	6190	100	6190	100
1675400	HERAKLION	3533	2518	39	GRE	a	l	L	1951	2001	1910	2000	6190	100	6190	100
1703000	SAMSUN	4128	3633	44	TUR	a	k	L	1929	2001	1880	2000	6190	100	6190	100
1706200	GOZTEPE	4097	2908	40	TUR	a	k	L	1839	2001	1846	2000	6190	100	6190	100
1711200	CANAKKALE	4015	2642	6	TUR	a	k	L	1951	2001	1931	2000	6190	100	6190	93
4002200	LATTAKIA	3560	3580	9	SYRIA	a	l	L	1952	2001	1928	2000	6690	83	6690	83
4010000	BEIRUT INT. AIRPORT	3390	3550	26	LEBANON	a	l	L	1843	2001	1888	2000	7190	63	6190	100
4018000	BEN GURION INT.	3200	3490	49	ISR	a	l	L	1951	2001	1951	2000	7790	43	6190	67

Appendix 5: characteristics of selected climate stations for central England

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External Memorandum

24 June 2002

From: M C Thorne
To: C M Goodess
Copies: D Texier, B M Watkins, P Degnan
Subject: Characteristics of Selected Climate Stations

Clare

I have examined the characteristics of the selected climate stations. My analysis is presented below. For convenience, I have assigned the stations indices 1 to 76, as listed in the Appendix to this note. I provide separately the spreadsheets on which the various computations were undertaken and which include the original graphs.

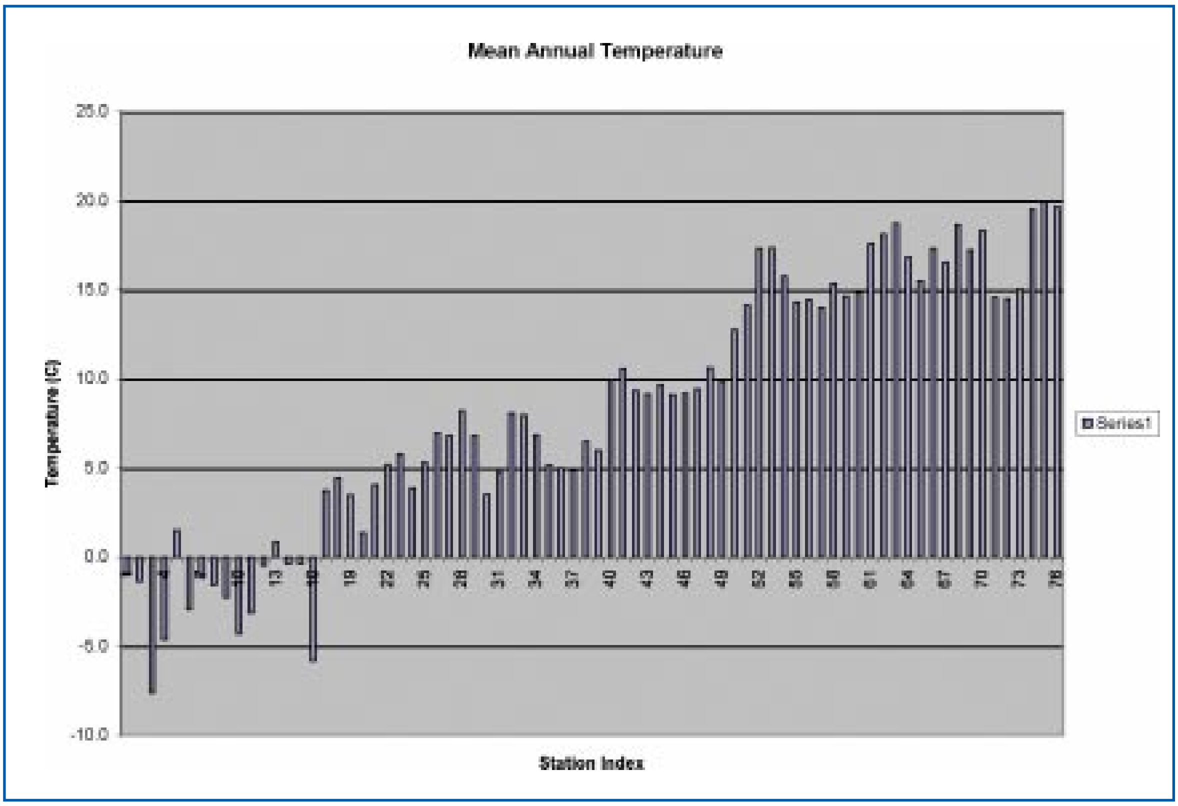
Temperature

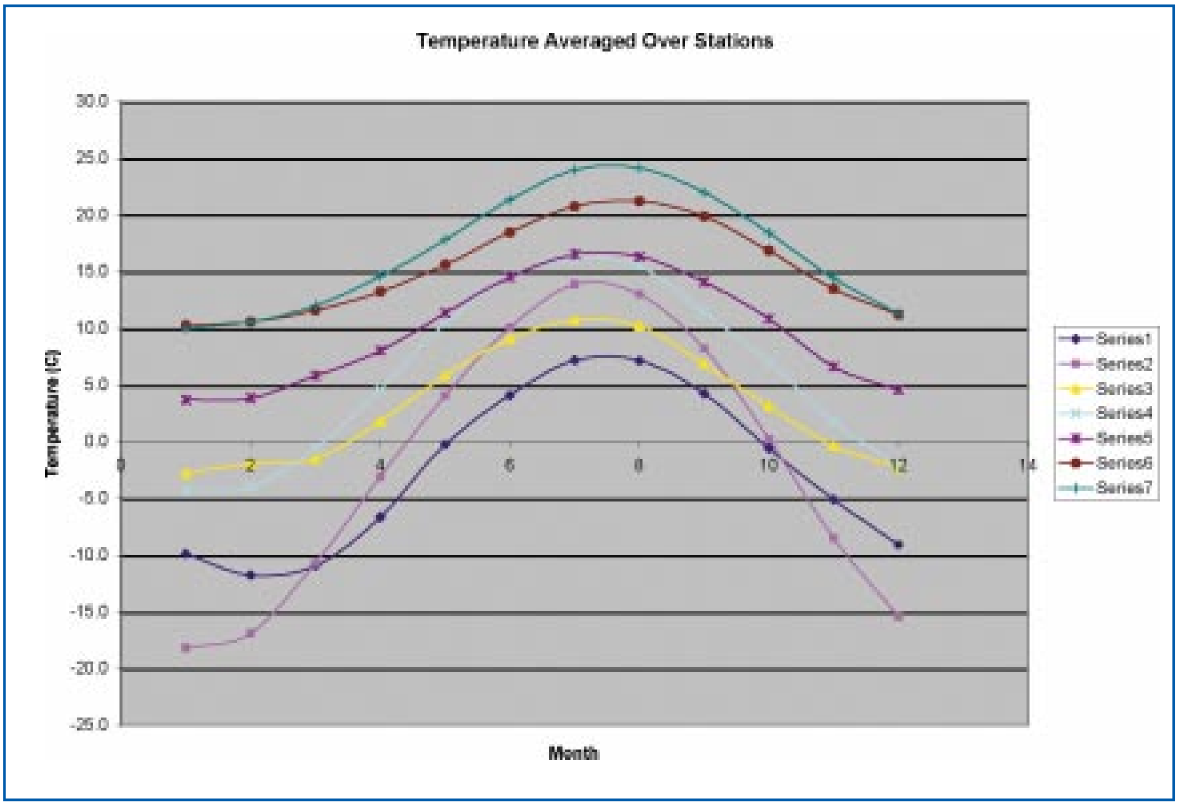
I have generated the following graphs:

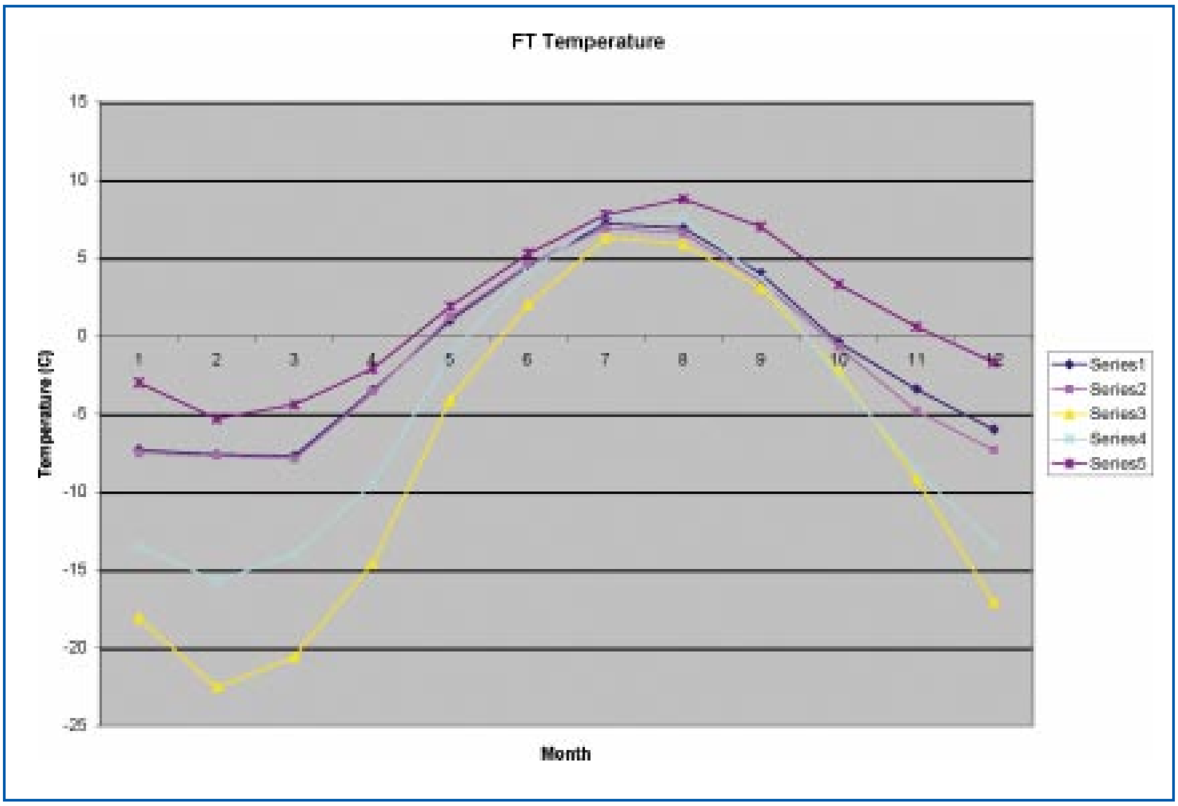
- Mean annual temperature by station;
- Mean monthly temperature averaged over all stations in each climate class;
- Mean monthly temperature for each station in each climate class.

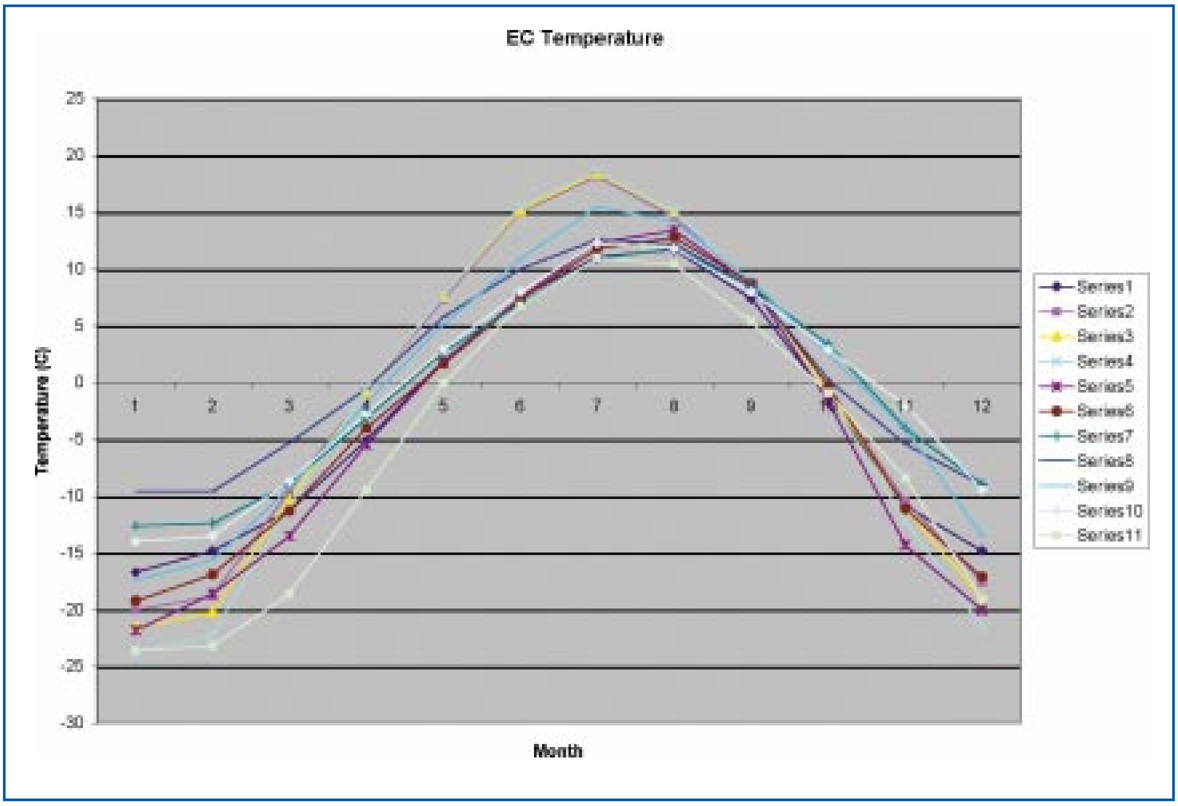
Conventions are that when data are presented by climate class, Series 1 to 7 are FT, EC, EO, DC, DO, Cr, Cs, respectively. On the figures for individual stations, the following table always applies.

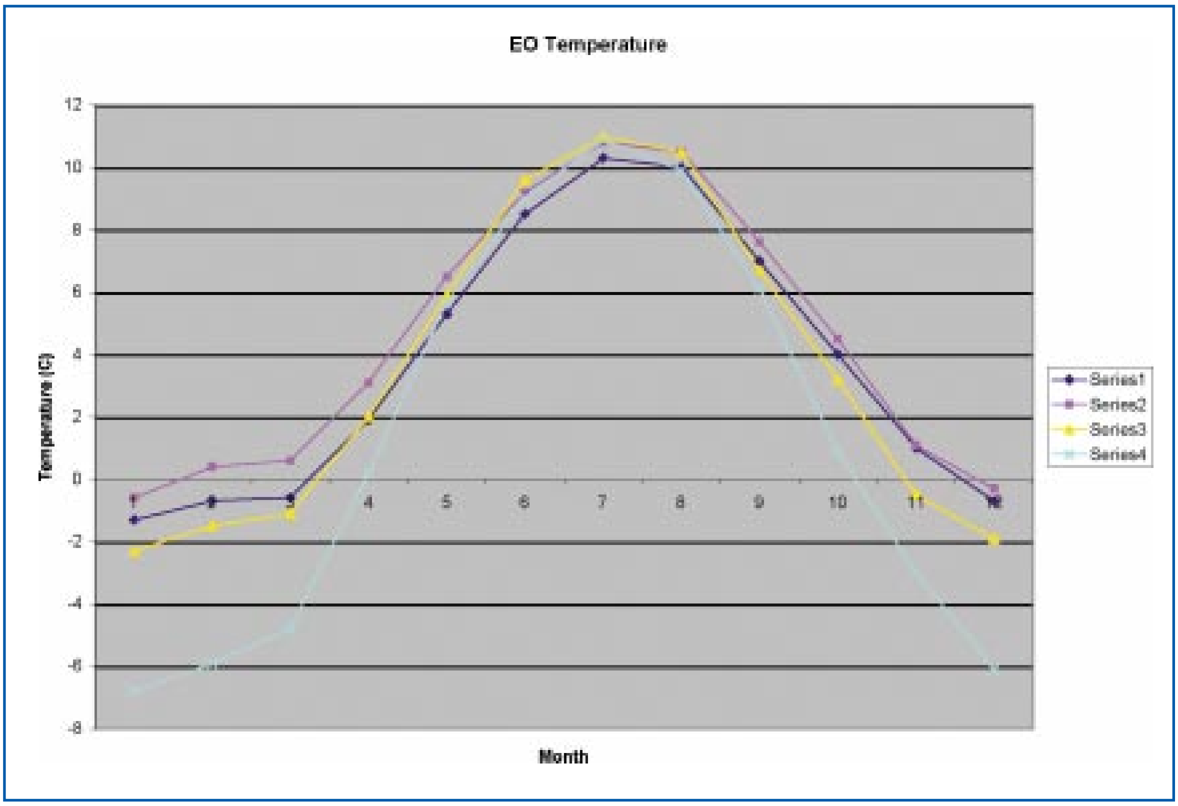
Class	Series	Index	Class	Series	Index	Class	Series	Index
FT	1	1	DC	1	21	Cr	1	50
	2	2		2	22		2	51
	3	3		3	23		3	52
	4	4		4	24		4	53
	5	5		5	25		5	54
EC	1	6		6	26		6	55
	2	7		7	27	Cs	1	56
	3	8		8	28		2	57
	4	9		9	29		3	58
	5	10		10	30		4	59
	6	11		11	31		5	60
	7	12		12	32		6	61
	8	13		13	33		7	62
	9	14		14	34		8	63
	10	15		15	35		9	64
	11	16		16	36		10	65
EO	1	17		17	37		11	66
	2	18		18	38		12	67
	3	19		19	39		13	68
	4	20	DO	1	40		14	69
				2	41		15	70
				3	42		16	71
				4	43		17	72
				5	44		18	73
				6	45		19	74
				7	46		20	75
				8	47		21	76
				9	48			
				10	49			

