



# Downscaling: An Introduction

- Horizontal resolution of most coupled GCMs is about 300-500km
- Regional climate is affected by forcings and circulations that occur at a finer scale, i.e., sub-grid scale
- A number of techniques have been developed to enhance the information from GCMs in order to bridge the gap between what is supplied by climate models and what is required by impacts researchers - 'downscaling' or 'regionalisation' methods

Prepared by Elaine Barrow, CCIS Project

Downscaling, or regionalisation, is the term given to the process of deriving finer resolution data (e.g., for a particular site) from coarser resolution GCM data. Most impacts researchers feel that the horizontal resolution of most GCMs is generally too coarse to be used in impacts models in its original format. A lot of useful information can be derived from GCMs without the need for downscaling to be undertaken, but it is recognised that sometimes it is necessary to try and add value to a scenario by making it more applicable for finer resolution studies.

Most concerns are related to the fact that regional climate is affected by forcings and circulations which occur at sub-grid scale and hence are not explicitly taken into account at the scales at which GCMs operate. It may be possible to define a relationship, or relationships, between site climate and large-scale (i.e., GCM grid box scale) climate which can then be used to derive more realistic values of the future climate at the site scale.

## Using original grid box information

Simplest method of applying GCM changes is to use values for the nearest grid box to the study area.

### *Problems:*

- lack of confidence in regional estimates of climate change has led to suggestions that the minimum effective spatial resolution should be defined by at least 4, and probably more, GCM grid boxes
- sites in close proximity but falling in different grid boxes, while having a very similar baseline climate, may be assigned a quite different scenario climate
- a site on land may be located in a GCM grid box defined as ocean

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Although most global climate modellers would not be very confident in using single grid box estimates (the smallest horizontal spatial scale that a model can resolve is generally of the order of 2 grid boxes) in scenario studies, this is in fact what has been done in the majority of impacts studies to date. The scenario values for the grid box within which a site lies have simply been applied to the observed data for that site. Some studies have considered the use of more than one grid box, but these are few and far between.

Using the scenarios constructed at the original GCM resolution may lead to problems if there is a large discontinuity between adjacent grid boxes - this is particularly apparent at the land-ocean boundary, and sometimes for neighbouring land grid boxes. The ocean response to a change in forcing is damped compared to that of the land, due to its large thermal inertia, so the changes seen over the ocean are generally smaller (in the case of temperature) than those over the land. The coarse resolution of the grid boxes may result in a box being designated as ocean, when it does in fact contain some land area in reality.

## Interpolating grid box outputs

Simplest downscaling method is to interpolate change fields to the site or region of interest from nearby grid boxes.

- Overcomes problems of discontinuities in change between adjacent sites in different grid boxes

*But*

- introduces a false geographical precision to the estimates

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One of the simplest ways of obtaining finer resolution data is to interpolate the coarse resolution fields to a finer resolution. This doesn't add any value to the scenarios - the change fields are simply being smoothed so that the discontinuities between adjacent grid boxes are not as large. It does, however, introduce a false geographical precision to the scenario estimates.

## Downscaling: Use of GCMs

General approach is to use coupled GCM output as the starting point of any regionalisation technique.

Therefore:

- very important that the GCMs perform well in simulating circulation and climatic features affecting regional climates, e.g., jet streams, storm tracks
  - better to use variables where sub-grid scale variations are weak, e.g., mean sea level pressure
- Main advantage of using GCMs is that:

- internal physical consistency is maintained

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Downscaling, or regionalisation, techniques rely on GCMs to provide coarse- climate information. Hence, it is important that GCMs simulate well those atmospheric features which determine regional climate, e.g., jet streams and storm tracks.

