Future climate scenarios for Ireland using high resolution statistical downscaling techniques

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Abstract

Polynomial regression techniques were used to derive a baseline climatology for Ireland at a scale of $1km^2$ for the period 1961-90. Monthly climate variables were related to position and elevation on a digital elevation model and these were found to provide good predictors for precipitation and maximum/minimum temperature. Baseline maps for mean monthly radiation receipt and potential evapotranspiration were also derived at $1km^2$ scales. The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Data were then related to this baseline climatology and relationships between upper air variables and surface climate established as a basis for statistical downscaling of global climate models.

Monthly output for the spatial domain over Ireland were extracted from the latest Hadley Centre Clobal Climate Model (HadCM3). Using the upper air/surface relationships the climate differences between a modelled run for the 1961-90 period and the period 2041-70 was established. These differences were then applied to the baseline climate data to provide future climatic scenarios for Ireland for these periods.

Mean temperature increases of 2-3°C were projected for mid century for both summer and winter. Precipitation changes showed winter increases of the order of 10% in western Ireland and similar summer decreases especially in eastern Ireland. Observational data trends appear to match these projections.

Introduction

The United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in 1992, marked the first tangible recognition by the international community of the real threat posed by anthropogenically-induced climate change. As part of the Convention, developed countries were committed to returning greenhouse gas emissions to 1990 levels by the end of the century. These aspirations have not been realised, and more recently, the Kyoto Protocol of 1997, which sought to reduce global emissions by 5.2% from 1990-2012, has also shown signs of being an unattainable objective. Like its predecessor, it has become stalled due to the unwillingness of key developed countries to bear the economic costs of emission controls. It is nonetheless an objective of the European Union that the Kyoto Protocol should be ratified in 2002 and that an EU emissions reduction target of 8% shall be achieved. As part of the burden sharing agreement decided on by individual member states to implement this policy, Ireland was allowed a growth in greenhouse gas emissions of 13%. However, over the period 1990-2012, Irish greenhouse gas emissions are projected to rise by 37.3% in the absence of effective controls (Stapleton, 2000). While the successful implementation of the National Climate Change Strategy (DOELG, 2000) may mitigate this rise somewhat, there is clearly a pressing need to anticipate the magnitude and spatial dimensions of greenhouse gas-led climate change in Ireland over the next half century.

To address this need requires the generation of climate scenarios from computerised models of the global climate system. These have become increasingly sophisticated due to improvements in understanding climate processes in recent years and due to the major advances which have been made in computing speed. This is important since each iteration of a global climate model may require the retrieval, calculation and storage of up to 10^5 numbers for each grid point for each atmospheric variable. As a result of these limitations, relatively coarse grid sizes of the order of 2.5° x 3.75° continue to characterise global climate models and a technique known as downscaling is required to make use of GCM output at a finer regional scale.

Principles of statistical downscaling

The relatively coarse resolution of Global Climate Model (GCM) output has prompted a number of approaches whereby finer regional details may be ascertained. The first of these, regional climate modelling, employs a dynamical approach making use of GCM output for grid cells in the vicinity of the study area. Essentially, the boundary conditions for the region of interest are supplied by output from a full-scale coupled ocean-atmosphere GCM. This in turn drives a nested regional climate model at a higher spatial resolution with grid scales typically of the order of tens of kilometres. A good example of this is provided by an exploration of regional climate change scenarios for Scotland at a resolution of 50 x 50kms which has recently been carried out using the Hadley Centre Regional Climate Model (RCM)

(HadRM2) (Hulme *et al.*, 2001). Serious uncertainties, however, persist with this approach (Giorgi and Francisco, 2000). These centre on the problem that the level of accuracy of the parent GCM largely determines the level of accuracy of the output (a problem applicable to all downscaling methods). Other difficulties persist, such as interfacing the coarse resolution data from the GCM to provide boundary conditions for the finer resolution nested RCM (Hewitson and Crane, 1996). The resolution of RCMs is also still of the order of 50 x 50km, too high for many policy applications. Accordingly, regional climate models cannot yet supersede statistical downscaling from the parent GCM for the generation of high-resolution scenarios. Ultimately it is the finer regional scales which are of importance to national policy makers and they alone offer the possibility of tailoring climatic scenarios more specifically to projected impacts and possible mitigation efforts (Lamb, 1987).

A second approach to downscaling involves using atmospheric GCM directly to produce high resolution output for a restricted time slice (Cusbach *et al*, 1995). This has not been widely employed as yet and entails running an Atmospheric GCM at high resolution while receiving output from a coarser resolution Oceanic GCM.