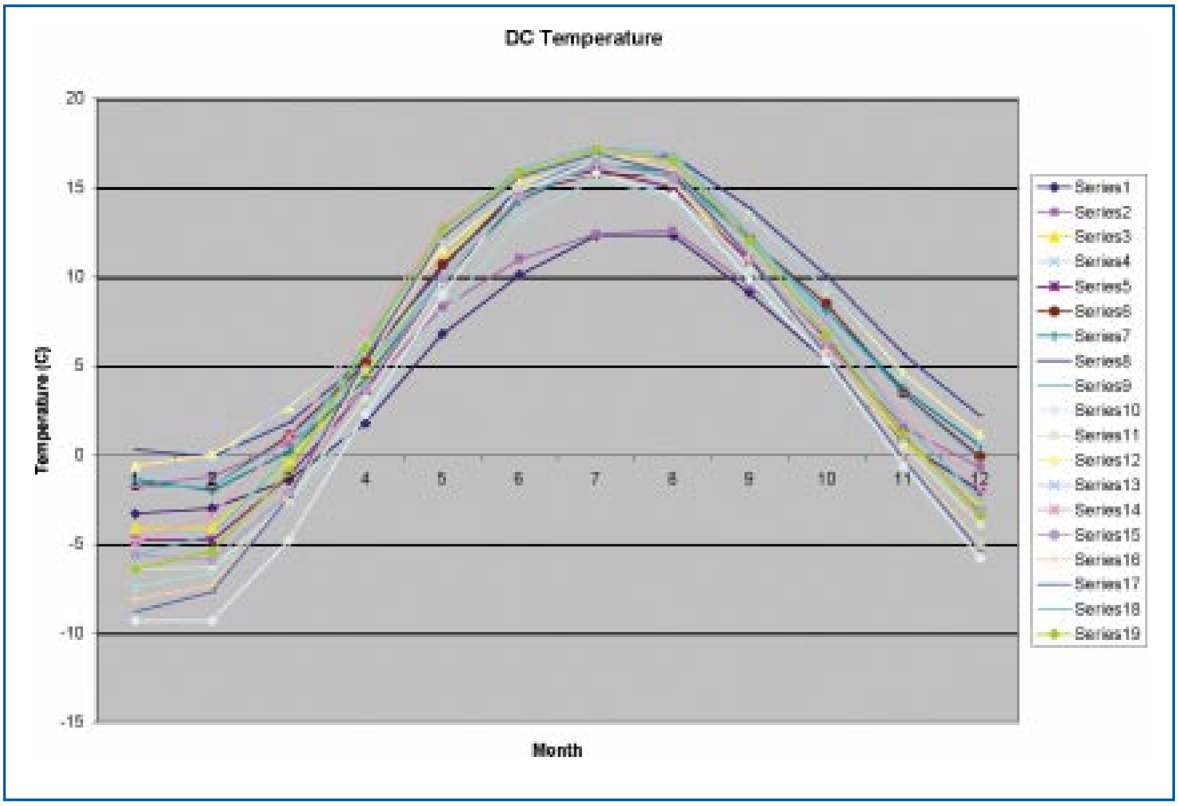

Mean Annual Temperature
Temperature (C)
Station Index
Series1

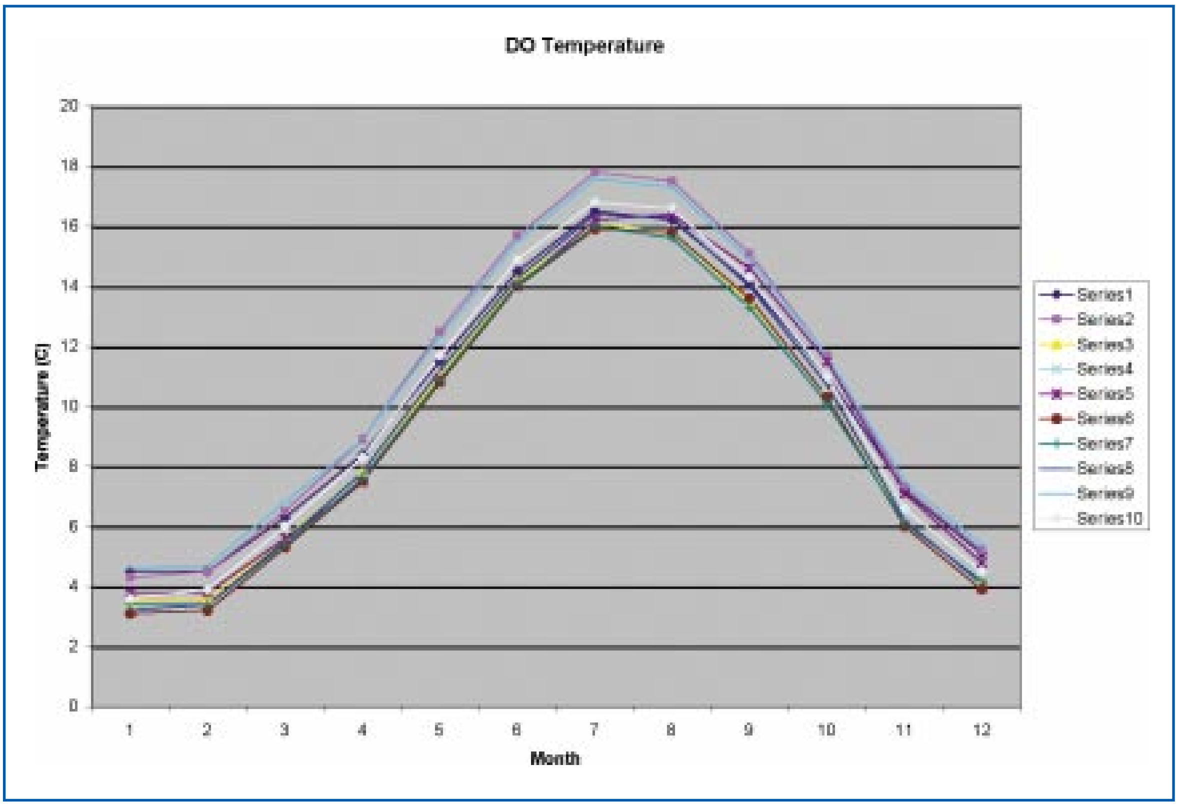

Temperature Averaged Over Stations
Temperature (C)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7

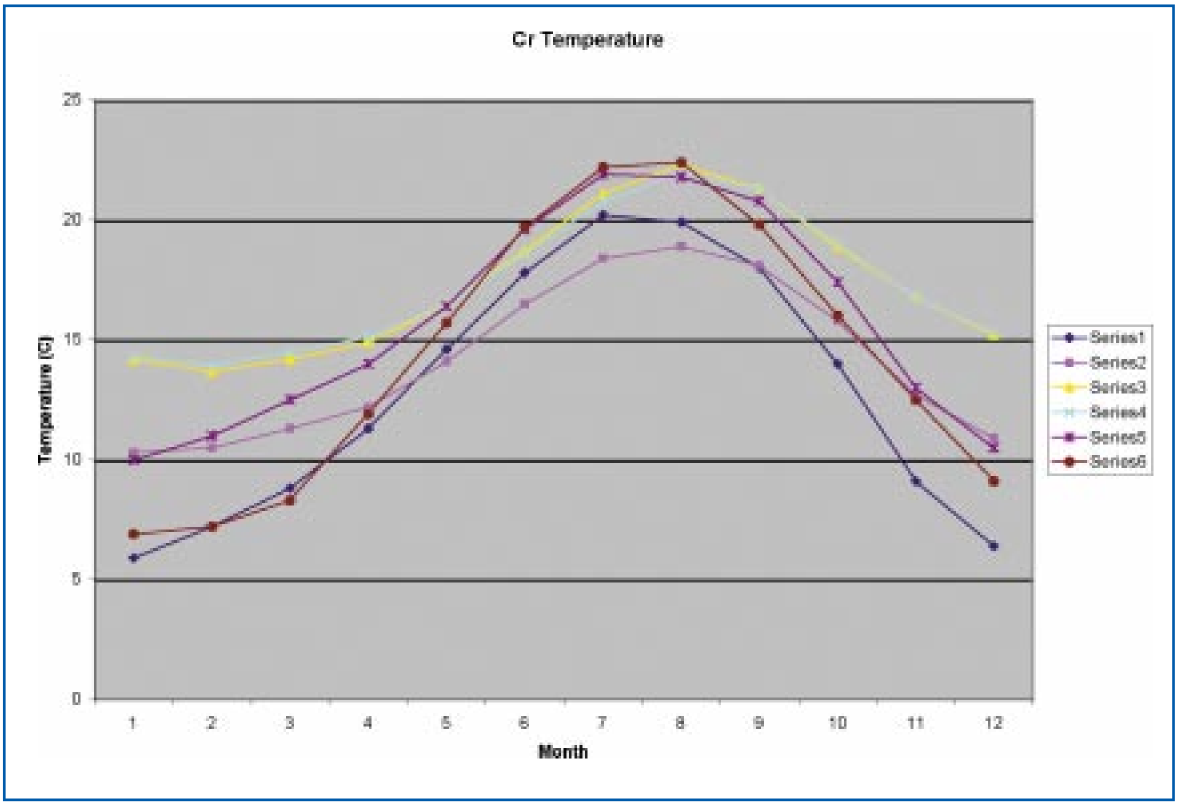

FT Temperature
Temperature (C)
Month
Series1
Series2
Series3
Series4
Series5

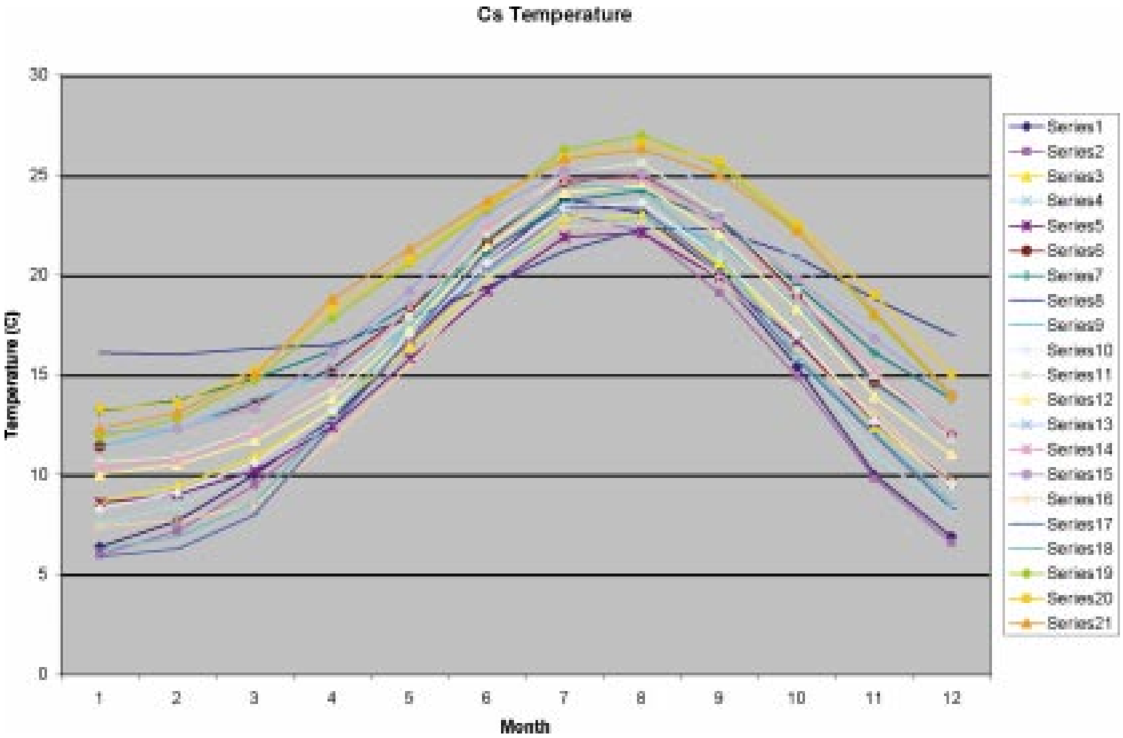

EC Temperature
Temperature (C)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11


EO Temperature
Temperature (C)
Month
12
10
8
6
4
2
0
-2
-4
-6
-8
1
2
3
4
5
6
7
8
9
10
11
12
Series1
Series2
Series3
Series4


DC Temperature
Temperature (C)
Month
20
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
7
8
9
10
11
12
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12
Series13
Series14
Series15
Series16
Series17
Series18
Series19


DO Temperature
Temperature (C)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10


Cr Temperature
Temperature (C)
Month
Series1
Series2
Series3
Series4
Series5
Series6



The trends in mean annual temperature across classes are reasonable and none of the stations is strongly out of line. Comparing temperatures averaged over stations, EC and DC (Series 2 and 4) clearly demonstrate greater continentality than EO and DO (Series 3 and 5).

It is useful to list mean annual temperatures by station. This is done in the following table.

Class	Series	Annual Temperature (C)	Class	Series	Annual Temperature (C)	Class	Series	Annual Temperature (C)
FT	1	-1.0	DC	1	4.1	Cr	1	12.8
	2	-1.4		2	5.2		2	14.1
	3	-7.6		3	5.8		3	17.3
	4	-4.6		4	3.9		4	17.3
	5	1.5		5	5.3		5	15.7
EC	1	-2.9		6	7.0		6	14.3
	2	-1.2		7	6.8	Cs	1	14.4
	3	-1.6		8	8.2		2	14.0
	4	-2.3		9	6.8		3	15.3
	5	-4.3		10	3.5		4	14.6
	6	-3.1		11	4.7		5	14.8
	7	-0.5		12	8.1		6	17.6
	8	0.8		13	7.9		7	18.1
	9	-0.4		14	6.8		8	18.7
	10	-0.4		15	5.2		9	16.8
	11	-5.8		16	5.0		10	15.5
EO	1	3.7		17	4.8		11	17.3
	2	4.5		18	6.5		12	16.5
	3	3.5		19	6.0		13	18.6
	4	1.3	DO	1	10.0		14	17.2
				2	10.6		15	18.3
				3	9.3		16	14.6
				4	9.2		17	14.5
				5	9.7		18	15.0
				6	9.1		19	19.5
				7	9.2		20	20.0
				8	9.4		21	19.6
				9	10.6			
				10	9.9			

Overall, the FT stations may be slightly too warm. However, they are consistent with the range of palaeotemperatures reconstructed for Central England.

