The CLIMGEN Model

Provided by Tim Osborn
Climatic Research Unit
School of Environmental Sciences
University of East Anglia
Norwich NR4 7TJ, UK
t.osborn@uea.ac.uk

- CLIMGEN currently produces 8 climate variables on a 0.5 x 0.5 degree grid: temperature (max[1], mean and min), precipitation, vapor pressure, cloud cover and wet-day frequency.
- For each month, season, or annually
- HadCM3, CSIRO2, ECHAM4, PCM2 (it may be possible to extend this list to CGCM2)
- The user can choose which variables are required. The user can choose which variables are required. The outputs are averaged over a time-slice, the length of which can also be specified by the user.
- It was built by Tim Mitchell at the Tyndall Centre and Tim Osborn at the Climate Research Unit (both at the University of East Anglia).

More details can be found at http://www.cru.uea.ac.uk/~timo/climgen/, and in Mitchell et al. (2004).

How CLIMGEN works: Pattern scaling

CLIMGEN contains a database of outputs from GCMs for the annual global mean temperature rises in 2070-2100. A few of these datasets are ensemble means from a small number of separate GCM runs. The footnote details the GCM runs used. Specifically, the GCM patterns are for two time-periods 2071-2100 and 1961-1990. In CLIMGEN, the difference between the future 30-year average climate for 2071-2100, and the 19561-1990 mean climate, both simulated by the GCM, is calculated. This pattern is then standardized by dividing the global mean warming for the particular GCM model experiment between 2071-2100 and 1961-1990, so that the resultant standardized climate change pattern P is expressed per degree C of warming. This assumes linearity with increase in temperature.

Hence the pattern P for regional temperature change, per degree C, for GCM *g*, scenario *s*, cell *i*, and month *m*, is given by:

[1] Note that the maximum monthly temperature is the average of the ~30 daily maxima for each month. It is therefore not equal to the highest daily maximum temperature recorded during the month. Similarly for the minimum monthly temperature.

$$P_{gsim} = \frac{\left[T_{gsim}(2071-2100) - T_{gsim}(1961-1990)\right]}{\left[Tglobe_{gs}(2071-2100) - Tglobe_{gs}(1961-1990)\right]} \qquad \text{[Eqn. 1]}$$

The pattern P is then re-scaled for the desired global warming increment, *t*, from the simple climate model. Using a GCM forced with a high-emissions scenario would provide climate change patterns for all the required temperatures. However, the GCM output is the transient, not the equilibrium climate change, so the outputs depend upon the dynamics of forcing. Hence in CLIMGEN at least two GCM patterns are used, one for the A2 scenario and the other for the B2, in order to provide both rapid and slow forcing dynamics (see footnote).

In CLIMGEN temperature and precipitation for pattern scaling were obtained directly from model outputs, whilst cloud cover change was derived from the GCM's change in downward short-wave flux, assuming that the change in cloud cover would have the same magnitude, but opposite sign. Vapor pressure was derived indirectly from dew point temperatures (which are output from the GCM) using the Magnus equation (detail available on request). Temperature extremes (monthly maxima and minima) are derived in the same way as the mean monthly temperature. An exception is ECHAM4 which does not statistics about daytime and night-time temperature as an output so these are generated by assuming that diurnal temperature range is a function of temperature and that the relationship is the same from one GCM to another. This relationship was thus estimated for each grid cell and month using the scenarios for the other 4 GCMs on the half degree grid, applying it to the ECHAM4 temperature scenario on the half degree grid.

At this stage the resolution of the climate change patterns is that of the GCMs, on 5x5 degree grid cells, covering the globe.

The patterns for A1FI were assumed to be the same as for A2, and for B1 the same as B2 in cases where the GCMs did not simulate B1 or A1FI. This gives a set of 20 patterns of change, P, for 5 GCMs and 7 variables: tmp, dtr, tmn, tmx, pre, vap, and cld (temperature, diurnal temperature range, maximum monthly temperature, minimum monthl temperature, precipitation, vapor pressure, and cloud cover).