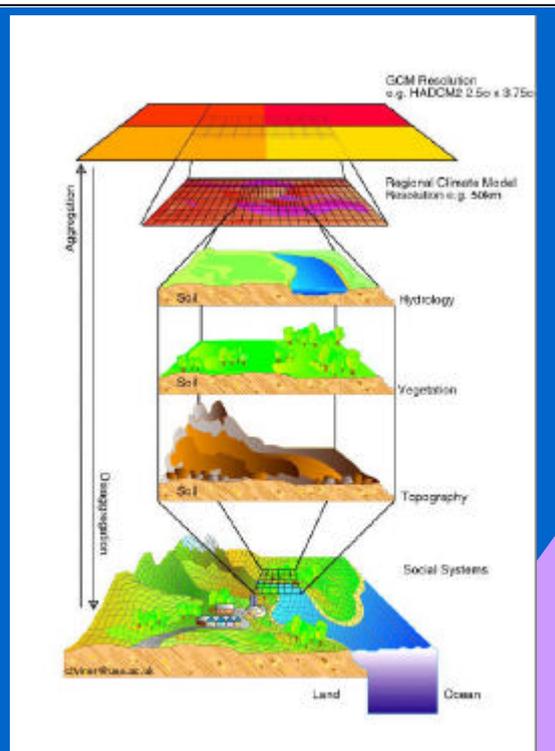
Comparing GCM output with observed climate information won't necessarily give good results, but this doesn't automatically mean that the model is not performing adequately. In order to make a more robust assessment of model performance, ideally one would have a large sample of GCM experiments available (with identical forcing conditions) and it would be the average of all these experiments (the ensemble-mean) which should be compared with the observed climate data, in order to obtain a more robust result. A single experiment is only one solution of the climate system response to a particular set of forcing conditions - there is an almost infinite number of possible solutions, so we shouldn't expect that the results of a single experiment will closely match the observed climate, although major features of the atmospheric circulation should be represented. Averaging the available solutions concentrates the signal within the data and reduces the noise due to natural variability, so the ensemble-mean should match the observed climate more closely than any of the individual experiments. These comparisons should be undertaken at a reasonably large scale - the smaller the number of grid boxes being compared, the less likely it is that the model will be able to simulate observed climate features well.

For the purposes of downscaling, it is better to use GCM variables which do not exhibit large sub-grid scale variations, for example, mean sea level pressure. It is better to use primary GCM variables, i.e., those variables which are direct model output and which are used by the model to determine other climate variables (for example, mslp, mean surface air temperature and precipitation). Precipitation is less likely to be simulated well, since it is a parameterised variable.

# Downscaling

Application of scenarios using the simple approaches may not be suitable for regional impacts assessments. May be better to use:

- empirical/statistical or statistical/dynamical downscaling processes, or:
- information from higher resolution experiments



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Figure courtesy of David Viner, of the UK Climate Impacts LINK Project. Figure illustrates the complexity of the downscaling process.

For some studies, the simple methods of constructing finer resolution scenarios may not be sufficient and it may be better to use empirical/statistical or statistical/dynamical downscaling techniques to obtain data at the necessary resolution. An alternative is to use information from higher resolution experiments.

## Empirical/Statistical, Statistical/Dynamical Methods

Sub-grid scale changes in climate are calculated as a function of larger-scale climate.

Statistical relationships - **transfer functions** - can be calculated between:

- **large-area and site specific surface climates**
- **large-scale upper air data and local surface climate**

In **weather typing** relationships are calculated between:

- **atmospheric circulation types and local weather**

The parameters of a **weather generator** - a random number generator of realistic-looking sequences of local climate variables - can be conditioned upon the large-scale state