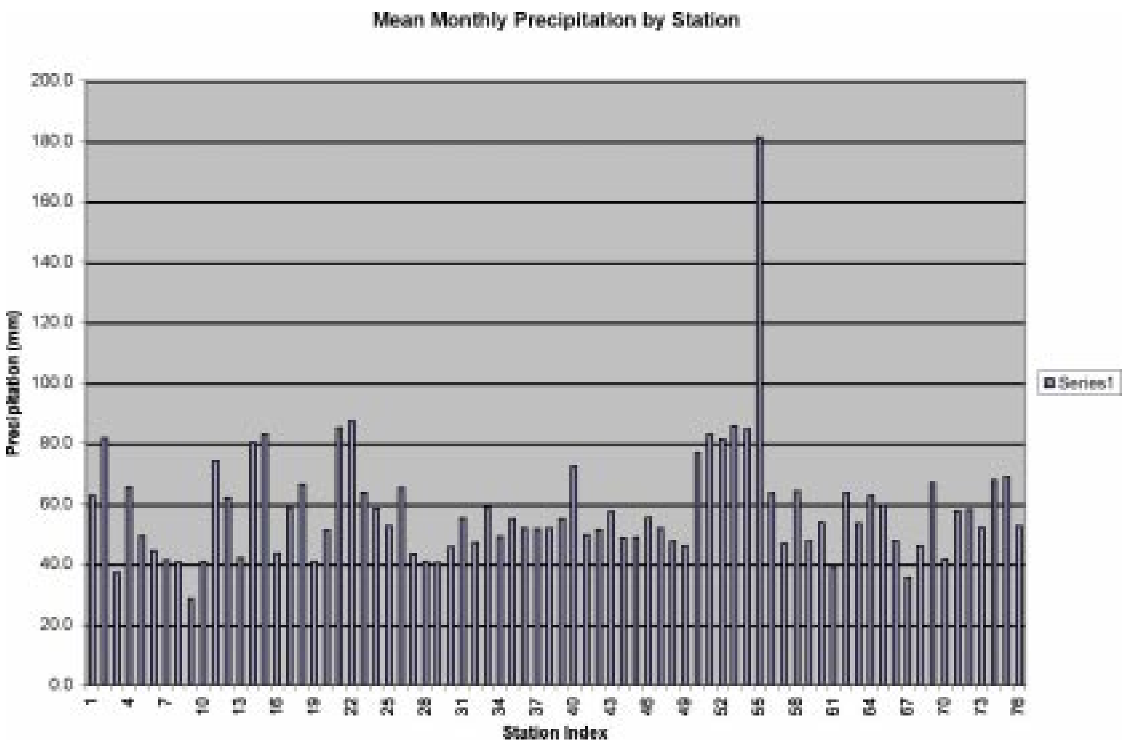
As to individual stations, within FT, the two Greenland stations and St Paul are significantly more oceanic than the two Russian Federation stations. However, mean annual temperatures for the Russian Federation stations are more consistent with palaeotemperature reconstructions for Central England, so I see no good reason for excluding any of these stations. For EC, none of the stations seems substantially out of line. For EO, there is a slightly greater degree of continentality for the Greenland station than for the three Icelandic stations, but there is no strong reason to prefer either set. For DC, the two Norwegian stations (Series 1 and 2) are significantly more oceanic than the others. However, they are significantly colder than the DO stations characteristic of the UK, reflecting their more northerly location.

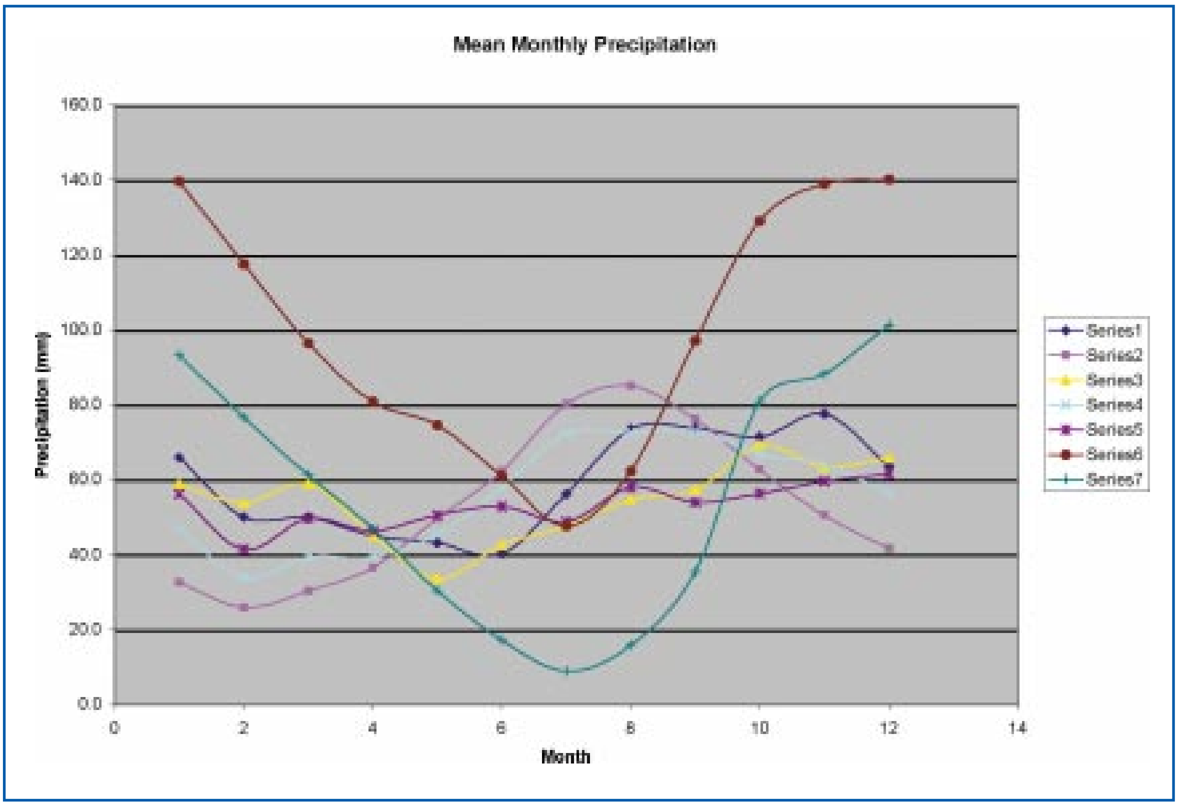
Among the Cs stations, those in the Azores (Series 3 and 4) exhibit an extreme oceanic climate. It is debatable whether these constitute appropriate analogues for Central England. Interestingly, the Turkish stations (Series 6) has similar characteristics to the French, Spanish and Portugese stations.

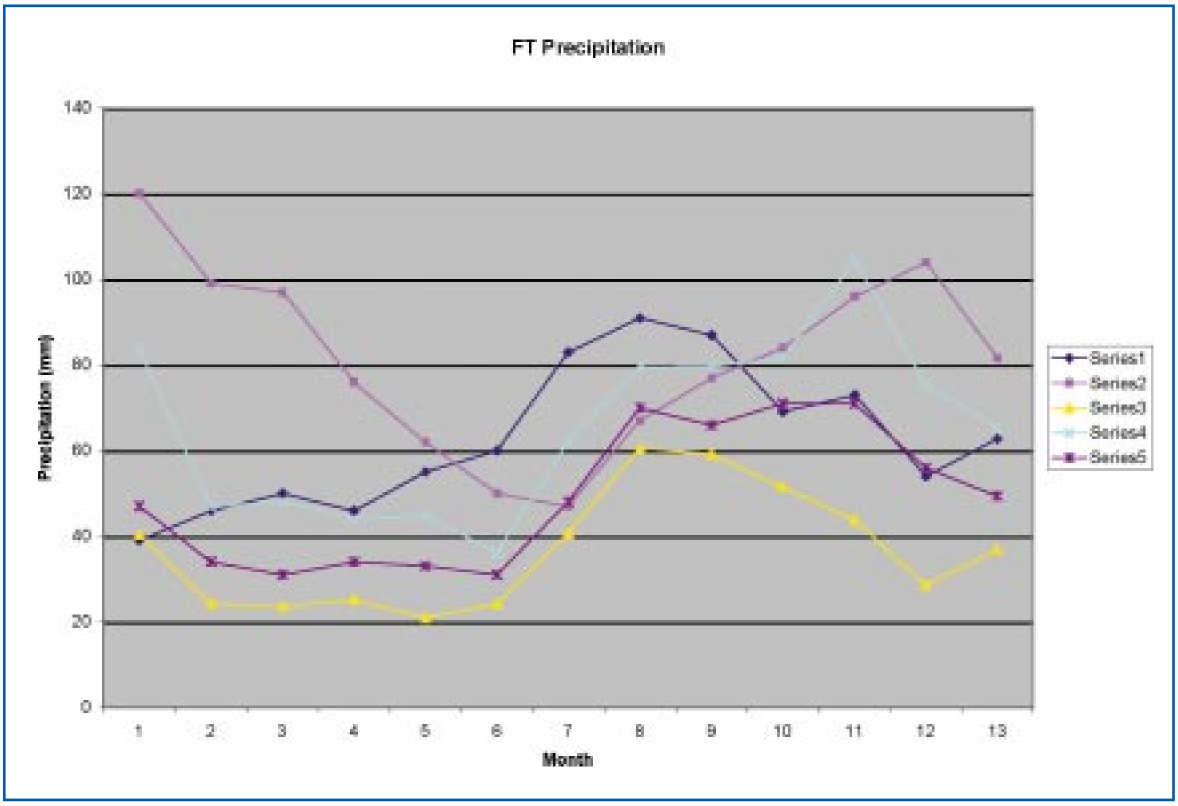
Among the Cs stations, Funchal, Madiera (Series 8) is clearly hyper-oceanic. As with the Cs stations in the Azores, it is not considered to be a suitable analogue for Central England.

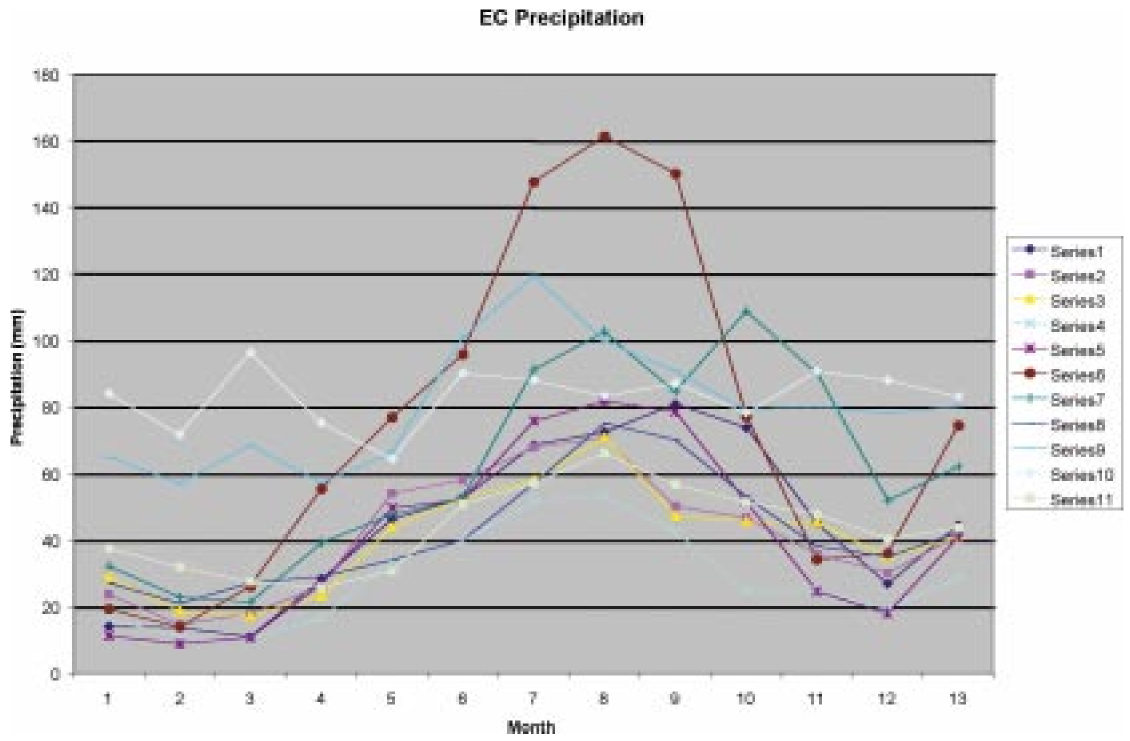
Precipitation

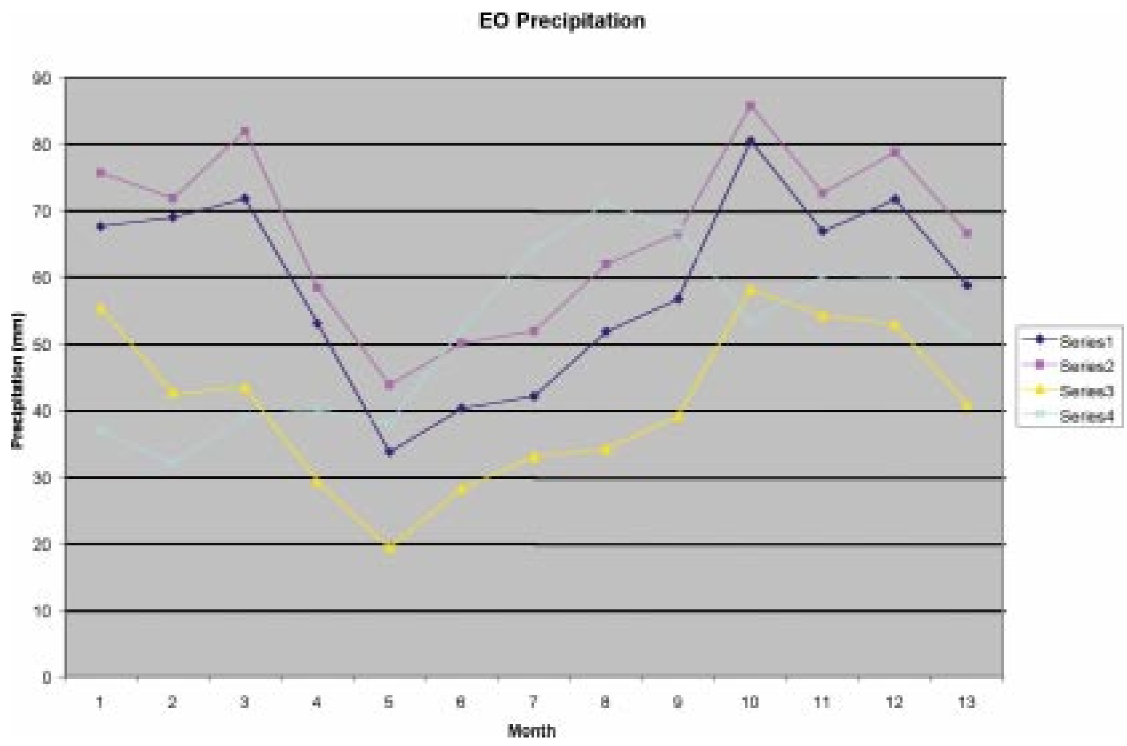
The presentation for precipitation is similar to that for temperature.