The simplest form of downscaling involves applying GCM output directly to a high resolution baseline climatology. This approach entails calculating the difference between a current and future GCM simulation and then adding a 'blanket figure' to the observed data. This is known as pattern scaling because the existing spatial pattern tends to be largely replicated for the future scenario. While over-simplified, it does provide a useful preliminary product which can subsequently be improved as the baseline climatology is improved, and as the statistical relationships between larger scale meteorological controls and that baseline climatology is rendered more sophisticated. This approach was first described by Santer *et al* (1990) and was the basis for the projections for 2030 in the First Assessment Report of the IPCC (Mitchell *et al*, 1990).

Pattern Scaling was employed for a preliminary production of climate scenarios for Ireland for 2050 using a gridded baseline climatology for Ireland derived as part of the Climate Impacts LINK project of the University of East Anglia (Hulme and Jenkins, 1998). Since then the authors have developed a more detailed baseline climatology (Sweeney and Fealy, 2001) and this paper uses this together with a more sophisticated downscaling technique known as statistical downscaling.

Statistical downscaling involves establishing relationships between mesoscale data, such as upper air observations, and local surface observations. Such relationships would be expected to remain robust in a changing climate situation (Wilby and Wigley, 1997). The relationship is initially established using present day observational data and then used to predict future surface variables based on GCM output for the variables concerned. Downscaling is done to individual point locations for present and future runs of the model. The differences resulting are then applied to the observational data to provide a change scenario.

Derivation of the baseline climatology

A Digital Elevation Model (DEM) at a resolution of $1km^2$, derived from the GTOPO 30 Arc Second global elevation dataset of the U.S. Geological Service, was incorporated into a Geographical Information System. The DEM, comprising a grid of 83,880 cells, was then projected to the Irish National Grid. This formed the baseline on which the trend surfaces were derived and on which the climate data was mapped. The accuracy of this height dataset was such that the mean modelled height of 90% of grid squares would be +/- 30m from the actual values. This is adequate for most climatological modelling purposes, particularly in areas such as the Central Plain, and in plateau upland areas such as the Wicklow Mountains and Antrim Plateau. It does, however, provide an underestimate of height where a free-standing mountain exists, or where narrow ridge-like upland areas exists, such as in the mountains of Cork/Kerry or the Ox Mountains of Sligo. Against this, the resolution of $1km^2$ does enable relatively fine discrimination of relief features over wide areas.

Monthly climate data for both the Republic of Ireland and Northern Ireland for the period 1961-91 were obtained from Met Éireann and from the British Atmospheric Data Centre of the UK Meteorological Office. In total this consisted of approximately 570 stations for precipitation and 70 stations for max/min temperature. In each case a criterion of at least 70% data capture was applied, otherwise the data was discarded. The altitudinal range of the precipitation stations extended from sea level to 808m O.D., while the temperature stations reached up to 710m O.D.

A less than adequate network of surface observations exists for estimating incoming solar radiation across the grid with only 15 stations available. However, a well-established empirical relationship exists between sunshine hours and radiation (Brock, 1981) based on original work by Angstrom (1924).

$$Q/Q_a = a + b(n/N)$$

where Q = solar radiation received on the Earth's surface (MJ m^{-2}),

Q_a = potential solar radiation at the top of the atmosphere (MJ m^{-2})

n = sunshine hours

and N = total day length (hours).

Values for the constants a and b were established for Ireland by McEntee (1980) as 0.21 and 0.67 respectively.

Some 42 stations measuring sunshine hours were utilised and the radiation values derived from them validated with direct measurements made at the 15 Met Éireann stations. Similar problems arose in the calculation of Potential Evapotranspiration (PE) due to the sparse wind monitoring network. In this case regressions on mean temperature and radiation were used to predict PE and the values validated using actual Penman PE measurements at the 15 synoptic stations.

A polynomial regression was used to construct the baseline climatology for each 1km^2 grid cell. As had already been found by Goodale *et al* (1998) a quadratic trend surface proved to be the best at predicting the monthly values concerned. Intuitively, a quadratic trend surface represents many of the key spatial trends in Irish climatology with a coastal-interior contrast superimposed on a south west-north east gradient (Figure 1). Each of the climate variables modelled was predicted according to the following equation:

$$\text{Climatic Variable} = a + bx + cy + dx^2 + ey^2 + fxy + gz$$

where a is a constant,

b - g are co-efficients derived from the regression,

x is the row number of the grid cell, y is the column number, and

z is the elevation.