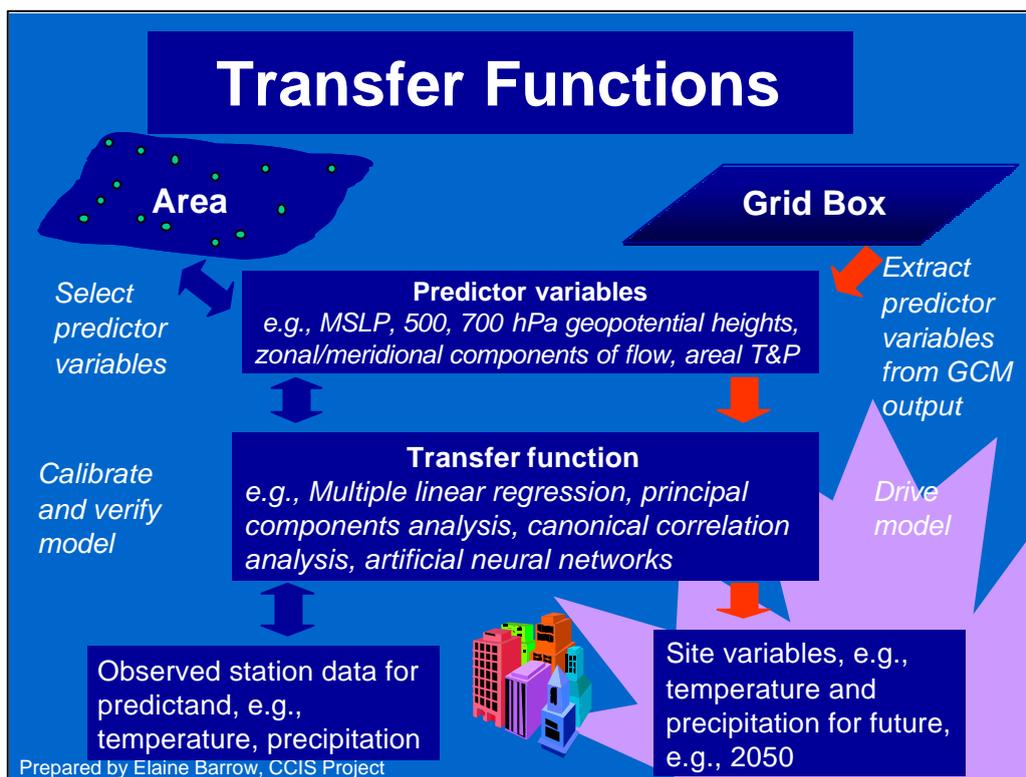
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There are three main types of empirical/statistical, statistical/dynamical downscaling:

transfer functions

weather typing

weather generation



### Transfer functions:

Large-scale values of particular climate variables (predictors) will be used to predict the values of the site specific variables (predictands). The large-scale area should roughly correspond to the size of the GCM grid box. It may be necessary to construct area-average values of, say, mean temperature or precipitation (usually simple averaging of station data, or weighted averaging). Follow blue arrows on lefthand side of figure. First step is to define the predictor variables - they must explain a high proportion of the variance in the predictand. Second: construct the transfer function relating the site specific variable to the larger-scale predictors using an appropriate technique - be aware of the constraints associated with the method being used. For example, in multiple linear regression it is assumed that the predictor variables are independent, i.e., the correlation between them is effectively zero. If this is not the case then the regression coefficients will not be a true estimate of the contribution of each of the predictor variables to the variance of the predictand. Keep back some data in order to test the performance of the model (validation).

To derive the predictand values under a future climate, the larger-scale predictors derived from GCM data are used to drive the transfer functions (follow red arrows on righthand side).

# Transfer Functions

## Fundamental Assumption

the observed statistical relationships will continue to be valid under future radiative forcing