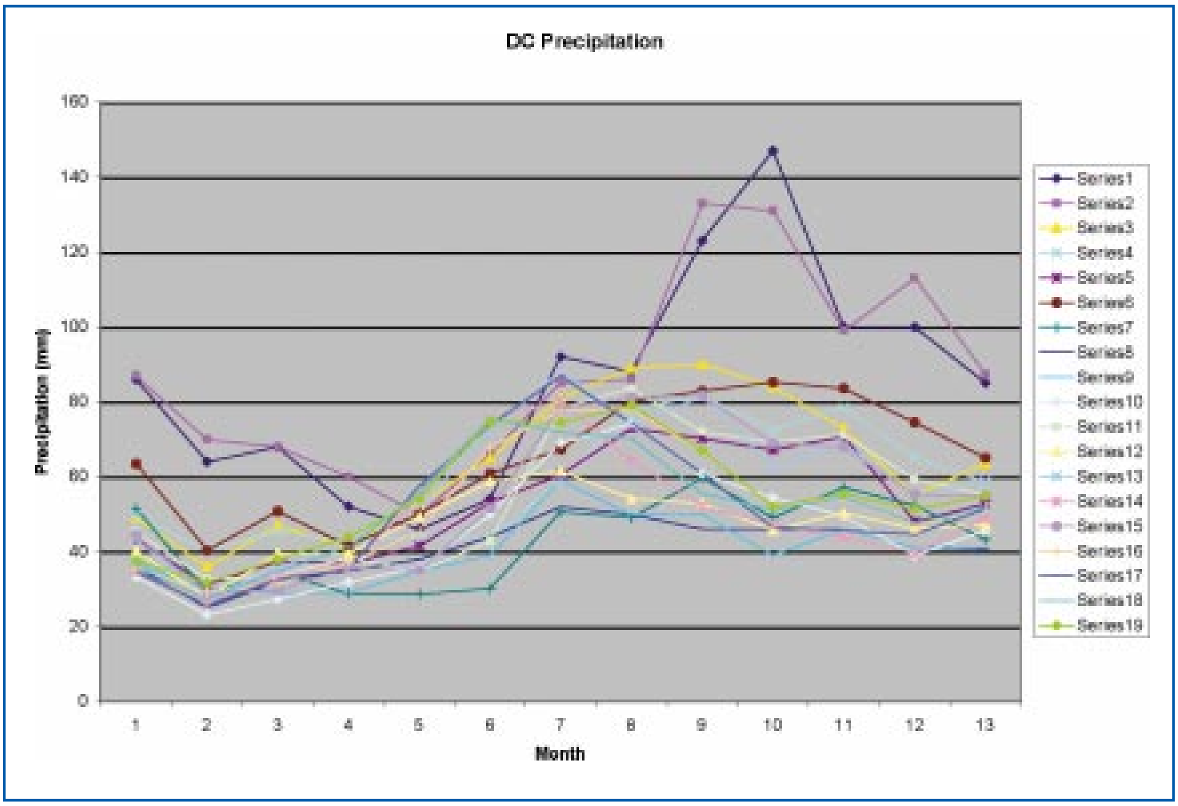


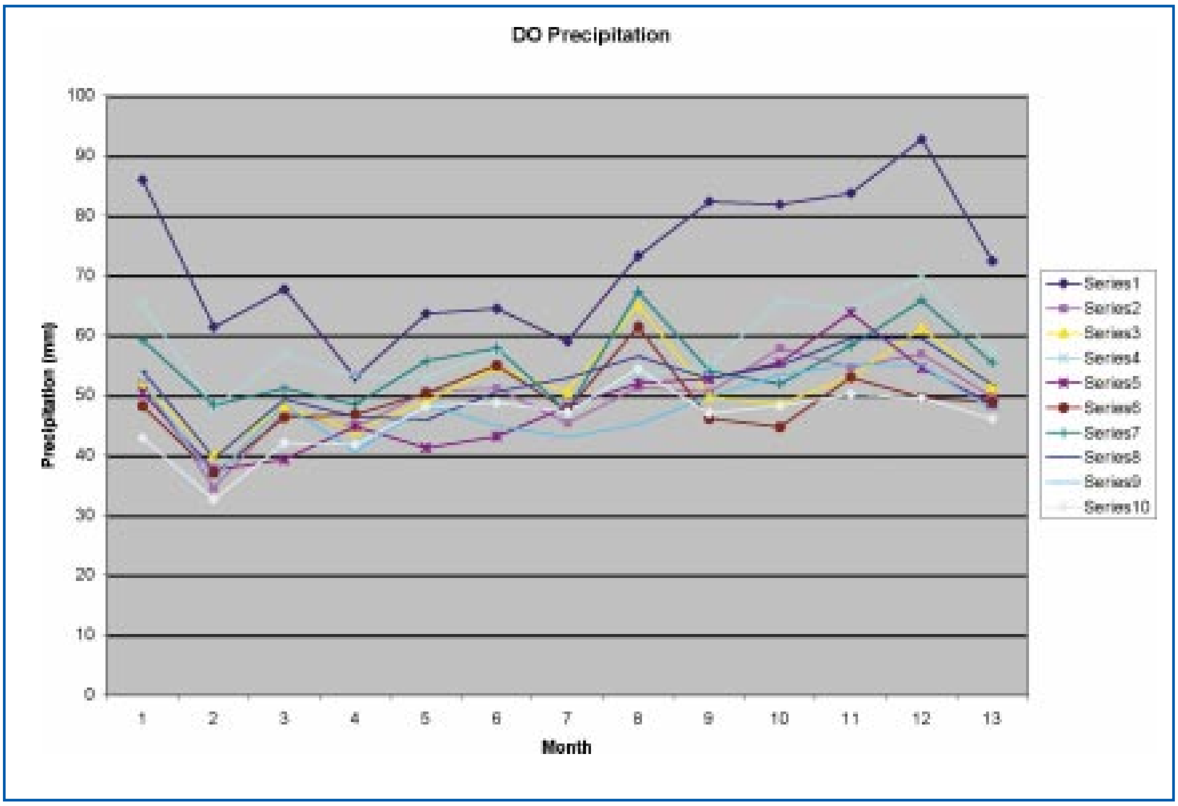

Mean Monthly Precipitation
Precipitation (mm)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
2
4
6
8
10
12
14
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7

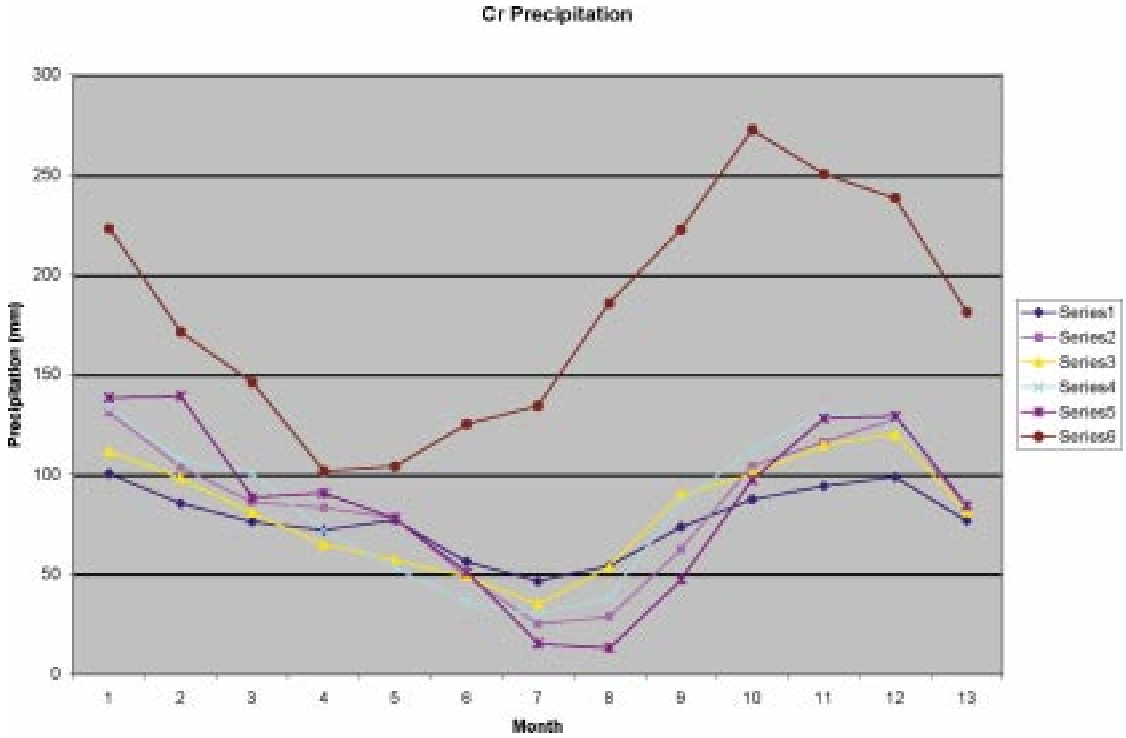

FT Precipitation
Precipitation (mm)
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Month
Series1
Series2
Series3
Series4
Series5

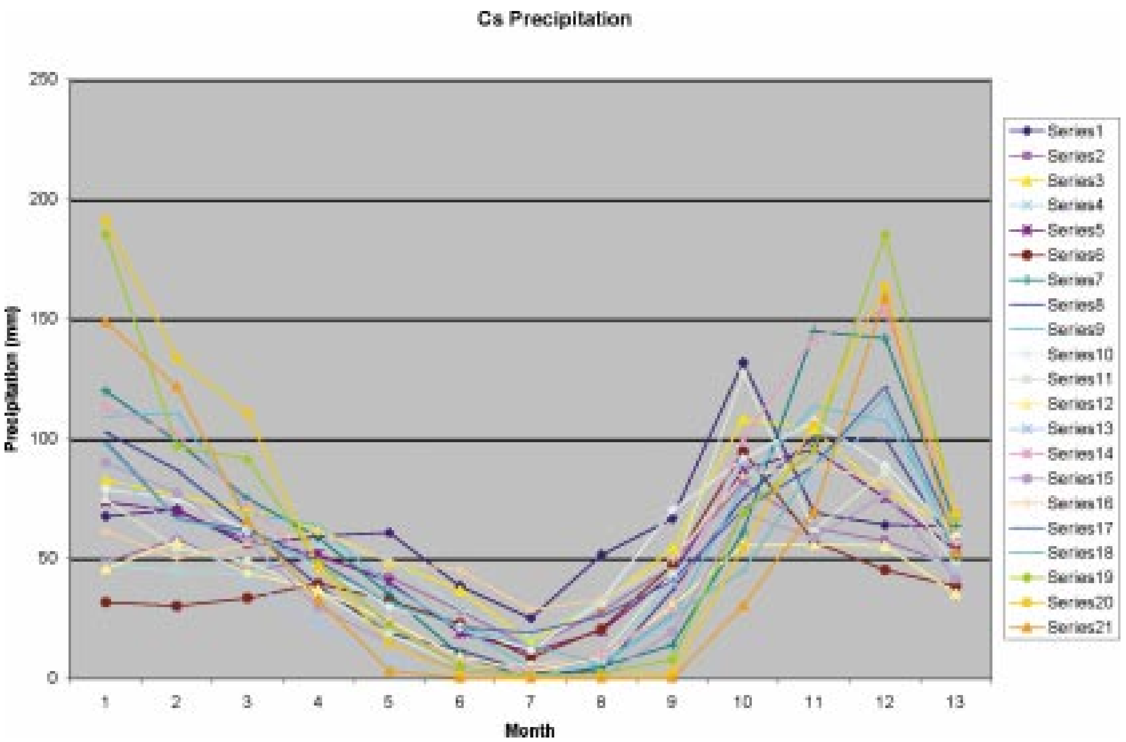

EC Precipitation
Precipitation (mm)
Month
0
20
40
60
80
100
120
140
160
180
1
2
3
4
5
6
7
8
9
10
11
12
13
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11


EO Precipitation
Precipitation (mm)
Month
0
10
20
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
11
12
13
Series1
Series2
Series3
Series4


DC Precipitation
Precipitation (mm)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12
Series13
Series14
Series15
Series16
Series17
Series18
Series19


DO Precipitation
Precipitation (mm)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10


Cr Precipitation
Precipitation (mm)
Month
Series1
Series2
Series3
Series4
Series5
Series6


Cs Precipitation
Precipitation (mm)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12
Series13
Series14
Series15
Series16
Series17
Series18
Series19
Series20
Series21

The mean monthly precipitation does not show a strong trend with climate class. However, Rize, Turkey (Index 55) is clearly out of line with the other Cr stations. Given its location, it should probably be rejected as an analogue. Seasonality of precipitation seems reasonable for all the FT stations. However, the strong summer peak for EC station Ajan (Series 6) seems anomalous and requires further investigation as to its cause. It suggests that this may not be a suitable analogue. For all EO stations, seasonal patterns of precipitation are similar, though absolute amounts vary. For DC stations, two Norwegian stations (Series 1 and 2) exhibit their oceanic marginal context with a high autumn peak in precipitation. This might be more appropriate to western Britain than Central England. For DO stations, all the seasonal trends are similar, as expected. For Cr, Rize (Series 6) is clearly anomalous, as noted previously. For Cs, the seasonal patterns from the 21 stations are remarkably similar given their wide geographical distribution.

Water Balance

Based on the temperature data provided, potential evapotranspiration (PE, units mm) was calculated using Thornthwaite's formula.

$PE_m = 16N_m(10T_m/I)^a$

Wherethe subscript m denotes month;

T_m (°C) is mean monthly temperature;

$I = \sum i_m$

$i_m = (T_m/5)^{1.5}$

$a = 6.7\ 10^{-7}I^3 - 7.7\ 10^{-5}I^2 + 1.8\ 10^{-2}I + 0.49$

I made the adjustment of only calculating im for months in which $T_m>0$ and setting PEm to zero for months in which $T_m \leq 0$.

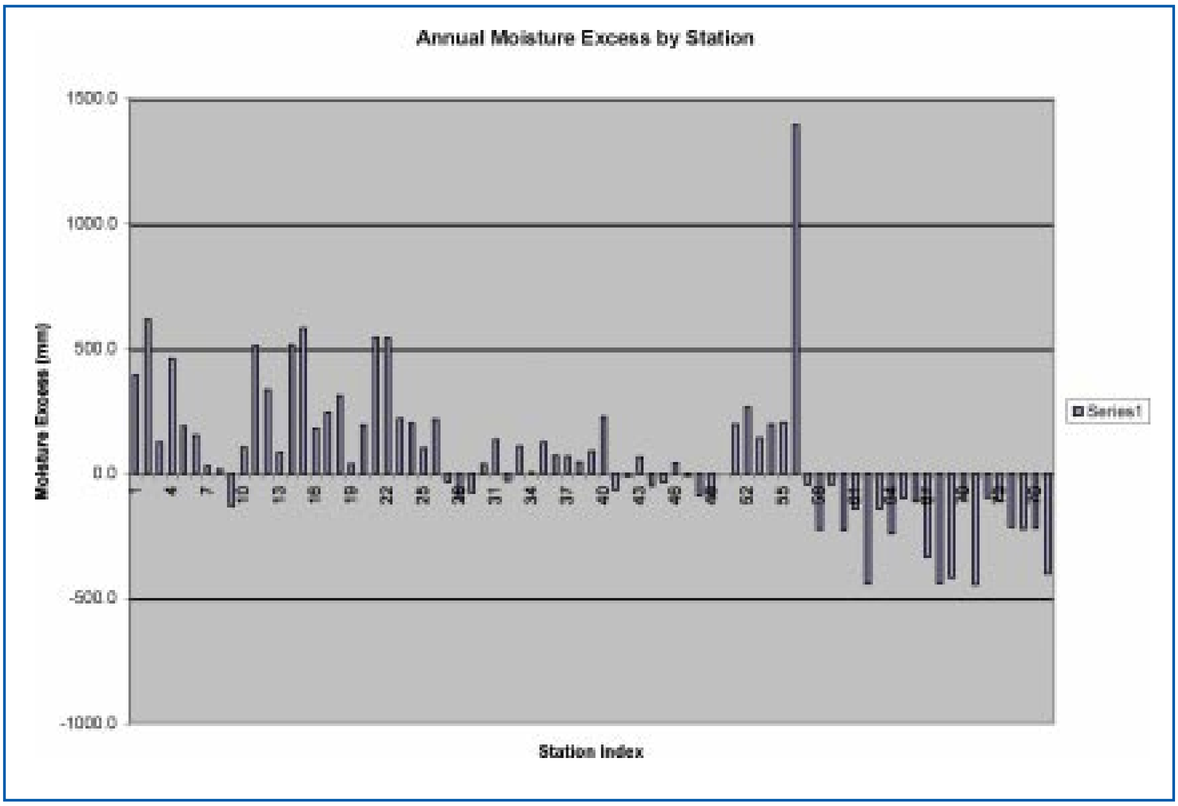
Although this is only an approximate approach and neglects distinctions between actual and potential evapotranspiration, it can be used together with precipitation to give an indication of monthly, seasonal and annual water balances.

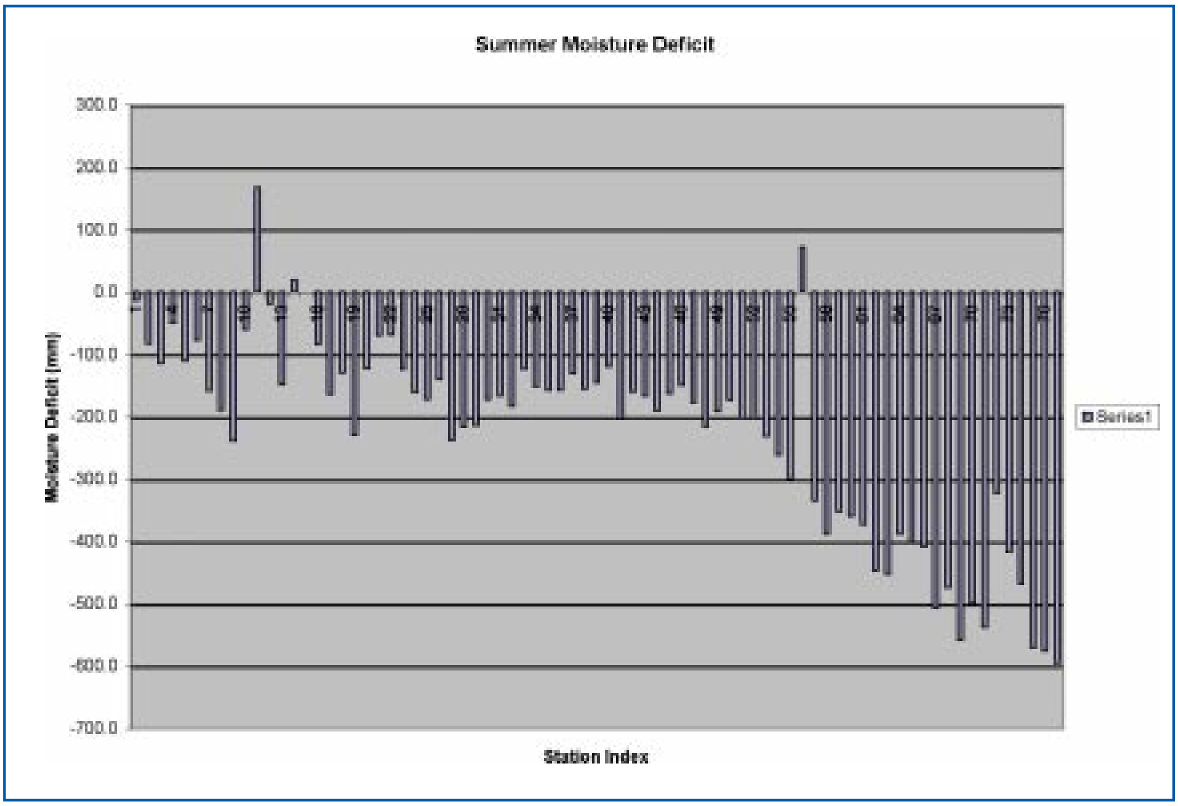
For the purpose of this calculation, I took values of N_m for Keele, as reasonably characteristic of Central England. These values, by month, are 0.68, 0.82, 0.98, 1.15, 1.31, 1.39, 1.36, 1.23, 1.06, 0.88, 0.72, 0.63. These are not the values that would apply at the original latitudes of the stations.