For maximum temperature it can be seen from Table 1 that the polynomial regressions accounted for between

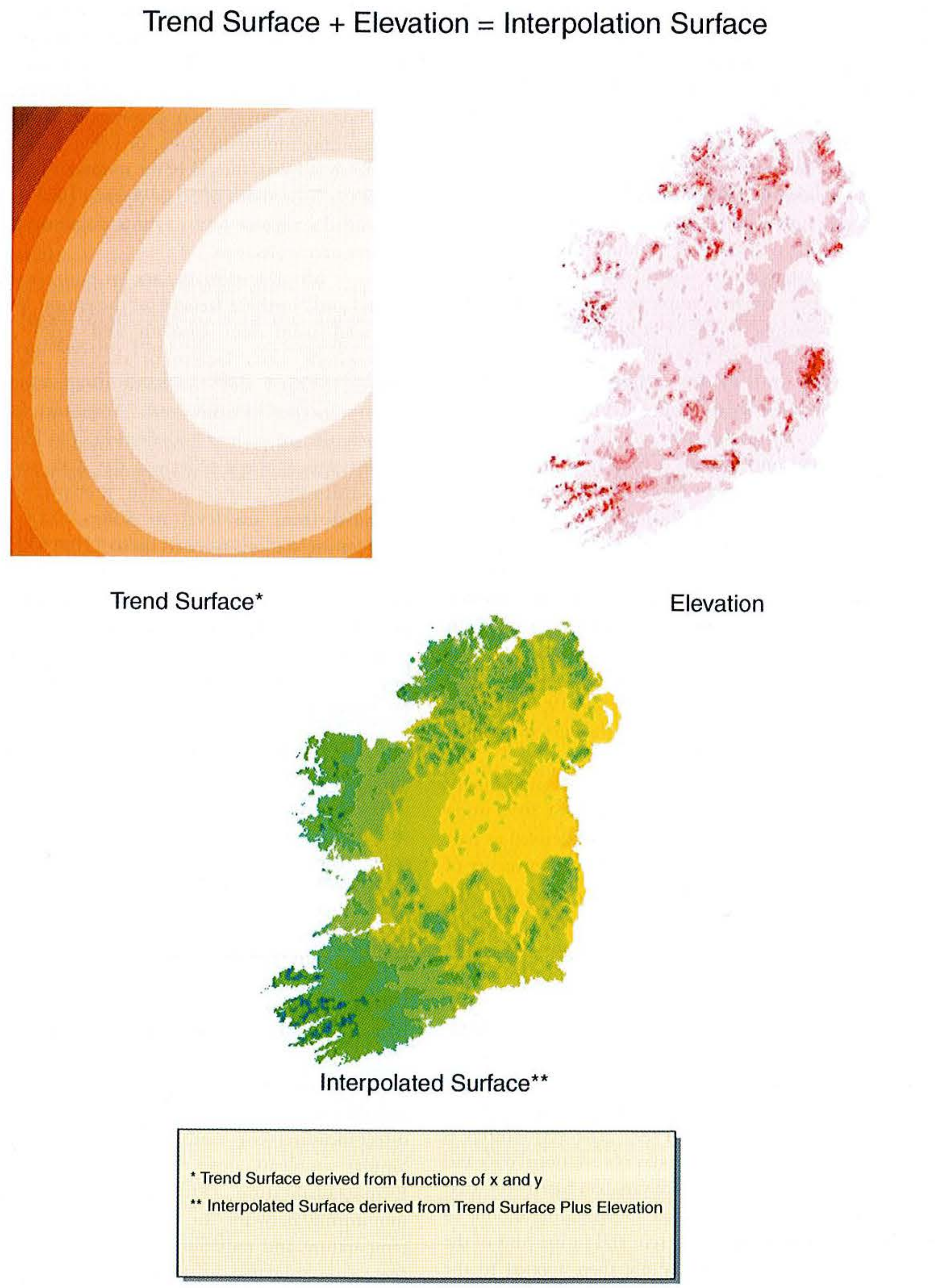

Fig. 1. Trend Surface and Elevation – a schematic view of baseline climate procedure