### ADVANTAGES

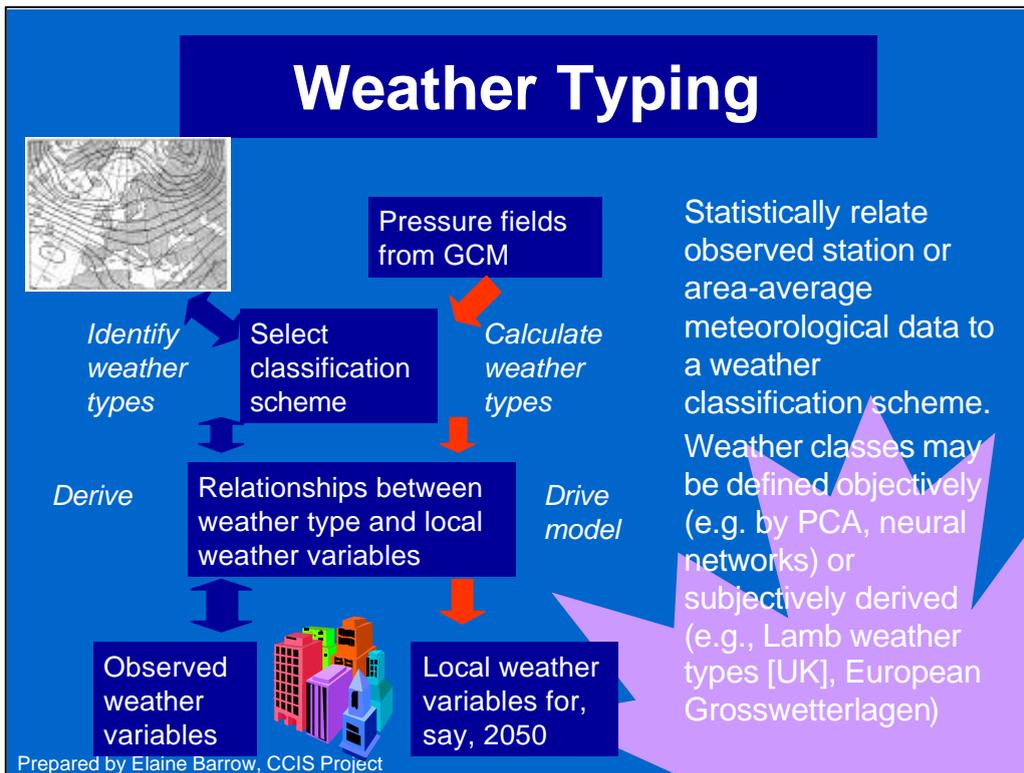
- much less computationally demanding than physical downscaling using numerical models
- ensembles of high resolution climate scenarios may be produced relatively easily

### DISADVANTAGES

- large amounts of observational data may be required to establish statistical relationships for the current climate
- specialist knowledge required to apply the techniques correctly
- relationships only valid within the range of the data used for calibration - projections for some variables may lie outside this range
- may not be possible to derive significant relationships for some variables
- a predictor which may not appear as the most significant when developing the transfer functions under present climate may be critical for determining climate change

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This method assumes that the statistical relationships derived using observed data will continue to be valid in the future.



Weather typing (or circulation patterns) can be used in a similar manner to the transfer function methodology - observed station meteorological data is statistically related to a weather classification scheme. In this case the starting point is the identification of the weather types - this may be by using an objective methodology, e.g., principal components analysis, or they may be subjectively derived. Once the classification scheme has been selected and the weather types derived, relationships between the type and local weather variables are calculated (blue arrows on lefthand side).

For climate change studies, pressure fields from a GCM are used to drive the model. The weather types are calculated based on these pressure fields and the relationships derived using observed data are then implemented to derive site information for, say, temperature and precipitation for some point in the future (red arrows).

# Weather Typing

## Fundamental Assumption

the relationships between weather type and local climate variables will continue to be valid under future radiative forcing

### ADVANTAGES

- founded on sensible physical linkages between climate on the large scale and weather on the local scale

### DISADVANTAGES

- the fundamental assumption may not hold - differences in relationships between weather type and local climate have occurred at some sites during the observed record
- scenarios produced are relatively insensitive to future climate forcing - using GCM pressure fields alone to derive types, and thence local climate, does not account for the GCM projected changes in, e.g., temperature and precipitation, so necessary to include additional variables such as large-scale temperature and atmospheric humidity

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Again, it is assumed that relationships derived from using observed data will hold in the future.

Although this method is founded on sensible physical linkages between large-scale climate and local weather, there are some concerns. It has been demonstrated that the fundamental assumption may not hold - i.e., that the relationships between weather type and site weather may not be stationary over time.