How CLIMGEN works: Downscaling from 5 degree to 0.5 degree resolution

CLIMGEN combines GCM-resolution climate change data derived from the pattern scaling method at a 5 degree resolution with observations of climate at half –degree resolution to simulate future climates at half-degree resolution. The simplest downscaling method is to simply add the observe monthly mean climate, and the observed fluctuations in the monthly mean climate to the future scaled pattern of climate change $P * t$ to obtain the new climate. In CLIMGEN this method is used for temperature and precipitation producing an annual time series including natural variability.

This simple downscaling, for each variable (*v*), GCM (*g*),, emissions scenario (*s*), grid cell (*i*), year (*y*), and month (*m*) is expressed as an equation as:

$$X_{vgsiym} = \left(observed.annual.mean.1961-1990\right)_{vim} + \\ (observed.\mathrm{int}\,erannual.deviation.from.observed.annual.mean)_{viym} + \\ (P_{vgsim} * t_{gsy}) \qquad \text{[Eqn. 2]}$$

However, the simplest downscaling method described here when applied to precipitation has potential flaws, so two other methods are available to the user as alternatives when downscaling the precipitation data.

(i) In the ratio method instead of assuming that the finer scale observations (the observed interannual deviation from the observed annual mean) are additive to the climate change pattern to create it is assumed that the important factor is the change in the ratio of the precipitation in each year relative to the precipitation normal for 1961-1990.

Hence for precipitation PRE, the ratio method has the formula:

$$PRE_{gsiym} = \left(observed.annual.mean.PRE.1961-1990\right)_{im} * \\ (observed.\mathrm{int}\,erannual.PRE.deviation.from.observed.annual \\ mean.\mathrm{exp}\,ressed.as.ratio)_{iym} + \exp(P_{vgsim} * t_{gsy}) \qquad \text{[Eqn. 3]}$$

Where the pattern P_{gsim} is derived from the pattern scaling method in the normal way.

(ii) A third alternative is the gamma method, which requires the use of additional observational data and additional simulations from GCMs. The additional observational data is the shape parameter of the “gamma” distribution for rainfall each calendar month in each year. The average value of this parameter was obtained for the years 1946-1995. The additional data from GCM runs required is the fit of a gamma probability distribution for precipitation for (a) 1951-2000 and (b) 2051-2100, for each grid cell and each month.

The “shape” parameter is a parameter in the gamma distribution, a statistical distribution which has been shown (Ison, Feyerherm, and Dean Bark, J. Applied Met., pp 658-665, August 1971) to provide an adequate model to describe variation in precipitation amount over a wet period of a given number of days. Its two parameters are the scale parameter alpha and the mean parameter beta.

The changes in the mean precipitation alpha and the shape parameter beta are then interpolated to the half degree grid. The multiplicative factor A (B) for the mean and shape parameter is given by:

$$A_{gsiym} = 1 + \left(alpha_{gim} * t_{gsy}\right) \text{ if alpha} >= 0 \qquad \text{[Eqn. 4]}$$

$$A_{gsiym} = \exp\left(alpha_{gim} * t_{gsy}\right) \text{ if alpha} < 0$$

$$B_{gsiym} = 1 + \left(beta_{gim} * t_{gsy}\right) \text{ if beta} >= 0 \qquad \text{[Eqn. 5]}$$
$$A_{gsiym} = \exp\left(beta_{gim} * t_{gsy}\right) \text{ if beta} < 0$$

More details are provided in Osborn (2009), Mitchell and Osborn (2005), and Osborn et al. (2009)

How CLIMGEN simulates: Wet day frequency

GCMs typically model rainfall as a constant drizzle and therefore do not provide a daily time series of precipitation, and thus even if there were access to the raw GCMs outputs these would not provide the information required.

Hence CLIMGEN calculates wet day frequencies from the downscaled precipitation data (which may be sumulated by either of three methods detailed above) according to the formula from the literature (New et al., 2000) which reads

aW = (observed mean wet day frequency)$^{2.22}$ / (observed mean precipitation) [Eqn. 6]

For each month and grid cell on the half degree grid from CRU CL 1.0 (New et al., 1999) the above formula was applied.

