Global Climate Data (GCD) Package User Manual

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1 Introduction

This document provides information on how to use the downscaling scripts provided at Global Climate Data. The scripts forming our Global Climate Data (GCD) package are written using Matlab, and thus require that the user has access to the basic set of Matlab packages. While the GCD package has not been tested in Octave, the scripts also likely work on that platform because they only rely on standard Matlab functions.

Starting with version 4.0, the GCD package has become much more versatile. There are now methods that work with daily as well as monthly input datasets, for example. There is also greater capacity for implementing new downscaling methods within the package.

The GCD package is designed for increasing the spatial resolution of gridded historic monthly observational data and global climate model (GCM) monthly projection-run data. The GCD package utilizes the Delta method for producing both historic reanalysis and projection downscaled data. The mathematical formulations and theoretical basis for the Delta downscaling methodology implemented herein are described in Mosier et al. [2014] and Mosier [2015]. When downscaling GCM data, an additional optional step is to bias correct the GCM data prior to downscaling it, which at described in Mosier [2015].

The GCD package is constructed to handle precipitation and temperature (minimum, mean, and maximum) downscaling, although many of the subroutines are much more general. For example, the 'read_geodata' can read NetCDF and ESRI ASCII files (among a few other niche formats) and organizes the data into a structure array format common to many of the other subroutines, including the 'write_geodata' function.

The spatial resolution of the downscaled output produced by this package depends on the spatial resolution of the high-spatial resolution reference climatology used. If WorldClim [Hijmans et al., 2005] is used, which allows data to be downscaled to any global land area, the output have a spatial resolution of between 30 arcseconds and 10 arcminutes, depending on the WorldClim product chosen.

Please do not hesitate to email Thomas Mosier (mosier.thomas@gmail.com) with any questions.

2 Requirements

The following are required to use the accompanying tools and produce 30 arc-second monthly time-series data:

- The package of downscaling scripts and code from Global Climate Data, which are available as a single archived file called '*downscaling_package_v[version #].zip*'.
- A working copy of Matlab
- Gridded time-series dataset (direct links to examples given in Tables 3)
- High-spatial resolution, monthly reference climatologies (e.g. direct link for WorldClim 30-arcsecond climatologies [Hijmans et al., 2005] given in Table 4)
- *If climate model projection simulations being downscaled,* user must acquire desired GCM projection-run(s) and the historic runs corresponding to the same GCM. The GCD package is designed to work with GCMs participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5) (direct links for many CMIP5 GCMs provided in Table 8).

3 Version Notes

3.1 GCD Package V4.2 (Released 13 March 2018)

- Fixed bug that prevented comparison of downscaled outputs and GHCN station records.

3.2 GCD Package V4.1 (Released 31 October 2017)

- Fixed assorted bugs, including error in the “eQM” bias correction method. The updated method conforms with that described in Mosier et al. [2017].

3.3 GCD Package V4.0 (Released 4 September 2017)

- New package architecture, designed to make GCD more versatile and easier to implement alternative methodologies.
- Added functionality of being able to “extract” time-series from daily or monthly gridded datasets. Bias correction can be used in this process.
- PRISM climatologies can be read by the program.
- Slightly edited version of the joint bias correction methodology. In the revised version if multiple points share the same empirical copula value, a unique mapping is created at the given copula value that minimizes the normalized distance between pairs of simulation and reference points.

3.4 GCD Package V3.3 (Released 6 January 2017)

- Minor bug fixes related to errors that occurred in reading certain formats of data. This resulted in some users being unable to calculate comparative statistics between GHCN station data and downscaled output.

3.5 GCD Package V3.2 (Released 1 February 2016)

- Updated quantile mapping bias correction method. See [Mosier, 2015] for explanation of updated method.

- Inclusion of an empirical joint bias correction method, which is the extension of empirical quantile mapping into two dimensions. See [Mosier, 2015] for explanation of updated method.
- GCD Package no longer uses NCToolbox. All '*_geodata' functions have been updated to use Matlab's built in NetCDF handling capabilities. These updates include functions for writing NetCDF files as well.
- 'Snowfall' Matlab function allows either linear ramp or step function snowfall partitioning model to be used and fitting parameters must now be specified.
- New options for comparing downscaled historic reanalysis or simulations to GHCN station records. The new options allow cumulative distribution functions (CDFs) to be of the downscaled product to be compared against GHCN CDFs analyzed and the joint histograms of each product to be compared.