Table 1. Polynomial Regression Statistics for Maximum Temperature 1961-90

Month	Constant	Height	x_km	x^2	y_km	y^2	xy	Adj.R^2	Std Err
Jan	10.755	-0.008264	-0.012420	0.0000256	-0.007142	0.0000056	0	91.2	0.254
Feb	9.951	-0.008922	-0.006325	0.0000084	-0.003455	0	0	94.7	0.193
Mar	10.242	-0.007919	0	-0.0000033	0.003958	-0.0000147	0	90.0	0.253
Apr	11.468	-0.006294	0.007239	-0.0000334	0.008226	-0.0000310	0.0000208	79.8	0.338
May	13.965	-0.005732	0	0	0.011260	-0.0000272	0	70.0	0.407
Jun	14.924	-0.005850	0.020010	-0.0000606	0.011950	-0.0000448	0.0000325	77.5	0.400
Jul	16.674	-0.006283	0.021110	-0.0000631	0.009679	-0.0000472	0.0000400	85.0	0.378
Aug	17.018	-0.006306	0.016830	-0.0000493	0.007753	-0.0000361	0.0000278	83.0	0.341
Sep	16.240	-0.007522	0.006493	-0.0000210	0.004334	-0.0000250	0.0000195	86.2	0.281
Oct	14.308	-0.007815	0	0	0	-0.0000074	0.0000036	92.2	0.179
Nov	11.718	-0.008750	0	0	-0.007777	0.0000078	0	91.1	0.225
Dec	11.505	-0.008067	-0.012420	0.0000255	-0.007548	0.0000074	0	91.0	0.241

70-95% of the spatial variation. Levels of explanation in excess of 90% generally applied during the winter half of the year. Standard errors were also smallest at this time of year at 0.22°C. For minimum temperatures (Table 2) the regression accounted for somewhat lower levels of explanation, approximately 53%, with again slightly higher levels in winter. The stepwise regression discarded the x (longitudinal) components in this regression. Intuitively these appear reasonable. Winter temperatures in Ireland do show a coast-interior contrast as the dominant spatial feature, while summer temperatures have more overt latitudinal controls apparent. Both these levels of prediction were similar to that found by Goodale *et al.* (1998) in a similar exercise using a different digital elevation model and the 1951-80 climate dataset.

Precipitation estimates based on the polynomial regression (Table 3) accounted for 76% of the spatial variance, with levels in excess of 80% during the winter months. An average standard error of approximately 1.5cms applied to monthly predictions.

Potential Evapotranspiration (PE) was found to strongly correlate with Penman PE measurements made at the sysnoptic stations. Summer values were very highly correlated (>90%). Winter values were less successful.

Table 2. Polynomial Regression Statistics for Minimum Temperature 1961-90

Month	Constant	Height	y_km	y^2	Adj.R^2	Std Err
Jan	4.931	-0.008927	-0.019330	0.00003068	62.7	0.575
Feb	4.864	-0.008977	-0.018650	0.00002820	68.7	0.533
Mar	5.348	-0.009179	-0.015350	0.00002315	68.6	0.496
Apr	6.669	-0.008211	-0.017170	0.00002669	63.4	0.530
May	8.739	-0.008943	-0.015200	0.00002383	61.8	0.540
Jun	11.127	-0.008560	-0.011180	0.00001638	66.0	0.463
Jul	12.770	-0.008057	-0.009252	0.00001268	67.0	0.430
Aug	12.906	-0.008466	-0.012680	0.00001948	57.1	0.540
Sep	11.901	-0.008852	-0.018350	0.00003044	61.7	0.536
Oct	9.691	-0.007552	-0.017910	0.00003025	57.3	0.517
Nov	7.524	-0.008131	-0.026990	0.00004497	65.6	0.584
Dec	5.934	-0.007562	-0.021540	0.00003507	60.9	0.575

Table 3. Polynomial Regression Statistics for Precipitation 1961-90

Month	Constant	Height	x_km	x^2	y_km	y^2	xy	Adj.R^2	Std Err
Jan	263.783	0.230	-0.846	0.001958	-0.55900	0.001626	-0.0010850	77.5	22.34
Feb	191.780	0.203	-0.503	0.001071	-0.57500	0.001347	-0.0004375	77.3	18.28
Mar	179.254	0.161	-0.622	0.001439	-0.30400	0.001077	-0.0008210	73.9	16.77
Apr	100.578	0.152	-0.245	0.000579	-0.19100	0.000552	-0.0002846	76.5	11.16
May	104.450	0.123	-0.276	0.000400	0	0.000000	0	72.2	10.52
Jun	95.261	0.106	-0.253	0.000328	-0.04609	0.000203	0	73.9	8.87
Jul	100.260	0.118	-0.258	0.000400	-0.12500	0.000445	-0.0001601	77.1	9.43
Aug	135.759	0.120	-0.372	0.000730	-0.08653	0.000487	-0.0004712	66.8	13.64
Sep	172.368	0.160	-0.639	0.001514	-0.17100	0.000924	-0.0009127	77.7	14.43
Oct	227.323	0.185	-0.823	0.001984	-0.31300	0.001386	-0.0013510	79.1	17.90
Nov	225.046	0.205	-0.906	0.002164	-0.28800	0.001347	-0.001288	82.4	16.78
Dec	248.994	0.231	-0.898	0.002172	-0.38100	0.001374	-0.001325	80.1	20.34

Undoubtedly this relates to the importance of wind as a winter control on PE, and its absence from consideration in this study. However, it should be emphasised that PE values are extremely low in winter, typically <20mm in December at inland locations, and, as such, the modelled PE values are not as important as water balance components at this time of year as in summer.