The wet day frequency may then be calculated according to any of the three ways of downscaling precipitation (by downscaling, ratio method, or gamma shape parameter method). Again the wet day frequency equation is taken from New et al. (2000) in which the relationship between wet day frequency and precipitation is assumed to hold in the future. This assumption may be incorrect in the tropics or the S hemisphere, because there is no observational data in the tropics or the S hemisphere to verify it.

$$W_{gsiym} = \left(PRE_{gsiym} * aW_{gsim}\right)^{0.45} \qquad \text{[Eqn. 7]}$$

Where PRE_{gsiym} is the future precipitation.

However, recently HadCM3 and CGCM2 have produced some daily precipitation data, and the assumed formula has been tested –and it was found that the relationship holds across the globe for both the 1961-1990 time period and the 2071-2100 time period, so the relationship is invariant with time. However, what is not known is whether the way the GCMs model wet day frequency, which is consistent with observations in the N Hemisphere, is consistent with observations in the S hemisphere and the tropics, as there are no observations.

Footnote:

Original GCM archived 5 degree data sets

The 13 GCM output datasets used are taken from the IPCC DDC: at http://ipcc-ddc.cru.uea.ac.uk where a GCM data archive may be found. The GCM outputs used in this calculation are those used in the TAR and are at 5 degree resolution:

- HadCM3 A1FI, A2, B1, B2, where A2 is an ensemble of 3 runs and B2 is an ensemble of 2 runs
- ECHAM4 A2 and B2 (not ensemble runs)
- CSIRO Mark 2 A2, B1, B2
- NCAR PCM A2, B2
- CGCM2 A2, B2 (each an ensemble of 2 runs)

In the future, if funding is obtained, CLIMGEN will be updated to use the AR4 datasets.

Footnote from the International Center for Tropical Agriculture (CIAT)

From the AVOID project (funded by DEFRA, UK), CLIMGEN was updated to use AR4 datasets from the A1B emission scenario. The data provided by CIAT at http://gisweb.ciat.cgiar.org/ was obtained following the same downscaling method described here, but applied to 7 GCMs, as follows:

- CCCMA-CGCM3.1
- CSIRO-Mk3.0
- IPSL-CM4
- MPI-ECHAM5
- NCAR-CCSM3.0
- UKMO-HadCM3
- UKMO-HadGEM1

The datasets were provided as full 2006-2100 timeseries, at half-degree spatial resolution. We averaged those timeseries and calculated 7 different 30-year periods (for the 7 GCMs), so that a set of 49 future climate scenarios were generated (permutation of 7 GCMs and 7 time-slices). The periods are the same as referred in Ramirez and Jarvis (2010).

References

Mitchell, T.D., and T.J. Osborn (2005) ClimGen: A flexible tool for generating monthly climate data sets and scenarios. Tyndall Centre for Climate Change Research Working Paper (in preparation).

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. and M. New (2004) A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: The observed record (1901-2000) and 16 scenarios (2001-2100). Tyndall Centre Working Paper 55, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 30pp.

New, M., Hulme, M. and P.D. Jones (1999) Representing 20th century space-time climate variability Part 2: development of 1961-1999 mean monthly terrestrial climatology. *Journal of Climate*, 12, 829-856.

New, M., Hulme, M., and P.D. Jones (2000) Representing 20th century space-time climate variability Part 2: Development of 1901-1996 monthly grids of terrestrial surface climate. *Journal of Climate*, 13: 2217-2238.

Osborn, T.J. (2009) A user guide for ClimGen: A flexible tool for generating monthly climate data sets and scenarios. Climatic Research Unit, University of East Anglia, Norwich, 17pp. Available online at http://www.cru.uea.ac.uk/~timo/climagen/ClimGen_v1-02_userguide_2feb2009.pdf

Osborn, T.J., Wallace, C.J., Harris, I.C., and T.D. Mitchell (2009) ClimGen: A flexible tool for generating monthly climate data sets and scenarios. In preparation.