3.6 GCD Package V3.1 (Released 12 December 2014)

- Various bug fixes pertaining to:
  - Changes in V3.0 may have interfered with performance of historic reanalysis climate data production. V3.1 restores historic reanalysis data performance. The two main aspects of the package fixed are compatibility with GPCC input data and calculation of the anomaly grid in the Delta downscaling process. Note that in the historic reanalysis case data quality can always be checked by turning on the option to compare output with GHCN station records.
  - Functions calculating differences in time have been generalized and made more accurate. For example, an issue was fixed which caused some dates in December to return errors.
  - Resampling of output written to ASCII format - Many input datasets have a non-uniform grid spacing. Writing to ESRI ASCII output format requires the data to have a uniform grid. Edits in V3.1 improved the algorithm for choosing the uniform spatial grid to resample to. The new algorithm minimizes total offset between original and transformed grids latitudinally and longitudinally.
  - Algorithm for choosing "window" of input datasets enhances - New algorithm should ensure GCM data have more uniform window encapsulating downscaling region, which reduces edge effects.
  - Settings in V3.0 had inadvertently prevented several warning messages from appearing; in V3.1 warning message output is restored.
  - Bias-correction algorithm changes:

    * Two bias-corrected GCM inputs are used in downscaling GCM data, a historic-run climatology and time-series projection runs. In V3.0 the GCM historic-run climatology was calculated and then bias-corrected. In V3.1 the GCM historic-run time-series are bias-corrected and then used to produce a climatology.
    * The maximum bias-correction factor is now 10. A limit is necessary for precipitation because a ratio of precipitation values is used in bias-correction. A ratio is used because it prevents negative precipitation values; however, it permits the possibility that the denominator be very close to zero and the numerator be a regular value, which could result a near infinite precipitation correction factor. This is obviously not physically representative.
  - Fixed issue from V3.0 that inhibited comparison of downscaled historic reanalysis to GHCN station data (caused by change to naming convention of output data).

3.7 GCD Package V3.0 (Released 9 September 2014)

- Downscale global climate model projection data:
  - Capability to downscaled GCM projection-run output. Requires both historic-run (i.e. 20th century simulation) of GCM and projection run (e.g. corresponding to specific representative concentration pathway)
  - Method for downscaling GCM data includes quantile mapping bias-correction step. Two output datasets are produced, one with bias-correction and another without
  - If GCM data are broken up into temporal chunks, script automatically searches for split NetCDF files with same root name and splices them together
- More generalized functions for reading climate data
- Can use other climatologies, such as PRISM, in place of WorldClim
- Approximately four-fold speed increase, largely related to ASCII file write speed
- Ability to create grids up to longitudinal edges (previously was only able to downscale to about -179 West and 179 East)
- Can now downscale across the Prime Meridian, allowing users to create downscaled output for all land surfaces in single run
- Capability added to downscale minimum and maximum temperature (previously only mean temperature could be downscaled)
- Improved error messages and better stability

3.8 GCD Package V2.1 (Released April 2014)

- Reorganized processing to use *significantly* less RAM.
- Output directory for downscaled products created within "downscaling_main_v*.m" instead of "downscale_v*.m". This was done in order to initiate the processing log earlier. The processing log now contains a complete record of all inputs and processes, thereby allowing full replication of results by another user.
- Minor fixes for assorted specific cases that could have caused program to crash unexpectedly.

3.9 GCD Package V2.0 (Released March 2014)

- Complete redesign of the scripts, making them more organized and generalizing the treatment of data formats over previous versions.
- Capability to read CRU data in NetCDF format.
- Option to write output as NetCDF file (previously only option is ESRI formatted ASCII grids).
- Capability to downscale minimum and maximum temperature (previously only mean temperature)
- Added file to output folder labeled "processing_log_*.txt" which records all strings displayed in command window.

3.10 GCD Package V1.3 (Released 22 November 2013)

- Fixes a few trivial issues, including a typo in a *disp* call that causes the script to crash.

3.11 GCD Package V1.1 (Released June 2013)

- Incremental updates including better feedback to user.

3.12 GCD Package V1.0 (Released May 2013)

- Initial release; allows user to downscale CRU, W&M, or GPCC 0.5 degree monthly surfaces to the 30-arcsecond WorldClim grid.

Table 1: Programmed bias correction methods.