The results that I have generated comprise:

- Annual moisture excess or deficit by station (Annual precipitation minus annual PE);
- Summer moisture deficit (Precipitation minus PE summed over May, June, July and August);
- Monthly moisture deficit for each station and averaged over each climate class.

Results are shown in the following figures.


Annual Moisture Excess by Station
Moisture Excess (mm)
Station Index
Series1


Summer Moisture Deficit
Moisture Deficit (mm)
Station Index
Series1

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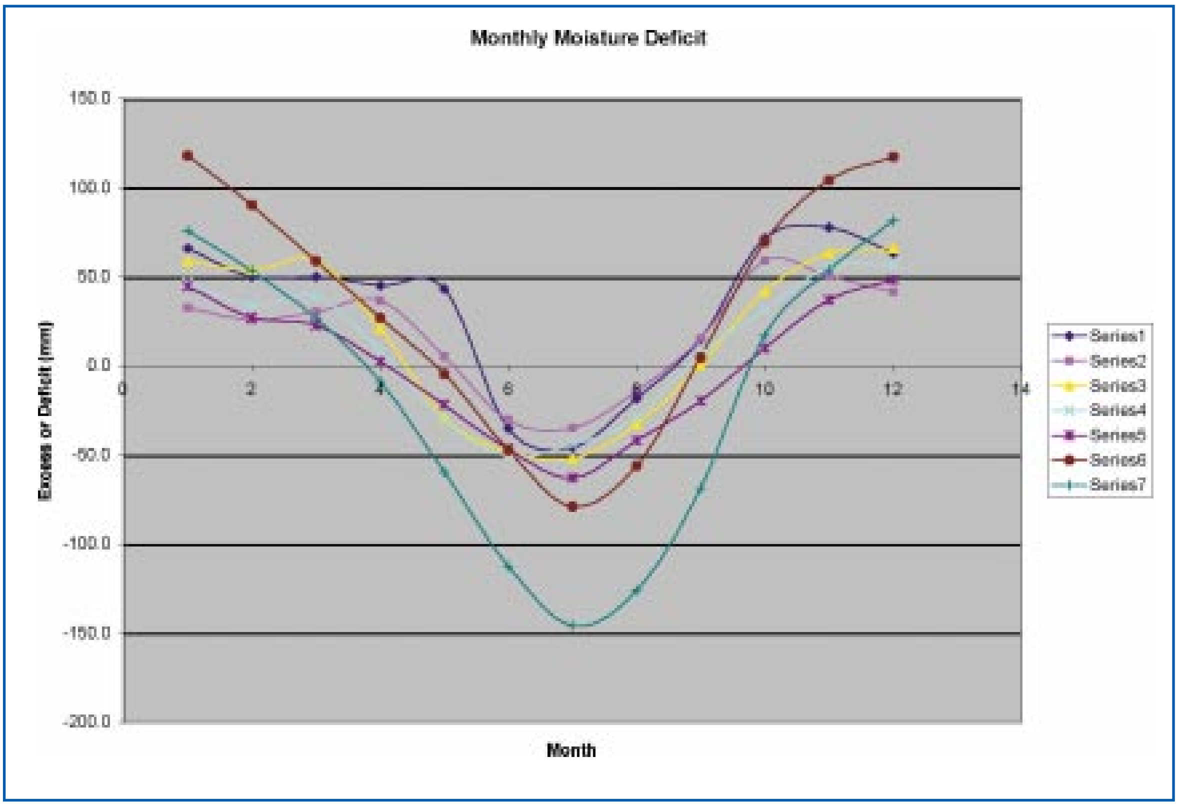
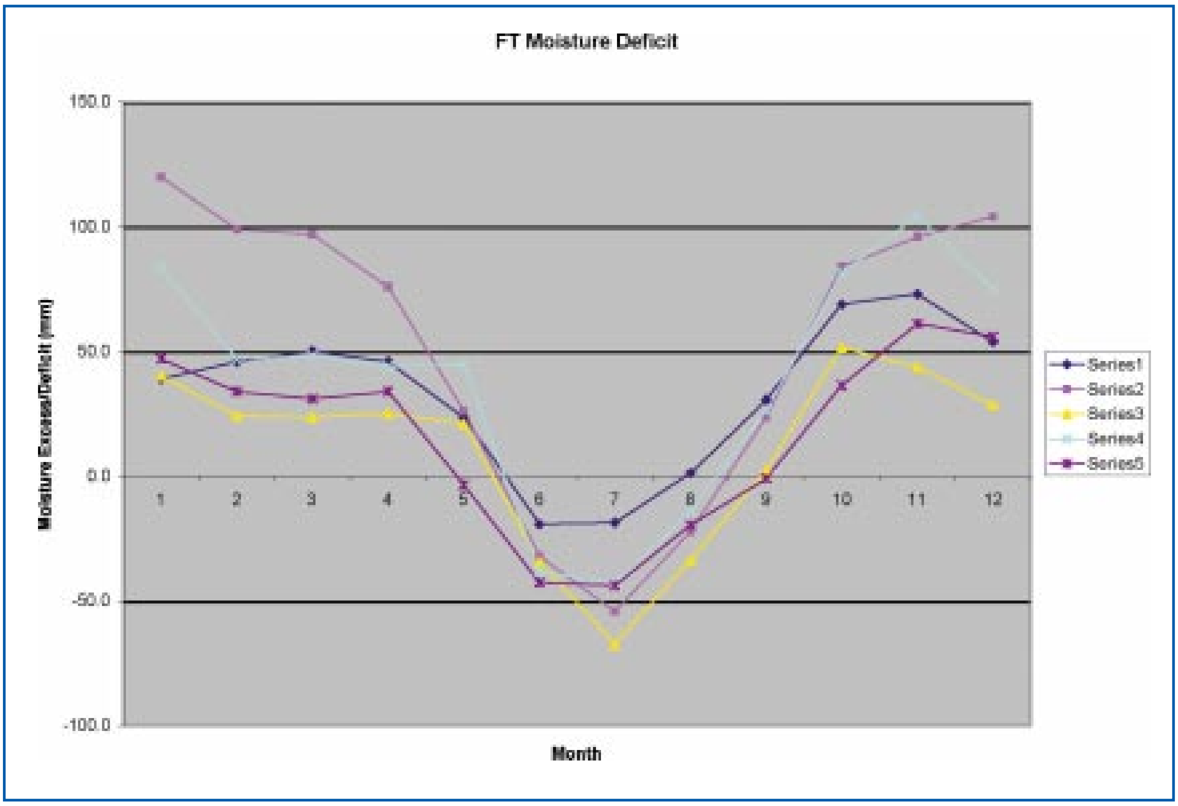
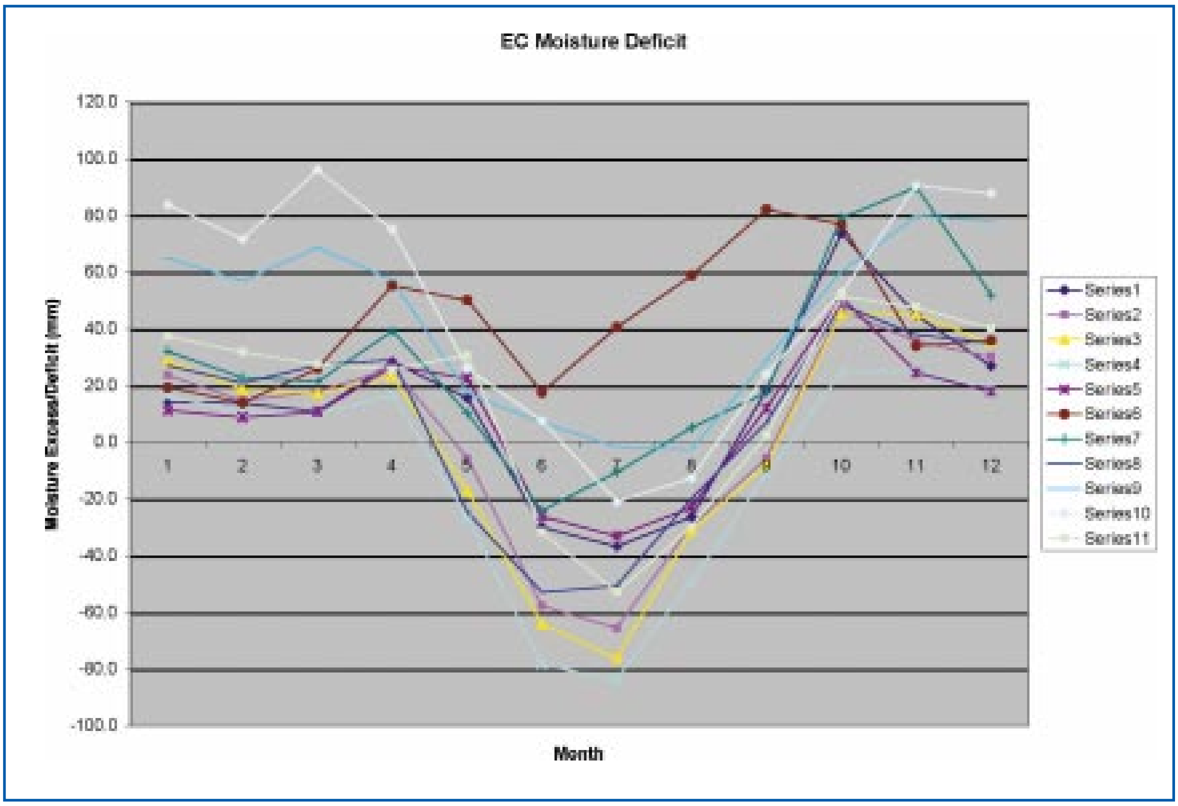
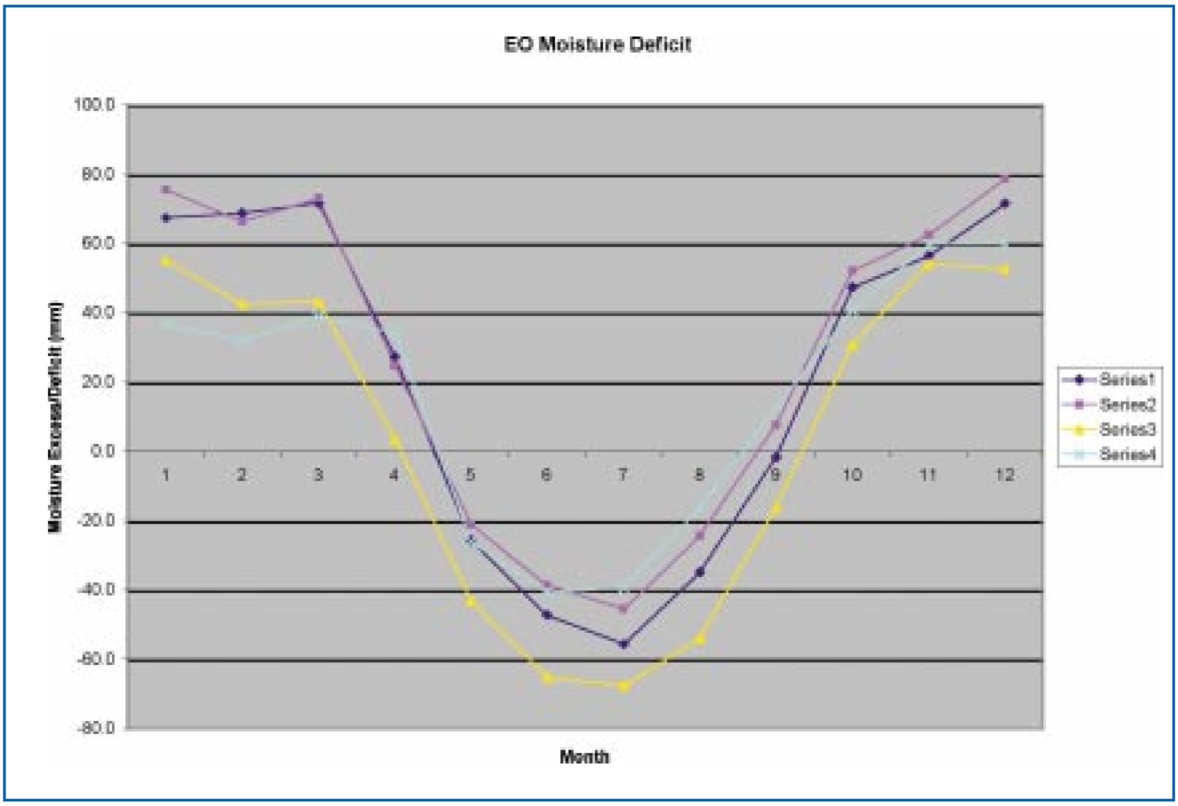

Monthly Moisture Deficit
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
0
2
4
6
8
10
12
14
Excess or Deficit (mm)
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7


FT Moisture Deficit
150.0
100.0
50.0
0.0
-50.0
-100.0
1
2
3
4
5
6
7
8
9
10
11
12
Moisture Excess/Deficit (mm)
Month
Series1
Series2
Series3
Series4
Series5


EC Moisture Deficit
Moisture Excess/Deficit (mm)
Month
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
1
2
3
4
5
6
7
8
9
10
11
12
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11


EO Moisture Deficit
Moisture Excess/Deficit (mm)
Month
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
1
2
3
4
5
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7
8
9
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11
12
Series1
Series2
Series3
Series4