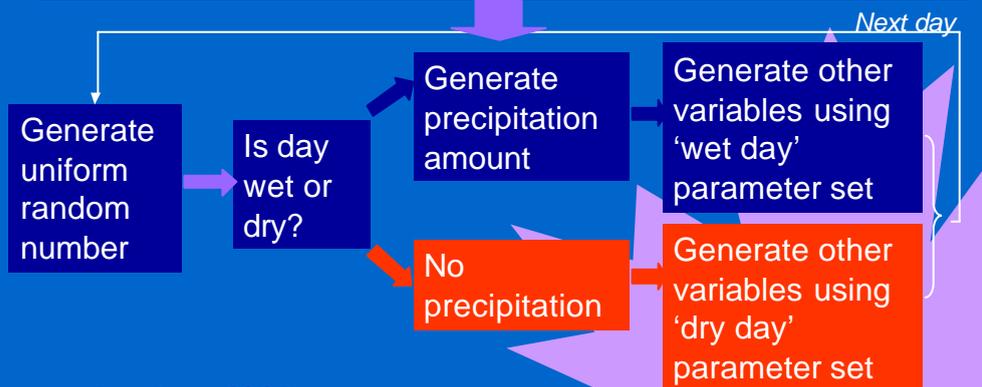
Also, in order to obtain the GCM-derived changes in, say, temperature and precipitation, it is necessary to include additional variables, such as atmospheric humidity. Using pressure patterns alone to drive the statistical relationships will not result in a downscaled scenario that reflects the temperature and precipitation changes occurring at the large-scale.

# Weather Generators

Statistical models of observed weather variables, generally at the daily time scale.

*Model calibration and verification*

Calibrate model → Parameter file → Model testing



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A stochastic weather generator is a statistical model of observed weather variables, with those variables generally conditioned on the occurrence of precipitation. It is possible to use stochastic weather generators to downscale large-scale climate (Wilks, 1999), by running a weather generator at both the site and area scales.

Wilks, D.S. (1999): Multisite downscaling of daily precipitation with a stochastic weather generator. *Climate Research* 11, 125-136.

# Weather Generators

## Fundamental Assumption

The statistical correlations between climatic variables derived from observed data are assumed to be valid under a changed climate

### ADVANTAGES

- the ability to generate time series of unlimited length
- opportunity to obtain representative weather time series in regions of data sparsity, by interpolating observed data
- ability to alter the WG's parameters in accordance with scenarios of future climate change - changes in variability as well mean changes

### DISADVANTAGES

- seldom able to describe all aspects of climate accurately, especially persistent events, rare events and decadal- or century-scale variations
- designed for use, independently, at individual locations and few account for the spatial correlation of climate

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# High Resolution Models

Numerical models at high resolution over region of interest

- GCM time-slice experiments
- variable resolution GCMs
- separate high resolution limited area model (regional climate model)

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An alternative to constructing empirical/statistical or statistical/dynamical relationships is the use of high resolution models. There are three basic types:

- GCM time-slice experiments - a particular GCM is run at a higher resolution for a short period of time, say 20 years, for the whole global field. This is not simply a case of increasing the resolution and then running the model - increased resolution means that the model parameterisations may need to be recalculated.
- Variable resolution GCMs - the resolution of the GCM is increased over the area of interest.
- Separate regional climate models - these high resolution models are nested within a GCM and driven by the GCM boundary conditions, with information being provided to the RCM from the GCM generally every six hours. This is generally a one-way process, i.e., there is no feedback from the RCM to the GCM.

# High Resolution Models

## ADVANTAGES

- are able to account for important local forcing factors, e.g., surface type & elevation

## DISADVANTAGES

- dependent on a GCM to drive models
- computationally demanding
- few experiments
- may be 'locked' into a single scenario, therefore difficult to explore scenario uncertainty

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Although RCMs are able to account for important local forcing factors, e.g., orography, their dependence on a GCM to drive them may be a disadvantage if the GCM is not able to simulate the major atmospheric features adequately. The RCM will not be able to correct for errors supplied by the GCM, if anything it will cause the higher resolution climate to become more unrealistic. There is a limited number of experiments available from RCMs because of the costs associated with running these types of experiment. In turn, this means that the number of scenarios will also be limited.