Name	Method string	Summary	Citation
Empirical Quantile Mapping	‘eQM’	Empirical quantile mapping using 100 bins.	Mosier et al. [2017]
Empirical Joint Bias Correction	‘eJBC’	Generates empirical mapping using copulas composed of two variables. Minimization of least squares distances are used to determine mapping in the case of tied copulas.	Mosier et al. [2017]
Empirical Quantile-2-Quantile Mapping	‘eQ2Q’	Empirical quantile mapping without bins. Uses interpolation between CDF values.	Hopson and Webster [2010]

4 Supported Methods

The GCD package is capable of implementing bias correction and downscaling methods using a variety of geospatial data. The currently supported bias correction methods are displayed in Table 1 and the supported climate data processing methods are displayed in Table 2.

Table 2: Programmed downscaling / processing methods.

Name	Method string	Summary	Citation
Extract	‘extract’	Extracts climate time-series at specific point. Requires csv or Excel file with station name, longitude, and latitude.	NA
Resample	‘resample’	Uses specified interpolation method to resample grid.	Mosier et al. [2014]
Delta	‘delta’	Implements delta change method by combining low-resolution time-series to high-resolution reference climatology.	Mosier et al. [2014]
Temperature lapse rate	‘tlapse’	Estimates low-resolution temperature lapse rates from input grid and projects those onto high-resolution elevation model.	Mosier et al. [2014]
Precipitable water scaling	‘pw’	Estimates relationship between change in elevation and change in precitable water (total column water). Projects estimated relationship onto high-resolution grid	

5 User Input

After downloading and locating the archived GCD package, '*downscaling_package_v[version #].zip*', uncompress it to the desired location on the hard drive. The scripts are packaged so that upon opening *downscaling_main_v[version #].m* in Matlab and running it, the Matlab search path will be automatically updated to include all necessary subroutines, provided that the file structure of *downscaling_package* is not altered from the downloaded state.

downscaling_main_v[version #].m contains two sections, "%%USER INPUTS:" and "%%IMPLEMENTATION CODE (DO NOT EDIT):". As the names suggest, the first section is where the user inputs all choices regarding downscaling method and geographic region, while the *implementation code* section translates these inputs into commands and produces the downscaled data. The variables to edit within the *user input* section are presented and described in Table 6 (Appendix A). The GCD package is distributed ready to produce a 30 arc-second precipitation grid for June 1986, using a Global Precipitation Climatology Centre (GPCC) 0.5 degree time-series grid and a WorldClim 30 arc-second climatology. The latitude and longitude bounding box in the distributed version are for the state of Oregon, USA. *Note that the data distributed with the GCD package is only sufficient to generate grids for June 1950 through 2000 using the GPCC time-series input or June 2051-2100 using the GISS-E2-H GCM for representative concentration pathway (RCP) 8.5.* The region and options related to downscaling methodology can be varied without downloading additional input data; however, to use another low-resolution time-series input or to produce downscaled data for more time steps, additional data must be downloaded from the original producer's website, which is discussed in Section 5.1.

Required input data for the *downscaling_main.m* script varies depending on whether the time period is set to 'historic' or 'projection'. The first two-three (depending on which options are selected) data prompts for both historic and projection data are the same, but an additional two prompts will appear when downscaling for the 'projection' period. The optional first prompt will check if there is a reference file (in the ESRI ASCII format) that the user desires to use to clip the output Delta downscaled grids to. This clipping simply sets the value of all grid points to the not-a-number (NAN) value for points in the reference file that are NAN. An example of why this may be desirable is if the user wishes to produce a downscaled grid for only the state of Oregon, USA, and to not include any of the points within the rectangular box outside of the state's boundary. An example clipping mask for the state of Oregon is provided in '\downscaling_package\input_climate_data_June\OR_shape_clip'.

Starting with version 4.0, the GCD package has become much more versatile. There are now methods that work with daily as well as monthly input datasets, for example. There is also greater capacity for implementing new downscaling methods within the package.

If the delta method is being used (which is still only designed to work with monthly data), the first required input data pop-up will request the user to navigate to the high-spatial resolution reference climatology (e.g. WorldClim) folder with data corresponding to the chosen climate parameter. The example WorldClim grid is located at the relative path '\downscaling_package\input_climate_data_June\WorldClim_clim'. The second required prompt is for a observational time-series input source (e.g. CRU) for the chosen climate parameter. In the example, this is '\downscaling_package\input_climate_data_June\GPCC_ts'. When downscaling 'historic' data, this is the time-series dataset being downscaled. When downscaling 'projection' data, this dataset is used to bias-correct the GCM data.