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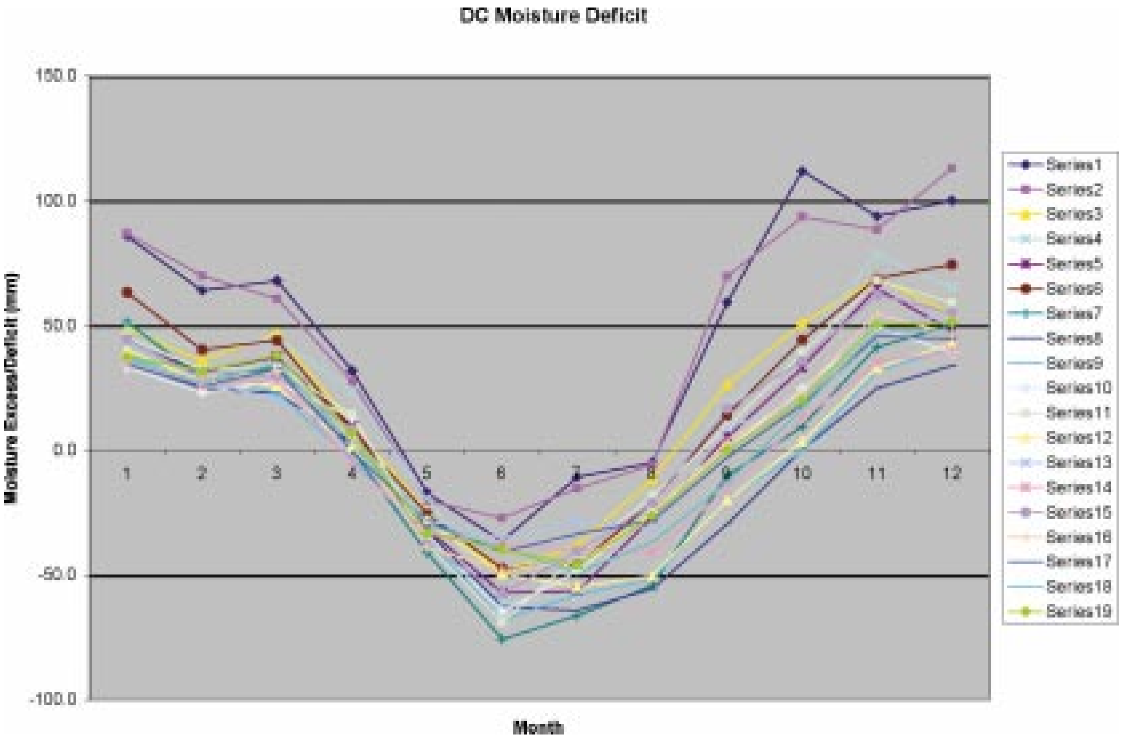
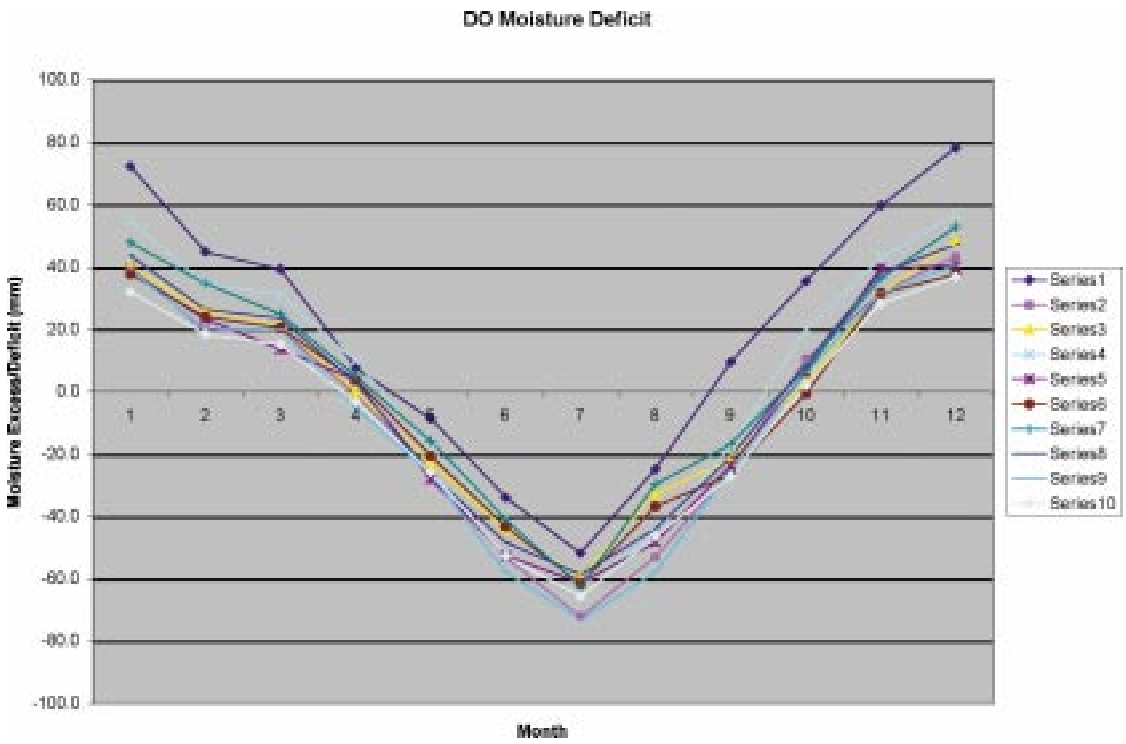

DC Moisture Deficit
Moisture Excess/Deficit (mm)
150.0
100.0
50.0
0.0
-50.0
-100.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12
Series13
Series14
Series15
Series16
Series17
Series18
Series19


DO Moisture Deficit
Moisture Excess/Deficit (mm)
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
1
2
3
4
5
6
7
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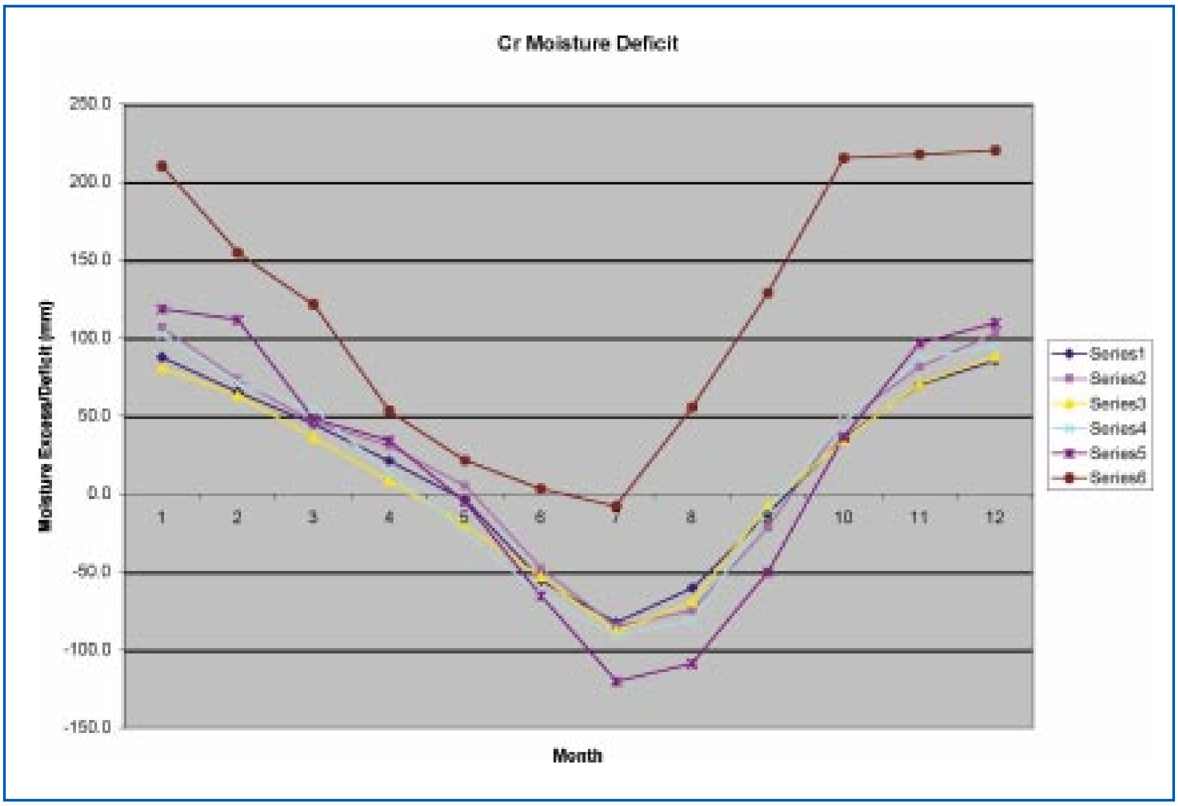
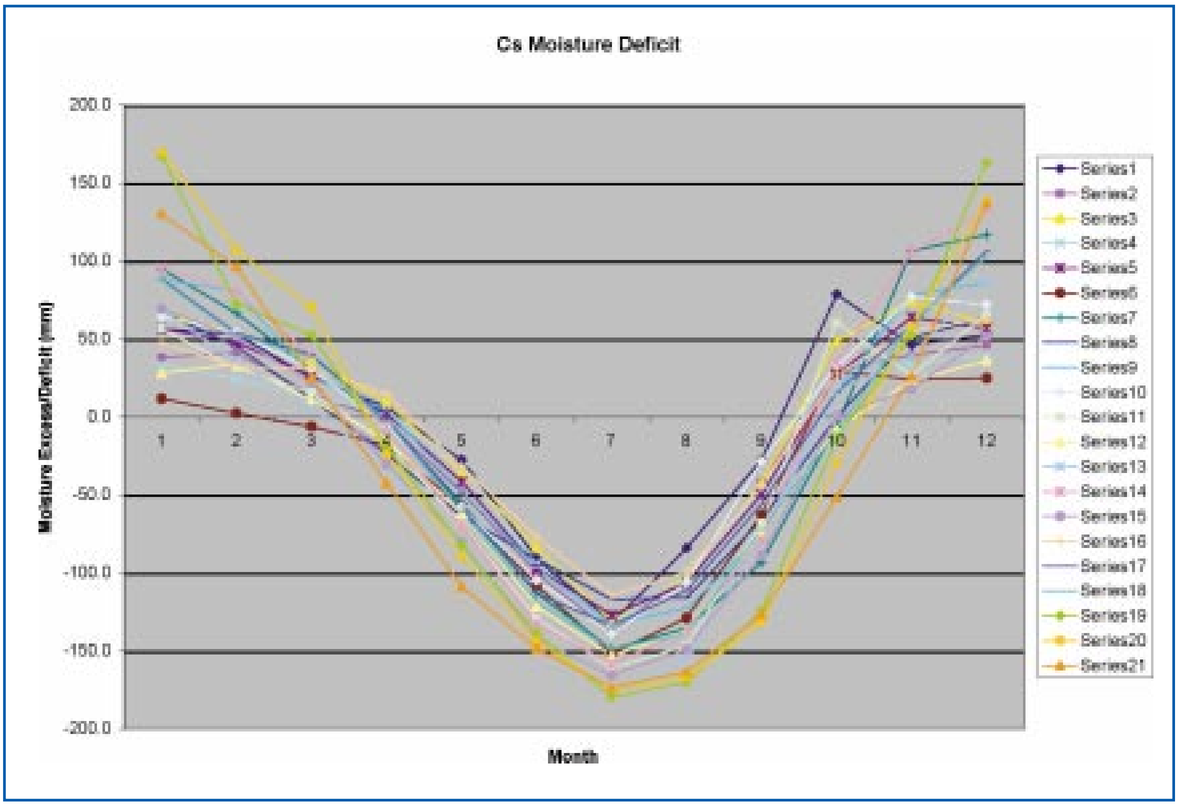
9
10
11
12
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10


Cr Moisture Deficit
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
Moisture Excess/Deficit (mm)
1
2
3
4
5
6
7
8
9
10
11
12
Month
Series1
Series2
Series3
Series4
Series5
Series6


Cs Moisture Deficit
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
Moisture Excess/Deficit (mm)
1
2
3
4
5
6
7
8
9
10
11
12
Month
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12
Series13
Series14
Series15
Series16
Series17
Series18
Series19
Series20
Series21

The annual moisture excess by station exhibits an appropriate trend. Cold stations typically exhibit an excess. Interestingly, because DC stations are colder than DO stations, they typically exhibit a slight moisture excess, whereas the DO stations are close to neutral. The Cr stations are distorted by Rize (Index 55), which should probably be excluded from consideration as an analogue. However, even excluding Rize, these stations have a significant annual excess of moisture. In contrast, the Cr stations uniformly exhibit an annual moisture deficit.

In respect of summer moisture deficit, this is characteristic of all the stations except for four. One of these is Rize (Index 55), as already discussed. The others are Ajan (Index 11; excess 167 mm), Goose (Index 14, excess 20.3) and Cartright (Index 15, excess 0.0). Small moisture excesses in EC conditions seem reasonable, with the development of northern wetlands being characteristic.

The strong increase in moisture deficit in Cs conditions is notable. As crop irrigation occurs in DO and Cr conditions (summer moisture deficit 100 to 200 mm), this suggests that pasture irrigation is likely to occur when summer moisture deficit passes a threshold of about 200 mm.

The monthly moisture deficits averaged over stations show the clear distinction between Cr (Series 7) and the other climate states.

In the individual monthly data by station, all the FT stations are broadly similar. For EC, the Ajan, Goose and Cartright data (Series 6, 9 and 10) are clearly distinct. For EO, the four station patterns are very similar. For DC, two Norwegian stations (Series 1 and 2) are characterised by unusually high winter excesses. For DO, there are no major distinctions. For Cr, the overall shape for Rize (Series 6) is similar to that for the other stations, but it is offset vertically by about 100 mm per month. For Cs, there are no major distinctions to be made.

Conclusions

Overall, it is considered that all except the following stations should be used as analogues:

EC: Ajan (index 11), because of its unusual strong summer precipitation peak;
DC: Possibly, Bodo and Orland (Indices 21 and 22), because of heavy winter precipitation that might be more representative for western Britain;
Cr: Azores stations (Indices 52 and 53), as hyperoceanic; Rize (Index 55), because of its unusually high rainfall;
Cs: Funchal (Index 63), as hyperoceanic.

Appendix: Selected Climate Stations

Stn-ID	is the (i7) WMO or pseudo-WMO station number
Station name	is the (a20) station name (may be truncated)
Lat.	is the (i5) latitude in (degrees decimal)*100
Long.	is the (i6) longitude in (degrees decimal)*100
Elev.	is the (i5) elevation in meters
Country	is the (a13) country (may be 3-letter abbrev.)
smr	is the (a1) thermal summer classification
wtr	is the (a1) thermal winter classification
L/G	is the (a1) elevation 'flag' – "L" indicates less than 500 m and "G" indicates 500-2499 m
tyr1	is the (i4) first year of any CRU temperature time series
tyr2	is the (i4) last year of any CRU temperature time series
pyr1	is the (i4) first year of any CRU precipitation time series
pyr2	is the (i4) last year of any CRU precipitation time series
tnorm	is the (i4) period of temperature normals calculation
t%	is the (i3) %-presence of temperature values in tnorm
pnorm	is the (i4) period of precipitation normals calculation
p%	is the (i3) %-presence of precipitation values in pnorm

FT STATIONS: NORTHERN HEMISPHERE

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
425000	GODTHAAB	6417	-5175	70	GRE	k	o	L	1866	2001	1874	2000	6190	100	6190	100	**1**
436000	AMMASALIK	6560	-3763	52	GRE	k	o	L	1894	2001	1897	2000	6190	100	6190	100	**2**
2539900	MYS UELEN	6617	-16983	7	RUSSIAN FEDE	k	c	L	1918	2001	1928	2000	6190	100	6190	100	**3**
2559400	BUHTA PROVIDE	6442	-17323	17	RUSSIAN-FEDE	k	c	L	1936	1990	1934	1993	6190	97	6190	100	**4**
7030800	ST. PAUL	5715	-17022	9	UNITED STATE	k	o	L	1916	2001	1915	2000	6190	100	6190	100	**5**

EC STATIONS: NORTHERN HEMISPHERE

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
2591300	MAGADAN	5955	15078	118	RUSSIAN FEDE	l	c	L	1930	1990	1930	1993	6189	96	6190	100	**6**
2923100	KOLPASEV	5830	8290	76	RUSSIA	b	c	L	1925	2001	1936	2000	6189	96	6190	100	**7**
2926300	ENISEJSK	5845	9215	79	RUSSIAN FEDE	b	c	L	1871	2001	1881	2000	6189	96	6190	100	**8**
2928200	BOGUCANY	5838	9745	134	RUSSIAN FEDE	b	c	L	1930	2001	1913	2000	6189	96	6190	100	**9**
3108800	OHOTSK	5937	14320	8	RUSSIAN FEDE	l	c	L	1890	2001	1891	2000	6189	96	6190	100	**10**
3116800	AJAN	5645	13815	9	RUSSIAN FEDE	l	c	L	1891	2001	1892	2000	6189	96	6190	100	**11**
3241100	ICA	5558	15558	10	RUSSIAN FEDE	l	c	L	1935	2001	1935	2000	6189	92	6190	100	**12**
7032600	KING SALMON	5868	-15665	15	UNITED STATE	l	c	L	1917	2001	1918	2000	6190	100	6190	100	**13**
7181600	GOOSE	5330	-6040	49	CANADA	l	c	L	1941	2001	1942	1998	4190	167	6190	100	**14**
7181800	CARTWRIGHT	5370	-5700	14	CANADA	l	c	L	1934	2001	1935	1998	6190	100	6190	100	**15**
7190600	FORT CHIMO	5810	-6840	37	CANADA	l	c	L	1942	2001	1948	1998	4790	147	6190	100	**16**

EO STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
401300	STYKKISHOLMUR	6508	-2273	17	ICE	l	o	L	1823	1999	1857	1998	6190	100	6190	100	**17**
403000	REYKJAVIK	6400	-2200	61	ICELAND	l	o	L	1870	2001	1829	2000	6190	100	6190	100	**18**
406300	AKUREYRI	6568	-1808	27	ICE	l	o	L	1882	2001	1928	2000	6190	100	6190	100	**19**
427000	IVIGTUT/ NARSARSUAQ	6120	-4542	32	GRE	l	o	L	1875	1990	1875	1990	6190	100	6190	100	**20**