Figures 2 and 3 show samples of the baseline climatology output. Good agreement was found between the maps and those published by Met Éireann for the same 30-year period. Due to the imperfect data network, neither provides a perfect picture of actual climate conditions, particularly at high altitude locations.

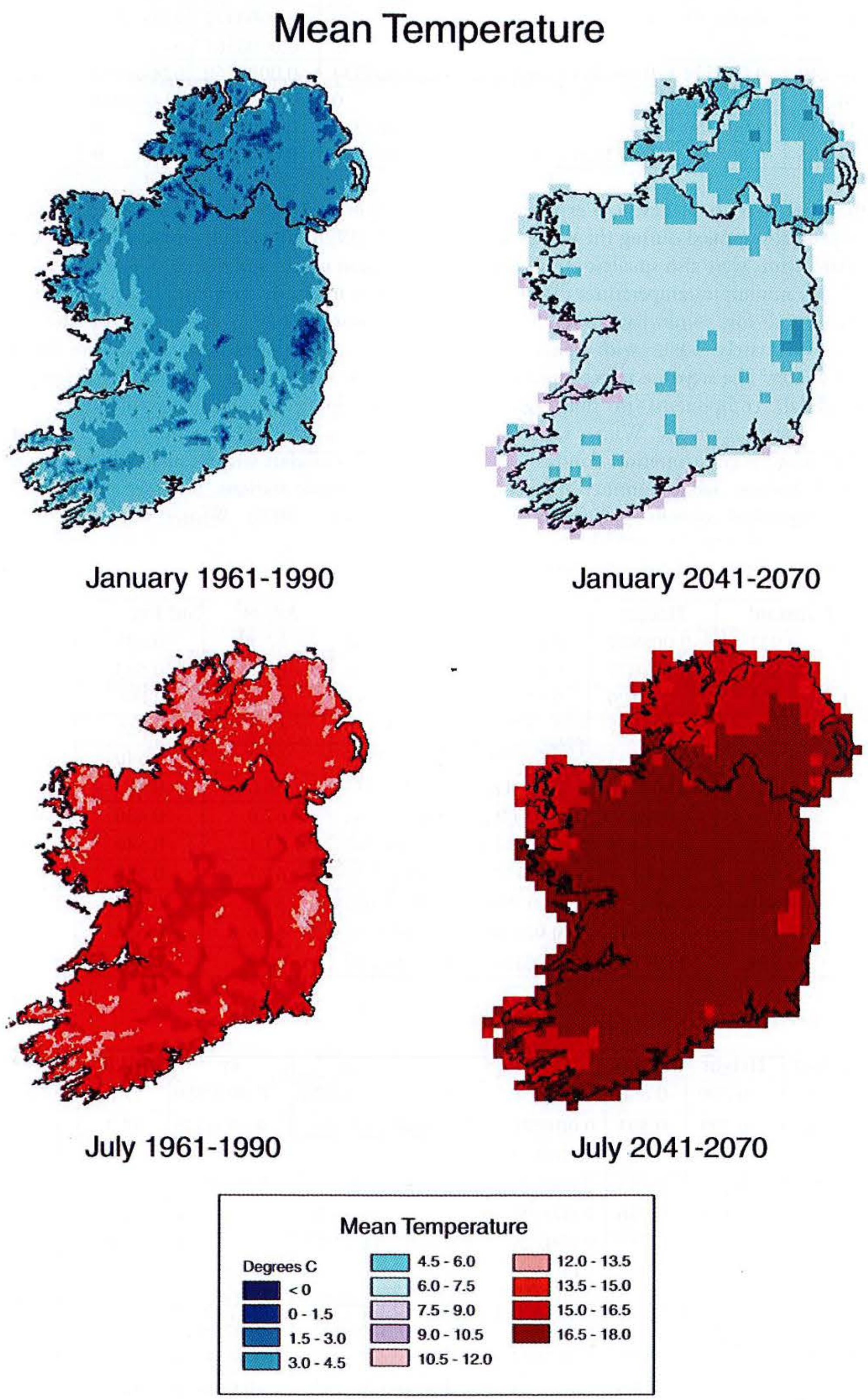

Fig. 2. Mean Temperatures 1961-90 (Baseline) and 2041-70 (Downscaled)