When downscaling 'projection' data, two additional data location prompts will appear. The first requires the user to navigate to the GCM projection-run data file and the second to the GCM historic-run data file. In the example, these data are located in the folder '\downscaling_package\input_climate_data_June\GISS-E2-H'. In this example, as with many other GCM runs, the data are distributed as multiple files broken up by year. Before starting the GCD package, ensure that all of the files spanning the desired years are present in the same folder. When the GCD package prompts you to select a GCM file, choose any of the files for the GCM run you wish to use. The package will automatically detect the other files and splice them together.

5.1 How to Obtain the Requisite Climate Data

Table 3 provides direct links to the sources of historic gridded observation time-series data that are compatible with the GCD package, while Table 4 links to the appropriate WorldClim climatologies (other climatologies may be used but links are not provided). Follow the links in these tables to download the desired input data. Remember that to downscale data for one of the climate parameters, it is necessary to have one of the time-series sources (Table 3) and the corresponding WorldClim source (Table 4). The time required for the script to finish running varies upon a number of factors, including the computer used, whether the data is stored locally or on a remote server, the number of time-series elements being created, the geographic size of the region, and the optional output data being written. For the example setting present in the distribution, it takes approximately 30 minutes to produce the downscaled grid and to calculate statistics between the grid and the GHCN data. It should be noted, though, that many of the computationally expensive processes are only calculated once for each month downscaled. Thus, the time required per grid is significantly less if June grids for the years 1950 to 2000 are being produced rather than for a single year.

GCM data from the coupled Model Intercomparison Phase 5 (CMIP5) are available through the Earth System Grid Federation (ESGF) Data Portal. This requires the extra steps of (1) setting up an ESGF user account, (2) registering for the "CMIP5 Research" group under the account settings, (3) navigating to the desired GCM run, and (4) downloading it via direct link or wget script. This is often a cumbersome processes, made more difficult by seemingly erratic instances where a given GCM will not be present or downloadable. In an effort to assist, direct links to some of the CMIP5 GCM runs are provided in Appendix C (links not updated and may be broken). These links are not a complete representation of available CMIP5 GCM data provided without warranty. Further, even with these links, the above outlined ESGF registration steps must be completed to obtain login credentials.

Table 3: Links to monthly gridded observation time-series data compatible with the GCD package.

Climate Parameter	**Download Link**
precipitation	W&M V3.02
	CRU V3.21[1]
	GPCC V6
mean temperature	W&M V3.01
	CRU V3.21[1]
minimum temperature	CRU V3.21[1]
maximum temperature	CRU V3.21[1]

Table 4: Links to WorldClim climatology data compatible with the GCD package.

Climate Parameter	**Download Link**
precipitation	WorldClim
mean temperature	WorldClim
minimum temperature	WorldClim
maximum temperature	WorldClim

[1] To access the CRU data, users must create a login account for the British Atmospheric Data Centre. Upon first following the link, a login page will appear. After creating and entering login credentials, the link will continue to the data and the download should begin automatically.

6 Generated Outputs

All output are recorded in a unique folder at the same level in the directory tree as the time-series input being downscaled. In the 'historic' case the output under the gridded observational time-series folder and in the 'projection' GCM downscaling case the output are under the GCM folder. The name and location of the output folder is displayed in the Matlab command history window upon being successfully written.

There are many gridded datasets that can be written to file using the GCD package, including the downscaled time-series output, subsets of the input data, seasonal averages, and derived snowfall; for a complete list see Appendix B. When downscaling 'projection' GCM data, downscaled data produced both with and without bias-correcting the GCM are provided in the folders '...\downscaled_TS_BC' and '...\downscaled_TS', respectively. Most additional gridded output are located in the folder under the parent labeled '*extras*'.