DC STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
115200	BODO	6730	1440	13	NOR	l	o	L	1868	2001	1869	2000	6190	100	6190	100	21
124100	ORLAND	6370	960	10	NOR	l	o	L	1951	2001	1951	2000	6190	100	6190	100	22
149200	OSLO BLINDERN	5995	1072	96	NORWAY	l	o	L	1816	2001	1866	2000	6190	99	6190	100	23
236100	HARNOSAND	6260	1800	8	SWEDEN	l	o	L	1859	2000	1860	1993	6190	100	6190	97	24
241800	KARLSTAD	5935	1347	55	SWE	l	o	L	1859	2001	1861	2000	6190	100	6190	100	25
251200	GOETEBORG/ GAVE	5777	1188	53	SWEDEN	l	o	L	1860	2000	1890	2000	6190	100	6190	100	26
259000	VISBY AIRPORT	5767	1833	51	SWE	l	o	L	1859	2001	1861	2000	6190	100	6190	100	27
261600	FALSTERBO	5538	1282	5	SWEDEN	l	k	L	1879	2000	1890	1990	6190	100	6190	100	28
267200	KALMAR	5673	1630	15	SWE	l	o	L	1859	2000	1861	1990	6190	100	6190	100	29
294300	TAMPERE	6150	2370	85	FINLAND	l	o	L	1890	1999	1890	1990	6170	33	6190	100	30
297200	TURKU	6052	2227	59	FINLAND	l	o	L	1890	2001	1909	2000	6190	100	6190	100	31
1018400	GREIFSWALD	5410	1340	6	GERMANY	l	o	L	1951	2001	1951	2000	6190	99	6190	97	32
1210500	KOSZALIN	5420	1615	34	POLAND	l	o	L	1848	1990	1861	1993	6690	83	6190	100	33
1229500	BIALYSTOK	5310	2320	151	POL	l	o	L	1951	2001	1951	2000	6690	83	6190	93	34
2603800	TALLIN	5942	2480	44	EST	l	o	L	1806	2001	1845	2000	6190	100	6190	100	35
2625800	PSKOV	5783	2835	45	RUS	l	o	L	1883	1990	1891	1995	6190	97	6190	100	36
2647700	VELIKIE LUKI	5635	3062	106	RUSSIAN FEDE	l	o	L	1881	2001	1881	2000	6190	97	6190	100	37
2662900	KAUNAS	5488	2383	77	LITHUANIA	l	o	L	1922	2001	1892	2000	6190	100	6190	100	38
2673000	VIL'NJUS	5463	2528	189	LIT	l	o	L	1777	1990	1881	2000	6190	97	6190	100	39

DO STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
-386780	LONG ASHTON	5143	-267	51	UK	l	k	L	*	*	1920	1999	6190	100	6190	100	40
-351130	HEATHROW	5148	-48	25	UK	b	k	L	*	*	*	*	6190	100	6190	100	41
-344320	STRATFORD ON AVON	5218	-173	49	UK	l	k	L	*	*	1961	1999	6190	100	6190	100	42
-335370	ROTHAMSTED	5180	-35	128	UK	l	k	L	*	*	1961	1999	6190	100	6190	100	43
-331970	LOWESTOFT	5248	175	25	UK	l	k	L	*	*	1961	1999	6190	100	6190	99	44
-324320	CRANWELL	5303	-50	62	UK	l	k	L	*	*	1961	1995	6190	100	6190	100	45
353400	BIRMINGHAM AIRPORT	5245	-173	99	UK	l	k	L	1951	1997	1949	1999	6190	100	6190	100	46
368300	STANSTED AIRPORT	5190	20	106	UK	l	k	L	*	*	1950	1997	6190	100	6190	100	47
378370	GREENWICH	5148	0	7	UK	b	k	L	*	*	1820	1994	6190	100	6190	70	48
389960	CAMBRIDGE	5220	10	12	UK	l	k	L	1871	1969	1848	1999	6190	100	6190	100	49

Cr STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
751000	BORDEAUX MERIGNAC	4483	-68	61	FRANCE	b	k	L	1851	2001	1842	2000	6190	100	6190	100	**50**
800100	LA CORUNA	4340	-840	67	SPAIN	b	l	L	1951	2001	1877	2000	6190	100	6190	100	**51**
850600	HORTA (ACORES)	3852	-2863	62	PORTUGAL	b	l	L	1920	1996	1902	1996	6190	100	6190	100	**52**
851300	PONTA DELG. (AZORES)	3770	-2570	67	PORTUGAL	b	l	L	1865	1996	1865	1996	6190	100	6190	100	**53**
854900	COIMBRA	4020	-842	141	POR	b	l	L	1866	1991	1866	1996	6190	100	6190	100	**54**
1704000	RIZE	4103	4052	9	TUR	b	k	L	1929	2001	1929	2000	6190	100	6190	100	**55**

Cs STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%	Index
764500	NIMES	4387	440	62	FRANCE	a	k	L	1951	1995	1951	1995	6190	100	6190	100	**56**
	COURBESSAC	4387	440	62	FRANCE	a	k	L	1951	1995	1951	1995	6190	100	6190	100	**57**
765000	MARIGNANE	4345	523	36	FRANCE	a	k	L	1838	2001	1749	2000	6190	99	6190	97	**58**
769000	NICE	4365	720	28	FRANCE	a	k	L	1951	2001	1951	2000	6190	100	6190	100	**59**
774700	PERPIGNAN	4270	290	48	FRANCE	a	k	L	1836	2001	1850	2000	6190	99	6190	97	**60**
776100	AJACCIO	4192	880	9	FRANCE	b	k	L	1951	2001	1855	2000	6190	100	6190	100	**61**
828500	VALENCIA	3948	-38	11	SPAIN	a	l	L	1900	1994	1859	2000	6190	100	6190	100	**62**
849500	GIBRALTAR	3615	-535	5	GIBRALTAR	a	l	L	1951	2001	1852	2000	6190	100	6190	100	**63**
852200	FUNCHAL	3263	1690	56	MADEIRA	b	l	L	1900	2001	1880	2000	6190	100	6190	100	**64**
853500	LISBOA	3872	-915	95	POR	a	l	L	1864	2001	1836	2000	6190	100	6190	100	**65**
1624200	ROMA FIUMICINO	4180	1223	3	ITALY	a	k	L	1811	1996	1871	1996	6190	100	6190	93	**66**
1646000	CATANIA/FONTA	3747	1505	17	ITALY	a	l	L	1892	1992	1892	1992	6190	100	6190	83	**67**
1656000	CAGLIARI ELMAS	3930	910	5	ITA	a	l	L	1951	2001	1942	2000	6190	100	6190	100	**68**
1659700	LUQA	3580	1450	91	MAL	a	l	L	1853	2001	1841	2000	6190	100	6190	100	**69**
1672600	KALAMATA	3700	2210	11	GREECE	a	l	L	1951	2001	1951	2000	6190	100	6190	100	**70**
1675400	HERAKLION	3533	2518	39	GRE	a	l	L	1951	2001	1910	2000	6190	100	6190	100	**71**
1703000	SAMSUN	4128	3633	44	TUR	a	k	L	1929	2001	1880	2000	6190	100	6190	100	**72**
1706200	GOZTEPE	4097	2908	40	TUR	a	k	L	1839	2001	1846	2000	6190	100	6190	100	**73**
1711200	CANAKKALE	4015	2642	6	TUR	a	k	L	1951	2001	1931	2000	6190	100	6190	93	**74**
4002200	LATTAKIA	3560	3580	9	SYRIA	a	l	L	1952	2001	1928	2000	6690	83	6690	83	**75**
4010000	BEIRUT INT. AIRPORT	3390	3550	26	LEBANON	a	l	L	1843	2001	1888	2000	7190	63	6190	100	**76**
4018000	BEN GURION INT.	3200	3490	49	ISR	a	l	L	1951	2001	1951	2000	7790	43	6190	67	**77**

Appendix 6: list of analogue stations selected for northeast France

Stn-ID	is the (i7) WMO or pseudo-WMO station number
Station name	is the (a20) station name (may be truncated)
Lat.	is the (i5) latitude in (degrees decimal)*100
Long.	is the (i6) longitude in (degrees decimal)*100
Elev.	is the (i5) elevation in meters
Country	is the (a13) country (may be 3-letter abbrev.)
smr	is the (a1) thermal summer classification
wtr	is the (a1) thermal winter classification
L/G	is the (a1) elevation 'flag' – "L" indicates less than 500 m and "G" indicates 500-2499 m
tyr1	is the (i4) first year of any CRU temperature time series
tyr2	is the (i4) last year of any CRU temperature time series
pyr1	is the (i4) first year of any CRU precipitation time series
pyr2	is the (i4) last year of any CRU precipitation time series
tnorm	is the (i4) period of temperature normals calculation
t%	is the (i3) %-presence of temperature values in tnorm
pnorm	is the (i4) period of precipitation normals calculation
p%	is the (i3) %-presence of precipitation values in pnorm

FT STATIONS: NORTHERN HEMISPHERE

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
425000	GODTHAAB	6417	-5175	70	GRE	k	o	L	1866	2001	1874	2000	6190	100	6190	100
436000	AMMASALIK	6560	-3763	52	GRE	k	o	L	1894	2001	1897	2000	6190	100	6190	100
2539900	MYS UELEN	6617	-16983	7	RUSSIAN FEDE	k	c	L	1918	2001	1928	2000	6190	100	6190	100
2559400	BUHTA PROVIDE	6442	-17323	17	RUSSIAN-FEDE	k	c	L	1936	1990	1934	1993	6190	97	6190	100
7030800	ST. PAUL	5715	-17022	9	UNITED STATE	k	o	L	1916	2001	1915	2000	6190	100	6190	100

EC STATIONS: NORTHERN HEMISPHERE

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
2591300	MAGADAN	5955	15078	118	RUSSIAN FEDE	l	c	L	1930	1990	1930	1993	6189	96	6190	100
2923100	KOLPASEV	5830	8290	76	RUSSIA	b	c	L	1925	2001	1936	2000	6189	96	6190	100
2926300	ENISEJSK	5845	9215	79	RUSSIAN FEDE	b	c	L	1871	2001	1881	2000	6189	96	6190	100
2928200	BOGUCANY	5838	9745	134	RUSSIAN FEDE	b	c	L	1930	2001	1913	2000	6189	96	6190	100
3108800	OHOTSK	5937	14320	8	RUSSIAN FEDE	l	c	L	1890	2001	1891	2000	6189	96	6190	100
3241100	ICA	5558	15558	10	RUSSIAN FEDE	l	c	L	1935	2001	1935	2000	6189	92	6190	100
7032600	KING SALMON	5868	-15665	15	UNITED STATE	l	c	L	1917	2001	1918	2000	6190	100	6190	100
7181600	GOOSE	5330	-6040	49	CANADA	l	c	L	1941	2001	1942	1998	4190	167	6190	100
7181800	CARTWRIGHT	5370	-5700	14	CANADA	l	c	L	1934	2001	1935	1998	6190	100	6190	100
7190600	FORT CHIMO	5810	-6840	37	CANADA	l	c	L	1942	2001	1948	1998	4790	147	6190	100

EO STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
401300	STYKKISHOLMUR	6508	-2273	17	ICE	l	o	L	1823	1999	1857	1998	6190	100	6190	100
403000	REYKJAVIK	6400	-2200	61	ICELAND	l	o	L	1870	2001	1829	2000	6190	100	6190	100
406300	AKUREYRI	6568	-1808	27	ICE	l	o	L	1882	2001	1928	2000	6190	100	6190	100
427000	IVIGTUT/ NARSARSUAQ	6120	-4542	32	GRE	l	o	L	1875	1990	1875	1990	6190	100	6190	100

DC STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
149200	OSLO BLINDERN	5995	1072	96	NORWAY	l	o	L	1816	2001	1866	2000	6190	99	6190	100
236100	HARNOSAND	6260	1800	8	SWEDEN	l	o	L	1859	2000	1860	1993	6190	100	6190	97
241800	KARLSTAD	5935	1347	55	SWE	l	o	L	1859	2001	1861	2000	6190	100	6190	100
251200	GOETEBORG/ GAVE	5777	1188	53	SWEDEN	l	o	L	1860	2000	1890	2000	6190	100	6190	100
259000	VISBY AIRPORT	5767	1833	51	SWE	l	o	L	1859	2001	1861	2000	6190	100	6190	100
267200	KALMAR	5673	1630	15	SWE	l	o	L	1859	2000	1861	1990	6190	100	6190	100
297200	TURKU	6052	2227	59	FINLAND	l	o	L	1890	2001	1909	2000	6190	100	6190	100
1018400	GREIFSWALD	5410	1340	6	GERMANY	l	o	L	1951	2001	1951	2000	6190	99	6190	97
1210500	KOSZALIN	5420	1615	34	POLAND	l	o	L	1848	1990	1861	1993	6690	83	6190	100
1229500	BIALYSTOK	5310	2320	151	POL	l	o	L	1951	2001	1951	2000	6690	83	6190	93
2603800	TALLIN	5942	2480	44	EST	l	o	L	1806	2001	1845	2000	6190	100	6190	100
2662900	KAUNAS	5488	2383	77	LITHUANIA	l	o	L	1922	2001	1892	2000	6190	100	6190	100

DO STATIONS: "GREATER" EUROPE ONLY

Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
631000	VLISSINGEN	5145	360	10	NETHERLANDS	b	k	L	1931	1990	1957	2000	6190	100	6190	100
670000	GENEVE COINTRIN	4625	613	420	SWI	b	k	L	1753	2001	1826	2000	6190	100	6190	100
718000	NANCY ESSEY	4868	622	217	FRANCE	b	k	L	1951	2001	1811	2000	6190	100	6190	100
719000	STRASBOURG	4855	763	154	FRA	b	k	L	1801	2001	1802	2000	6190	100	6190	100
722200	NANTES	4730	-160	27	FRANCE	b	k	L	1851	2001	1835	2000	6190	100	6190	100
725500	BOURGES	4710	240	166	FRA	b	k	L	1851	1991	1951	2000	6190	100	6190	100
728000	DIJON	4730	510	227	FRA	b	k	L	1951	2001	1831	2000	6190	100	6190	100
746000	CLERMONT FERRAND	4580	310	403	FRANCE	b	k	L	1856	1866	1858	1988	6190	100	6190	100
748000	LYON	4570	470	208	FRANCE	b	k	L	1851	1995	1841	1995	6190	100	6190	100
763000	TOULOUSE BLAGNAC	4363	137	154	FRANCE	b	k	L	1839	2001	1809	2000	6190	100	6190	100
1041000	ESSEN	5140	700	161	GER	b	k	L	1951	2000	1951	1997	6190	100	6190	100
1062800	GEISENHEIM	4998	795	123	GERMANY	b	k	L	1951	2001	1951	2000	6190	100	6190	100
1072700	KARLSRUHE	4903	837	145	GERMANY	b	k	L	1779	1930	1779	2000	6190	100	6190	100
1327400	BEOGRAD	4480	2050	132	SER	b	k	L	1888	2001	1888	2000	6190	100	6190	97

Cr STATIONS: "GREATER" EUROPE ONLY

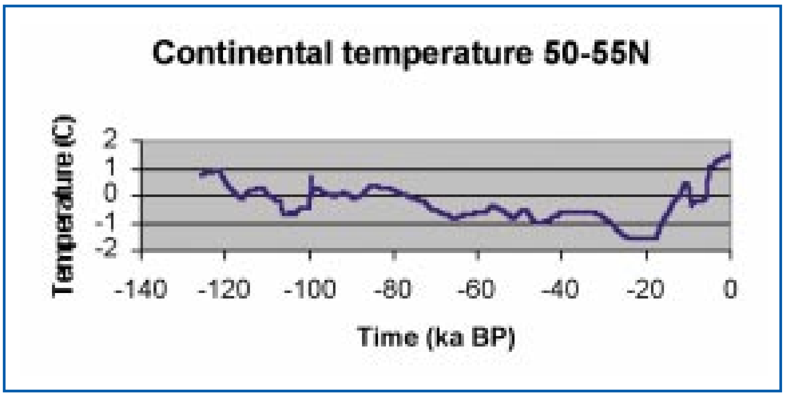
Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
800100	LA CORUNA	4340	-840	67	SPA	b	l	L	1951	2001	1877	2000	6190	100	6190	100
854900	COIMBRA	4020	-842	141	POR	b	l	L	1866	1991	1866	1996	6190	100	6190	100