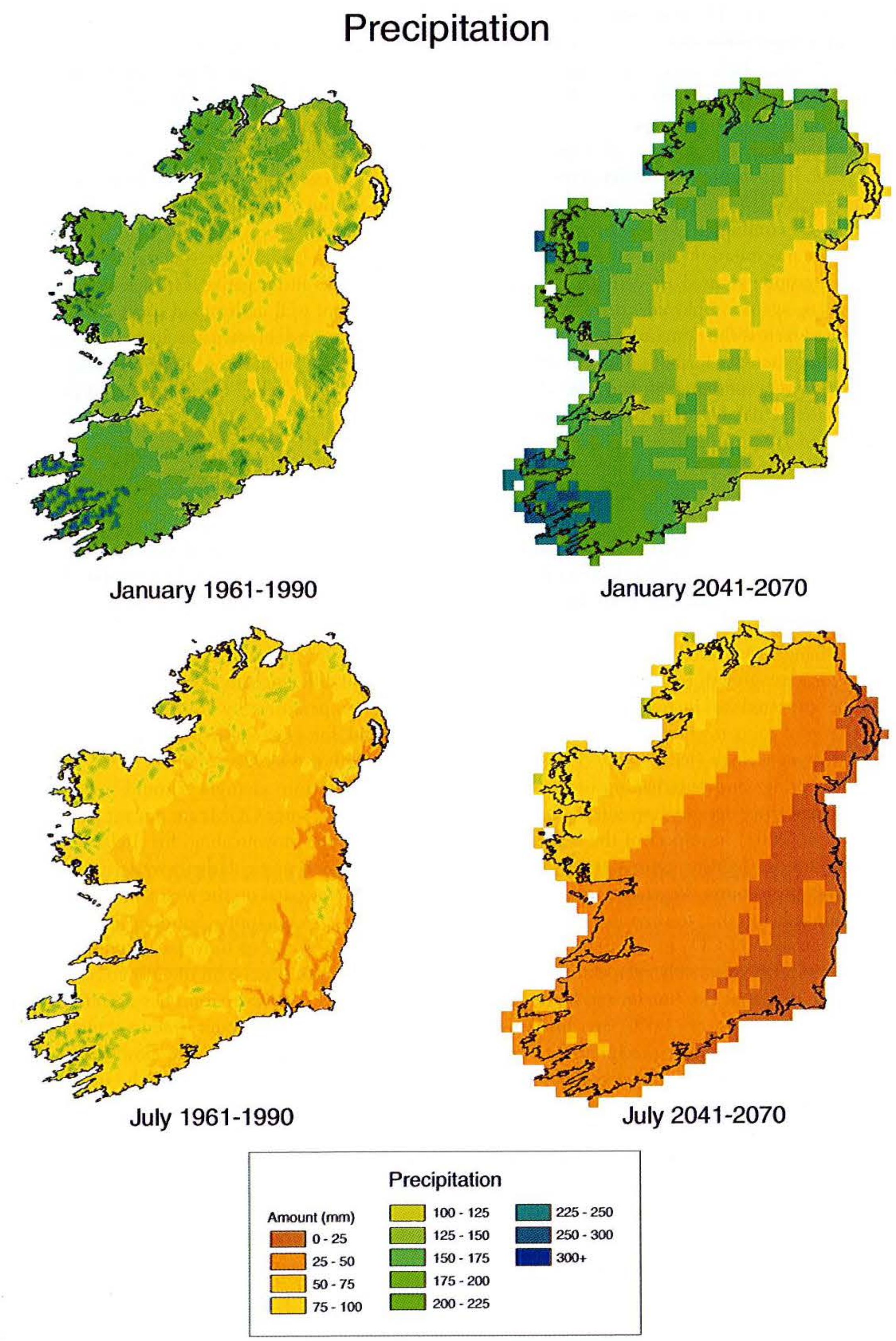

Fig. 3. Precipitation 1961-90 (Baseline) and 2041-70 (Downscaled)

Downscaled scenarios

An empirical statistical downscaling approach was employed to relate the HadCM3 general circulation model to the high resolution Irish baseline climatology. This technique is based on the assumption that GCMs simulate mesoscale aspects of climate better than surface variables such as temperature and precipitation (Palutikof *et al.*, 1997). In this case, the technique involved the use of upper air and large-scale surface variables extracted from the NCEP/NCAR Reanalysis database. A spatial domain comprising 16 cells in and around Ireland was selected and data from these cells were averaged. The variables included: the height of the 500hPa surface, the 500-850hPa thickness, mean sea level pressure and specific humidity at 2m. These averaged NCEP/NCAR predictors had a high correlation (r>0.9) with observed data from Valentia. This mesoscale data was then regressed on local surface variables to establish transfer functions unique to each downscaled point.