Additionally, when downscaling 'historic' data, the time-series output can be compared to available Global Historical Climatology Network (GHCN) station data for the region being downscaled. This process is time-intensive and is switched on using its own input parameter (see entry 'calcStats' in Appendix A). The six statistics calculated are defined in Table 5. These statistics are calculated by station (aggregated over all time series elements in the downscaled dataset), by month (aggregated over all stations with data for the given month), and aggregated over all stations and time series elements. All statistics produced are written to a file titled '[*data output folder*]\GHCN_stats\GHCN_stat_[*climate variable*]_[*GHCN data type*]_[*starting year*]_[*ending year*].asc'. Additionally, the station statistics are written to a text file that is directly interpretable by ArcGIS, named '[*data output folder*]\GHCN_stats\stn_geostats_[*climate variable*]_[*GHCN data type*]_[*starting year*]_[*ending year*].txt'. For regions where adjusted GHCN station data exists, GHCN statistics are calculated using both the GHCN adjusted and non-adjusted datasets. Non-adjusted GHCN data are available for all regions.

The output folder also contains a file labeled "processing_log_*[time stamp]*.txt". This file records all text displayed in the Matlab command history window and can therefore be used to check input data selected and many of the input parameters chosen.

Table 5: Statistics calculated between downscaled grids and GHCN station data, where P refers to the downscaled value, O to the GHCN value, and n is the number of data points being compared.

Statistic	**Definition**
Bias	$\frac{1}{n}\sum_{i=1}^{n}\left(P_i - O_i\right)$
Mean Absolute Error (MAE)	$\frac{1}{n}\sum_{i=1}^{n}\left\lvert P_i - O_i\right\rvert$
Root Mean Square Error (RMSE)	$\sqrt{\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}}$
Mean Absolute % Error (MAPE)	$\frac{1}{n}\sum_{i=1}^{n}\left\lvert\frac{P_i - O_i}{O_i}\right\rvert \times 100\%$
Weighted MAPE (WMAPE)	$\frac{\sum_{i=1}^{n}\left\lvert O_i\right\rvert \times \left\lvert\frac{P_i - O_i}{O_i}\right\rvert}{\sum_{j=1}^{n}\left\lvert O_j\right\rvert} \times 100\%$
Nash-Sutcliffe Efficiency (NSE)	$1 - \frac{\sum_{i=1}^{n}\left(O_i - P_i\right)^2}{\sum_{j=1}^{n}\left(O_j - \overline{O}\right)^2}$

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A Input Variables

Table 6: Required variables in the *user input* section of *downscaling_main.m*.

Variable	Default	Description
‘simPeriod’	’projection’	string specifying either ‘projection’ if GCM data being downscaled or ‘historical’ if gridded observation data being downscaled.
‘yrsDs’	[2051, 2100]	Vector with two entries, where the first entry is the first year to be downscaled and the second entry is the last year to be downscaled. All years in-between the first and last entry are also included.
‘mnths’	(6:6)	List of months to be downscaled. For all twelve months, the syntax is ‘(1:12)’.
‘dataTimeStep’	’monthly’	List of months to be downscaled. For all twelve months, the syntax is ‘(1:12)’.
‘metVarDs’	’pre’	An array of strings that determines which climate variable will be downscaled. String options are ‘pre’ and ‘tmn’. To downscale both mean temperature and precipitation, the variable should read ‘{’pre’, ’tmn’}’.
‘methodDs’	’eQM_delta’	A string dictating which downscaling method to implement. The current options are ‘eQM_delta’, which bias-corrects the projection data using empirical quantile mapping and then downscales the data using a Delta method.
‘region’	’OR’	A string of the region being downscaled, used to name the output data.
‘lonDs’	[-125, -116]	A two element vector that sets the western and eastern longitudes of the region to downscale. Units are decimal degrees and if the longitude is in the western hemisphere it must be entered as a negative.

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Table 6: (continued from previous page)

Variable	Default	Description
‘latDs’	[41, 46]	A two element vector that sets the southern and northern latitudes of the region to downscale. Units are decimal degrees and if the latitude is in the southern hemisphere it must be entered as a negative.
‘nSim’	1	Sets the number of simulations to process (e.g. can process multiple climate model projection simulations to produce ensemble.
‘yrsClim’	[1981, 2010]	Vector specifying years used in high-spatial resolution reference climatology.
‘writeType’	’ascii’	Sets the output format to use for writing georeferenced data (Either ‘netCDF’ or ‘ASCII’).
‘writeOpts’	’downscale_ts’	See write option descriptions in Appendix B and script.
‘unitsUse’	’’pre’, ’mm’; ’tas’, ’Celsius’’	Cell array that can be used to override the default data units (defaults are mm for precipitation and degrees Celsius for temperature).
‘ghcnStats’	’’joint’, ’adj_cdf’, ’non_cdf’’	Cell array that sets the type of comparison to be conducted between downscaled outputs and GHCN station records.
‘methodInterp’	’pchip’	A string that specifies which interpolation method to use with the chosen downscaling method. The options are ‘pchip’, ‘spline’ and ‘linear’.
‘methodResample’	’upscale_area_wgt’	A string that specifies what to do if the input grids have different spatial resolutions. The default upscales the higher-resolution grids to the lowest resolution grid by area-weighting the inputs.