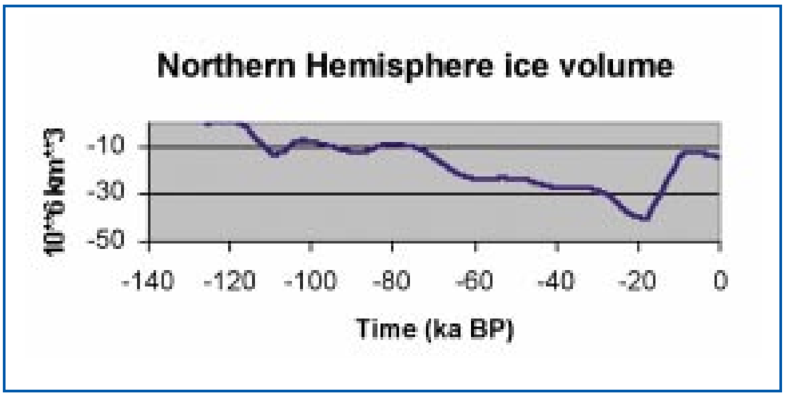
Cs STATIONS: "GREATER" EUROPE ONLY

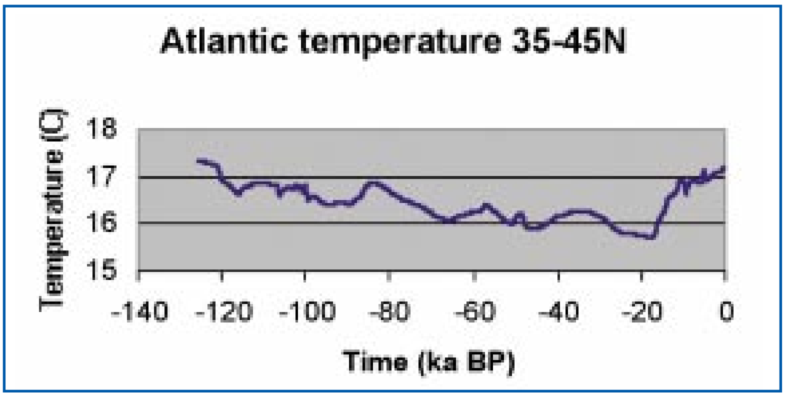
Stn-ID	Station name	Lat.	Long.	Elev.	Country	smr	wtr	L/G	tyr1	tyr2	pyr1	pyr2	tnorm	t%	pnorm	p%
828500	VALENCIA	3948	-38	11	SPAIN	a	l	L	1900	1994	1859	2000	6190	100	6190	100
849500	GIBRALTAR	3615	-535	5	GIBRALTAR	a	l	L	1951	2001	1852	2000	6190	100	6190	100
853500	LISBOA	3872	-915	95	POR	a	l	L	1864	2001	1836	2000	6190	100	6190	100
1646000	CATANIA/FONTA	3747	1505	17	ITALY	a	l	L	1892	1992	1892	1992	6190	100	6190	83
1656000	CAGLIARI ELMAS	3930	910	5	ITA	a	l	L	1951	2001	1942	2000	6190	100	6190	100
1659700	LUQA	3580	1450	91	MAL	a	l	L	1853	2001	1841	2000	6190	100	6190	100
1672600	KALAMATA	3700	2210	11	GREECE	a	l	L	1951	2001	1951	2000	6190	100	6190	100
4002200	LATTAKIA	3560	3580	9	SYRIA	a	l	L	1952	2001	1928	2000	6690	83	6690	83

Appendix 7: time-series plots of Mobidic output used in rule-based downscaling

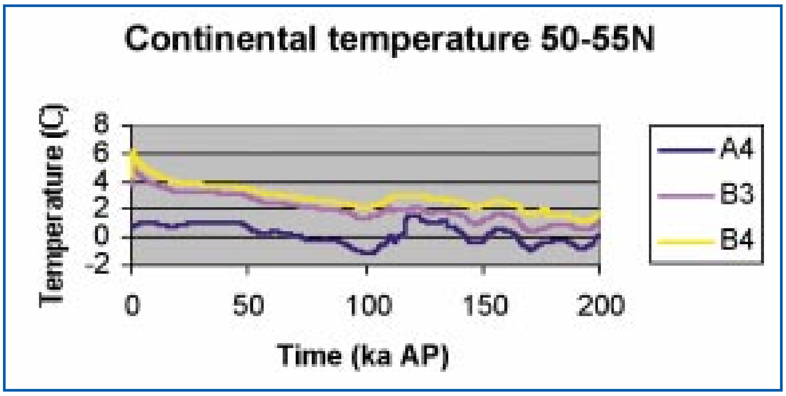
MoBidiC variables used to identify downscaling rules and thresholds from a simulation of the last glacial-interglacial cycle for Central England and Northeast France (annual average temperature for the 50-55°N Eurasian continental sector and Northern Hemisphere ice volume) and Central Spain (annual average temperature for the 35-45°N Atlantic oceanic sector):

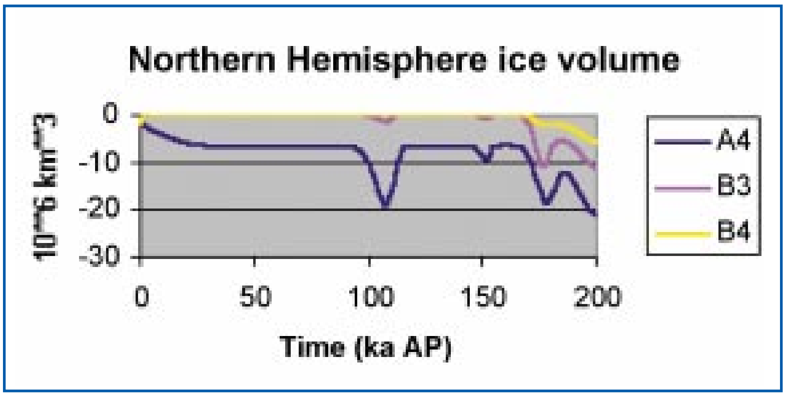


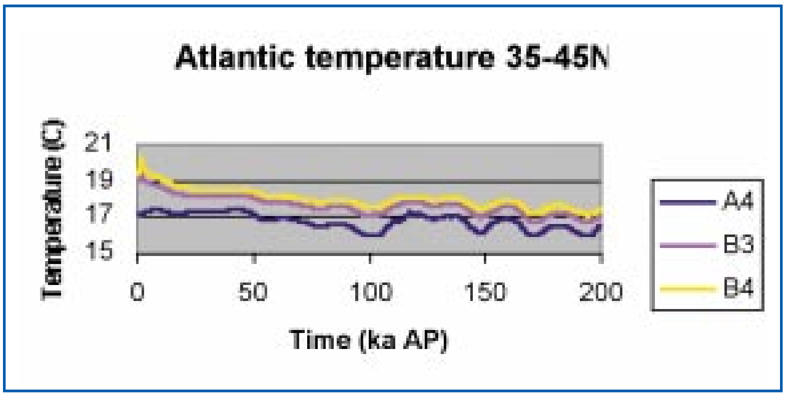




MoBidiC variables used to downscale output from simulations forced by natural CO_2 (A4), low anthropogenic CO_2 (B3) and high anthropogenic CO_2 (B4) scenarios for the next 200 ka for Central England and Northeast France (annual average temperature for the 50-55°N Eurasian continental sector and Northern Hemisphere ice volume) and Central Spain (annual average temperature for the 35-45°N Atlantic oceanic sector):

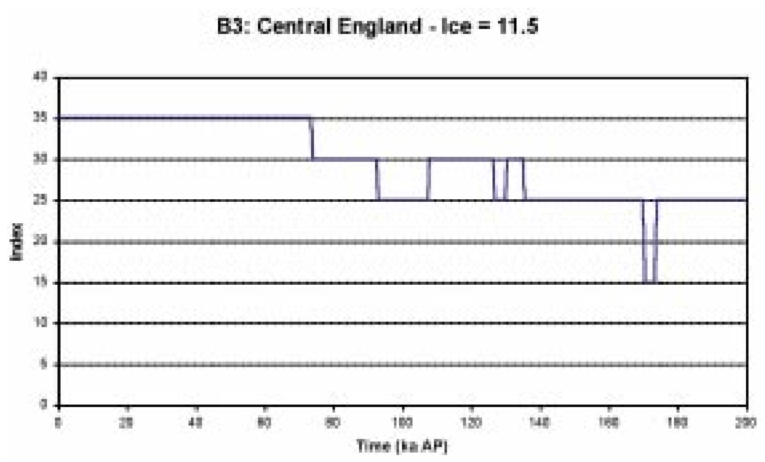


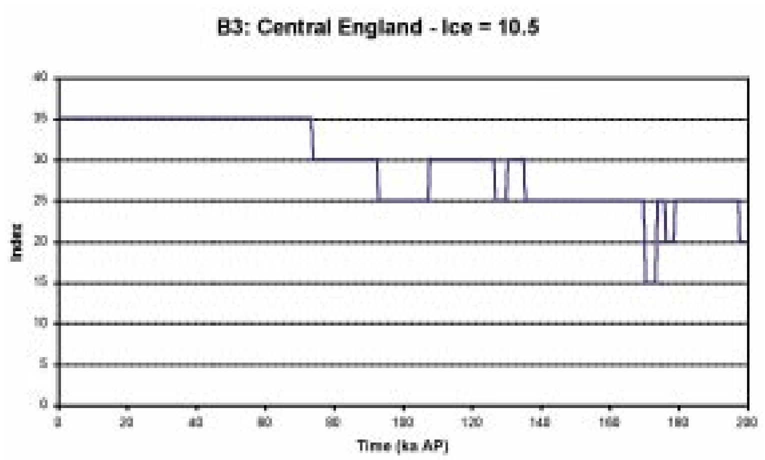


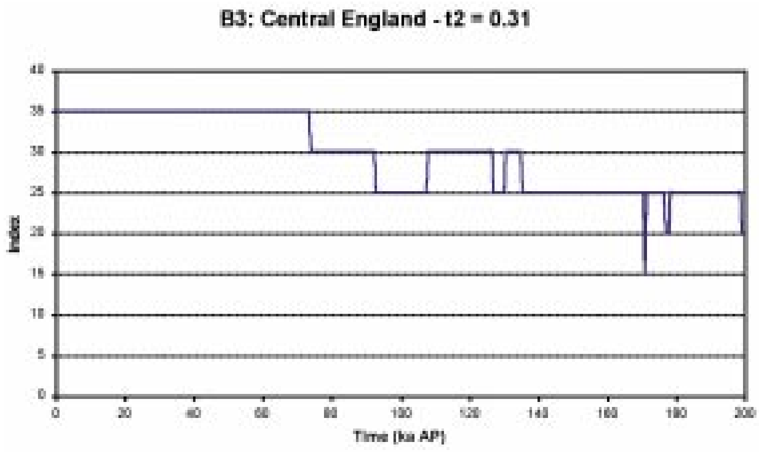


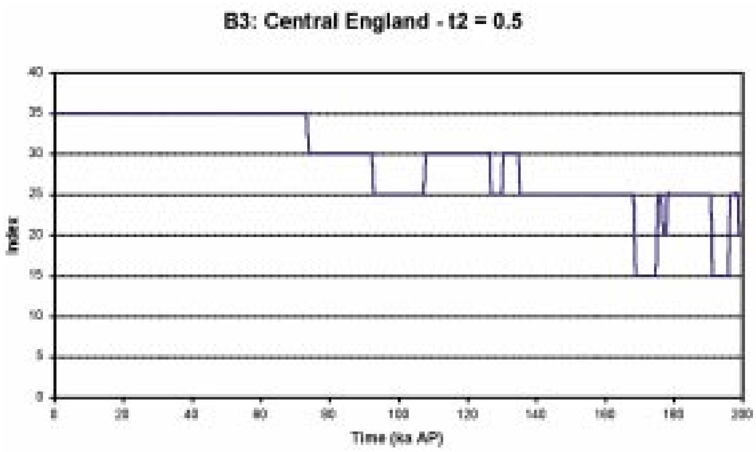
Appendix 8: effect of uncertainty in threshold value for downscaled Mobidic B3 indices for central England

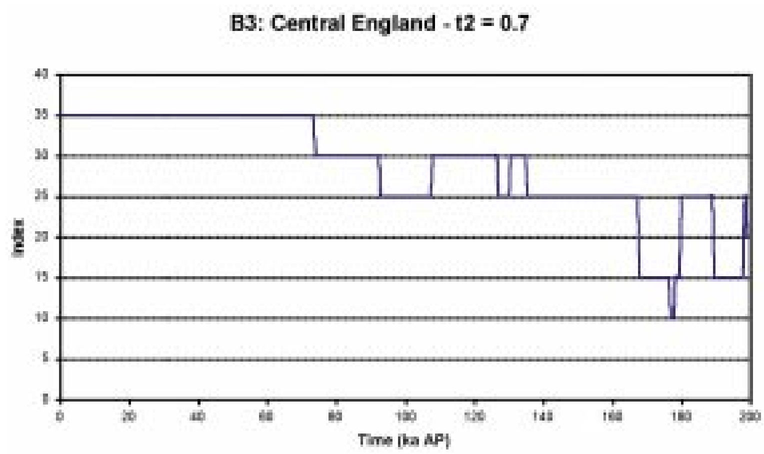
Unless otherwise indicated in the title of each figure, the threshold values given in Table 8 are used.

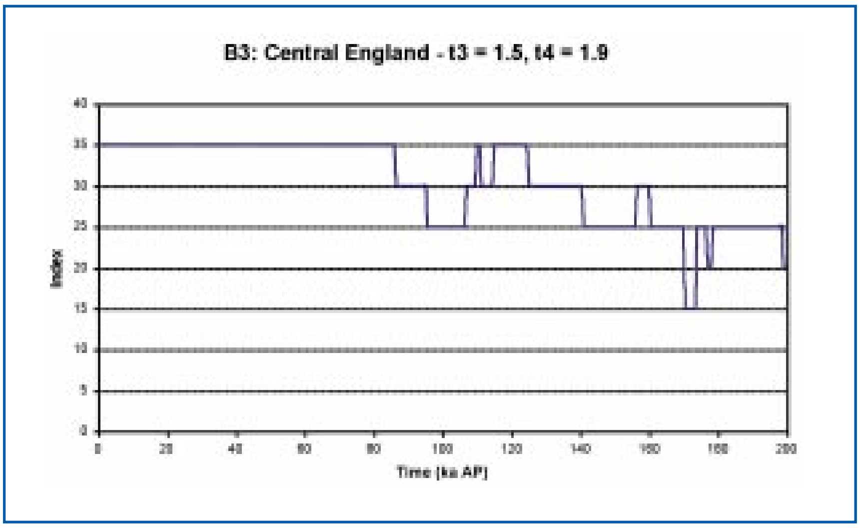


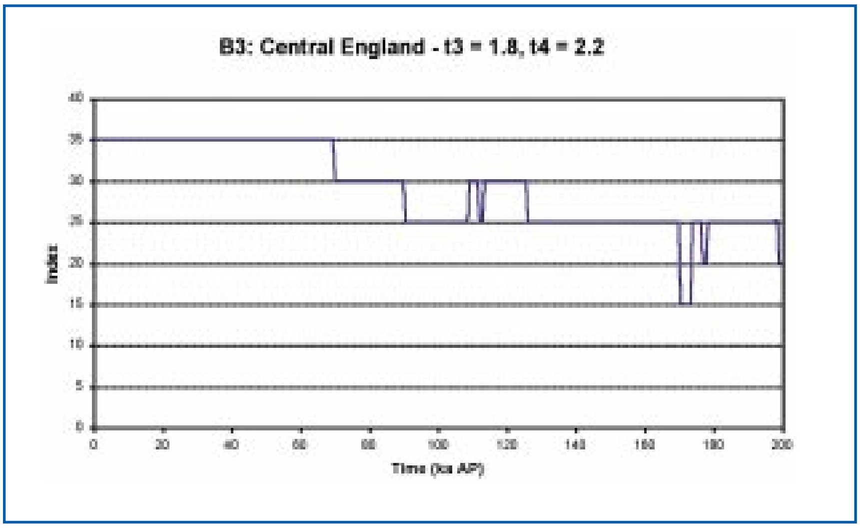


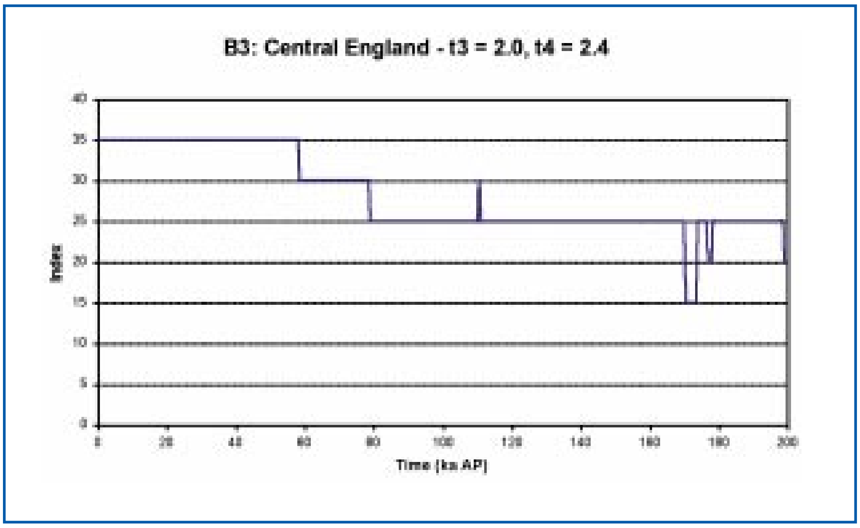

B3: Central England - t2 = 0.31
Index
Time (ka AP)


B3: Central England - t2 = 0.5
Index
Time (ka AP)


B3: Central England - t2 = 0.7
Index
Time (ka AP)


B3: Central England - t3 = 1.5, t4 = 1.9
Index
Time (ka AP)


B3: Central England - t3 = 1.8, t4 = 2.2
Index
Time (ka AP)


B3: Central England - t3 = 2.0, t4 = 2.4
Index
Time (ka AP)

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