The same reanalysis variables were also outputs of the HadCM3 GCM. This enabled the GCM output at a large scale to be related to individual points. Statistical downscaling was conducted for a large number of stations: 250 for precipitation, and 60 for temperature. Polynomial regression, as used in deriving the baseline climatology, was again employed to redistribute the downscaled values across the domain at a resolution of 10 km^2. Downscaling exercises for both the 1961-90 and the 2041-70 period were undertaken and the differences added to the baseline dataset for 1961-90. A scenario for the period around 2055 could now be constructed.

Figure 2 shows mean January temperatures in the range 6-7.5°C by mid century over much of the southern half of Ireland, and 7.5-9°C along southern coasts. Winters in Northern Ireland and in the north midlands at that time will be similar to those of Cork/Kerry during the 1961-90 period. Most importantly from an agricultural perspective, however, will be the growing season implications of these changes. A reduction in frost frequency and the capability of grass growth to continue almost all year round can be expected to increase standing biomass, increase the ratio of roots to shoots and have impacts on animal reproductive biology (Jeffrey *et al*, 1991). Indeed signs of earlier springs and lengthening of the growing season over the past three decades have already been noted by Donnelly *et al* (2001) in respect of the leaf unfolding and bird migrations, lending some credence to the suggested future projections. Vegetative growth will be further encouraged by the fertilisation effect of the increased concentration of CO_2 in the atmosphere.

Figure 2 also shows mean July temperatures of 16.5-18°C as far north as coastal Co. Antrim and Derry by mid century. General increases of 2-3°C are in evidence. Combined with reduced summer precipitation amounts, the principal impact of this is likely to manifest itself in increased evapotranspiration losses and increased occurrence of drought stress.

Figure 3 suggests precipitation increases will occur in winter in western and south western locations in Ireland in a greenhouse-warmed Irish climate. The strongest signal is seen at higher elevations in western Ireland. A somewhat unexpected feature of the winter map is the relatively drier areas of the south-east and north. Rainshadow effects appear to have increased – this may reflect greater westerliness in the rainfall regime. It may also be an artifact of the trend surface methodology employed and clearly more work is needed to examine this aspect further. A more convincing signal is apparent for summer, with marked reductions, along a north-west-south east gradient. The magnitude of these reductions will also require further examination.

If realised, these changes would pose significantly increased threats of winter flooding in parts of the west. By contrast, implications for soil moisture deficits and reduced stream flow in summer in eastern Ireland could be inferred. This would be very significant both for agriculture and domestic/industrial water consumption in urbanised catchments, as well as reducing dilution water for river pollutants from these same areas. However, it must be stressed that much less reliance can be placed on model output in respect of precipitation as opposed to temperature. This is because clouds both absorb and reflect both solar and terrestrial radiation, and thus exhibit both positive and negative feedback effects. The net result of this is not well understood. Accordingly, models show a greater spread of variance in predicting precipitation changes than with most other parameters and output cannot as yet be relied upon in scenario production.

Conclusions

It should be stressed that these results are preliminary and as yet unverified. Further work will be undertaken to confirm their validity and final results will include complete downscaling for all months (Sweeney, 2001).
Irish climate can be expected to exhibit changes over the next five decades broadly similar to those predicted for the global average. Mean temperatures appear to be set to warm by 0.3°C/decade, with no marked departure from the spatial differences in climate currently observed. Mean winter temperatures by mid century will be above the threshold for grass growth at all times of the year for almost all but the highest upland areas.

Precipitation changes should be considered less authoritative, since GCMs are not yet reliable in this area. However, the downscaling for Ireland firstly suggests wetter winters, particularly in western and south western areas. In some parts on the west a increase of 15% is likely in winter precipitation. Summer precipitation on the other hand shows a universal decrease. Most marked reductions appear to be on the east coast. Combined with increases in PE, this situation has significant implications for agriculture and water resource management. It is important therefore that the downscaled scenarios be utilised to drive further models in sectors such as agriculture, water resource management and biodiversity to further investigate the magnitude and spatial ramifications of these likely impacts of Ireland's future changed climate.

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References

Angstrom, A. (1924). Solar and terrestrial radiation. *Quarterly Journal of the Royal Meteorological Society* 50, 121.

Brock, T. D. (1981). Calculating solar radiation for ecological studies. *Ecological Modelling* 14, 1-19.