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Table 6: (continued from previous page)

Variable	Default	Description
‘stnExclude’	[]	A vector of length N, where N is the number of Global Historical Climatology Network (GHCN) stations to exclude when calculating statistics between GHCN and the downscaled grids. Each entry must be a numerical GHCN station identifier, which are all eleven digits long (e.g. 42572791000). If the GHCN station identifier is not recognized or is not within the region of interest, no warning will be produced. GHCN station identifiers can be determined retroactively by opening either of the two GHCN output files (see Section 6 for details) and recording the GHCN identifier of the desired station.
‘shepard’	0	Boolean value determining whether or not to produce a set of bias-corrected downscaled grids, where the bias-correction is relative to available Global Historical Climatology Network station data.

B Write Options

Table 7: Grids That Can Be Written to Files Using *downscaling_main.m*. All data clipped to extent used in processing.

Variable String	Description
‘downscale_ts’	High-resolution monthly downscaled data
‘input_clim’	Original resolution climatology from input time-series being downscaled
‘input_ts’	Original resolution input time-series being downscaled
‘downscale_clim’	Average of downscaled data for years processed

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Table 7: (continued from previous page)

Variable String	Description
'anomaly_lr'	Time-series of original resolution Delta anomaly
'anomaly_hr'	Time-series of Delta anomaly interpolated to downscaled output resolution
'ref_clim'	High-spatial resolution reference climatology (e.g. World-Clim)
'cdf'	Cumulative distribution functions of all input data (only applicable when downscaling 'projection' and quantile mapping or joint bias correction being used)
'downscale_seasonal'	Downscaled time-series seasonally averaged (in the case of temperature) or integrated (in the case of precipitation) for all months of year being downscaled.
'snowfall'	Calculates snow as any precipitation where surface air temperature for cell is at or below 0 degrees Celsius. Option only available if both mean temperature and precipitation downscaled in same package run.

C Direct Links to CMIP5 GCM Data

Table 8: Links to CMIP5 GCM Output compatible with the GCD package.

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
ACCESS 1.0	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP4.5	r1i1p1	r1i1p1	r1i1p1	
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
ACCESS 1.3	Historical				
	RCP 4.5				
	RCP 8.5				
BCC-CSM1.1	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
BCC-CSM1.1 (m)	Historical				
	RCP 4.5				
	RCP 8.5				
BNU-ESM	Historical	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
CCSM4	Historical	r1i1p1, r1i2p1, r1i2p2, r2i1p1, r3i1p1	r1i1p1, r1i2p1, r1i2p2, r2i1p1, r3i1p1	r1i1p1, r1i2p1, r1i2p2, r2i1p1, r3i1p1	r1i1p1, r1i2p1, r1i2p2, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 8.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
CESM1 (BGC)	Historical				

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
	RCP 4.5				
	RCP 8.5				
CESM1 (CAM5)	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 8.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
CESM1 (CAM5.1,FV2)	Historical				
	RCP 4.5				
	RCP 8.5				
CESM1 (WACCM)	Historical				
	RCP 4.5				
	RCP 8.5				
CMCC-CM	Historical				
	RCP 4.5				
	RCP 8.5				
CMCC-CMS	Historical	r1i1p1 (1990-1999), r1i1p1 (2000-2005)	r1i1p1 (1990-1999), r1i1p1 (2000-2005)	r1i1p1 (1990-1999), r1i1p1 (2000-2005)	r1i1p1 (1990-1999), r1i1p1 (2000-2005)
	RCP 4.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 8.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
CNRM-CM5	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1 (2006-2055), r1i1p1 (2056-2100)	r1i1p1 (2006-2055), r1i1p1 (2056-2100)	r1i1p1 (2006-2055), r1i1p1 (2056-2100)	r1i1p1 (2006-2055), r1i1p1 (2056-2100)
	RCP 8.5	r1i1p1 (2006-2055), r1i1p1 (2056-2100)	r1i1p1 (2006-2055), r1i1p1 (2056-2100)	r1i1p1 (2006-2055), r1i1p1 (2056-2100)	r1i1p1 (2006-2055), r1i1p1 (2056-2100)
CNRM-CM5-2	Historical				
	RCP 4.5				
	RCP 8.5				
CSIRO-Mk3.6.0	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 8.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
CSIRO-Mk3L-1-2	Historical				
	RCP 4.5				
	RCP 8.5				

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
CanESM2	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 8.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
EC-EARTH	Historical	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 4.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 8.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
FGOALS-g2	Historical	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 4.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 8.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
FIO-ESM	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 8.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
GFDL-CM3	Historical	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 4.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 8.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
GFDL-ESM2G	Historical	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 4.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 8.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
GFDL-ESM2M	Historical	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 4.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
	RCP 8.5	*decadal files*	*decadal files*	*decadal files*	*decadal files*
GISS-E2-H	Historical	r1i1p1 (1901-1950), r1i1p1 (1951-2005), r1i1p2 (1850-1950), r1i1p2 (1951-2005), r2i1p1 (1901-1950), r2i1p1 (1951-2005)	r1i1p1 (1901-1950), r1i1p1 (1951-2005), r1i1p2 (1850-1950), r1i1p2 (1951-2005), r2i1p1 (1901-1950), r2i1p1 (1951-2005)	r1i1p1 (1901-1950), r1i1p1 (1951-2005), r1i1p2 (1850-1950), r1i1p2 (1951-2005), r2i1p1 (1901-1950), r2i1p1 (1951-2005)	r1i1p1 (1901-1950), r1i1p1 (1951-2005), r1i1p2 (1850-1950), r1i1p2 (1951-2005), r2i1p1 (1901-1950), r2i1p1 (1951-2005)

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
	RCP 4.5	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)
	RCP 8.5	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)	r1i1p1 (2006-2050), r1i1p1 (2051-2100), r1i1p2 (2006-2050), r1i1p2 (2051-2100), r2i1p1 (2006-2050), r2i1p1 (2051-2100)
GISS-E2-H-CC	Historical				
	RCP 4.5				
	RCP 8.5				
GISS-E2-R	Historical				
	RCP 4.5				

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
	RCP 8.5				
GISS-E2-R-CC	Historical				
	RCP 4.5				
	RCP 8.5				
HadGEM2-AO	Historical				
	RCP 4.5				
	RCP 8.5				
HadGEM2-CC	Historical				
	RCP 4.5				
	RCP 8.5				
HadGEM2-ES	Historical	≈ 25 yr files	≈ 25 yr files	≈ 25 yr files	≈ 25 yr files
	RCP 4.5	≈ 25 yr files	≈ 25 yr files	≈ 25 yr files	≈ 25 yr files
	RCP 8.5	≈ 25 yr files	≈ 25 yr files	≈ 25 yr files	≈ 25 yr files
INM-CM4	Historical	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
IPSL-CM5A-LR	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 8.5	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
IPSL-CM5A-MR	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
IPSL-CM5B-LR	Historical				
	RCP 4.5				
	RCP 8.5				
MIROC-ESM	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
MIROC-ESM-CHEM	Historical				
	RCP 4.5				
	RCP 8.5				
MIROC5	Historical				
	RCP 4.5				
	RCP 8.5				
MPI-ESM-LR	Historical				
	RCP 4.5				
	RCP 8.5				
MPI-ESM-MR	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1

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Table 8: (continued from previous page)

GCM Name	Experiment	Precipitation	Mean Temp	Min Temp	Max Temp
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
MRI-CGCM3	Historical	r1i1p1, r2i1p1, r4i1p2, r5i1p2	r1i1p1, r2i1p1, r4i1p2, r5i1p2	r1i1p1, r2i1p1, r4i1p2, r5i1p2	r1i1p1, r2i1p1, r4i1p2, r5i1p2
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
MRI-ESM1	Historical				
	RCP 4.5				
	RCP 8.5				
NorESM1-M	Historical	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1	r1i1p1, r2i1p1, r3i1p1
	RCP 4.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
	RCP 8.5	r1i1p1	r1i1p1	r1i1p1	r1i1p1
NorESM1-ME	Historical				
	RCP 4.5				
	RCP 8.5				