Cusbach, U., Waszkewitz, G., Hegerl, H. and Perlwitz, J. (1995). Regional climate changes as simulated in time-slice experiments. *Climate Change* 31, 273-304.

Department of the Environment and Local Government (2000). *National Climate Change Strategy Ireland.* Dublin, Government Publications.

Donnelly, A., Jones, M., McElwaine, L., Sweeney, J., and Byrne, C. (2001). The use of biological indicators to detect climate change in Ireland. Poster presented at the 'Detecting Environmental change: Science and Society,' University College, London, 16th-20th July 2001.

Giorgi, F. and Francisco, R. (2000). Uncertainties in regional climate change prediction: a regional analysis of ensemble simulations with HadCM2 coupled AOGCM. *Climate Dynamics* 16, 169-82.

Goodale, C., Aber, J., and Ollinger, S. (1998). Mapping monthly precipitation, temperature and solar radiation for Ireland with polynomial regression and a digital elevation model. *Climate Research* 10, 35-48.

Hewitson, B.C. and Crane, R.G. (1996). Climate downscaling: techniques and application. *Climate Research* 7, 85-95.

Hulme, M., Crossley, J., and Lu, X. (2001). *An exploration of regional climate change scenarios for Scotland.* Edinburgh. Scottish Executive Central Research Unit.

Hulme, M. and Jenkins, G.J. (1998). *Climate Change Scenarios for the United Kingdom.* UKCIP Technical Report No.1. Norwich, Climatic Research Unit.

Jeffrey, D.W., Grainger, J.N.R., Dowding, P., Jones, M.B. and Khan, J. (1991). The Irish green mantle and its native fauna. In B.E. McWilliams (Ed.), *Climate Change: Studies on the Implications for Ireland,* 63-87. Dublin, Department of the Environment, Government Publications.

Lamb, H.H. (1987). On the development of regional climatic scenarios for policy oriented climatic impact assessment. *Bulletin of the American Meteorological Society* 68, 1116-1123.

McEntee, M. (1980). A revision of the equation relating sunshine hours to radiation income for Ireland. *Irish Journal of Agricultural Research* 19, 119-25.

Mitchell, J., Manabe, S., Tokioka, T. and Meleshko, V. (1990). Equilibrium climate change. In J. Houghton, G. Jenkins and Ephraums (Eds.), *Journal of Climate Change: the IPCC Scientific Assessment,* 131-172. Cambridge University Press.

Palutikof, J.P., Winkler, J.A., Goodess, C.M. and Andresen, J.A. (1997). The simulation of daily temperature time series from GCM output. Part 1: comparison of model data with observations. *Journal of Climate* 12, 1480-9.

Santer, B., Wigley, T., Schlesinger, M. and Mitchell, J. (1990). *Developing climate scenarios from equilibrium GCM results.* Hamburg. Report No. 47, Max Planck Institute für Meteorologie.

Stapleton, L. (2000). *Ireland's Environment: a Millennium Report.* Wexford, Environmental Protection Agency.

Sweeney, J. and Fealy, R. (2001). A Preliminary Investigation of Future Climate Scenarios for Ireland. *Proceedings of the Biodiversity Conference, 2000.* Dublin, Irish Environmental Sciences Association.

Sweeney, J. (Ed.) (2001). *Climate Change and Ireland: Scenarios and Impacts.* EPA Report on 2000-LS-5-MI-5.2.1 - Assessments of the Impacts of Climate Change in Ireland.

Wilby, R. and Wigley, T.M.L. (1997). Downscaling general circulation model output: a review of methods and limitations. *Progress in Physical Geography* 21, 530-48.

Estimates of soil and land cover carbon stocks in Ireland – a review of progress

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Abstract

Attempts being made to estimate soil and land cover carbon stocks in Ireland are placed in the context of international agreements and national policies. The IPCC approach to such inventories is introduced and the methods employed for Ireland are outlined. Problems in the acquisition of required data are discussed and weaknesses and gaps highlighted, particularly in relation to a lack of soil mapping and soil property data, and data on the extent, depth and bulk density of peat. Forests and peatland vegetation are shown to be significant in the land cover carbon stock and peat to be of major importance in the soil stock. The need for an iterative approach to estimates is stressed because the availability and quality of data and methods of calculation will improve as the research progresses.

1. Introduction

1.1 The international framework

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by governments, working through the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), to assess evidence and information on climate change, its possible impacts and alternative ways of adapting to and mitigating climate change. Initially, IPCC was asked to prepare a report for the United Nations Framework Convention on Climate Change (UNFCCC) to be held in 1990. Subsequently, it has prepared assessment reports and methodological and other analyses for the UNFCCC.