Package 'ClimDown'

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Title Climate Downscaling Library for Daily Climate Model Output

Author Nic Annau [aut],
Alex Cannon [aut],
James Hiebert [aut],
Cairo Sanders [ctb],
Arelia Schoeneberg [aut],
Stephen Sobie [aut],
Lee Zeman [aut, cre]

Maintainer Lee Zeman <lzeman@uvic.ca>

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Description A suite of routines for downscaling coarse scale global climate model (GCM) output to a fine spatial resolution. Includes Bias-Corrected Spatial Downscaling (BCDS), Constructed Analogues (CA), Climate Imprint (CI), and Bias Correction/Constructed Analogues with Quantile mapping reordering (BCCAQ). Developed by the the Pacific Climate Impacts Consortium (PCIC), Victoria, British Columbia, Canada.

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URL https://www.r-project.org

BugReports https://github.com/pacificclimate/ClimDown

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R topics documented:

`bccaq.netcdf.wrapper` *Wrapper function for the entire BCCAQ downscaling method*

Description

BCCAQ is a hybrid downscaling method that combines outputs from Climate Analogues (CA) and quantile mapping at the fine-scale resolution. First, the CA and climate imprint (CI) plus quantile delta mapping (QDM) algorithms are run independently. BCCAQ then combines outputs from the two by taking the daily QDM outputs at each fine-scale grid point and reordering them within a given month according to the daily CA ranks, i.e., using a form of Empirical Copula Coupling.

The combination mitigates some potential issues with the separate algorithms. First, because the optimal weights used to combine the analogues in BCCA are derived on a day-by-day basis, without reference to the full historical data set, the algorithm may fail to reproduce long-term trends from the climate model. Second, the CI/QDM bias correction step fixes precipitation "drizzle" and other residual biases caused by the linear combination of daily fields from CA. Third, reordering data for each fine-scale grid point within a month effectively breaks the overly smooth representation of sub grid-scale spatial variability inherited from CI/QDM, thereby resulting in a more accurate representation of event-scale spatial gradients; this also prevents the downscaled outputs from drifting too far from the climate model's long-term trend.

Usage

```
bccaq.netcdf.wrapper(gcm.file, obs.file, out.file, varname = "tasmax")
```

Arguments

`gcm.file`	Filename of GCM simulations in NetCDF format
`obs.file`	Filename of high-res gridded historical observations
`out.file`	The file to create (or overwrite) with the final BCCAQ NetCDF output
`varname`	Name of the NetCDF variable to downscale (e.g. 'tasmax')

References

Werner, A. T., & Cannon, A. J. (2016). Hydrologic extremes - an intercomparison of multiple gridded statistical downscaling methods. Hydrology and Earth System Sciences, 20(4), 1483-1508. doi: 10.5194/hess-20-1483-2016

Examples

```
## Not run:
out.nc <- tempfile(fileext='.nc')
options(
    calibration.end=as.POSIXct('1972-12-31', tz='GMT'),
    cend=as.POSIXct('1972-12-31', tz='GMT')
)
ClimDown::bccaq.netcdf.wrapper('./tiny_gcm.nc', './tiny_obs.nc', out.nc, 'tasmax')
unlink(out.nc)

## End(Not run)
```

---

ca.netcdf.wrapper — *High-level NetCDF I/O wrapper for the Constructed Analogues (CA) pipeline*

Description

CA starts by spatially aggregating high-resolution gridded observations up to the scale of a GCM. Then it proceeds to bias correcting the GCM based on those observations. Finally, it conducts the search for temporal analogues (which is the most expensive part of the operation). This involves taking each timestep in the GCM and searching for the top 30 closest timesteps (for some function of "close") in the gridded observations. For each of the 30 closest "analogue" timesteps, CA records the integer number of the timestep and a weight for each of the analogues. These are all saved in output.file.

Usage

```
ca.netcdf.wrapper(gcm.file, obs.file, varname = "tasmax")
```

Arguments

`gcm.file`	Filename of GCM simulations
`obs.file`	Filename of high-res gridded historical observations
`varname`	Name of the NetCDF variable to downscale (e.g. 'tasmax')

Value

A list object with two values: 'indices' and 'weights', each of which is a vector with 30 items

References

Maurer, E. P., Hidalgo, H. G., Das, T., Dettinger, M. D., & Cayan, D. R. (2010). The utility of daily large-scale climate data in the assessment of climate change impacts on daily streamflow in California. Hydrology and Earth System Sciences, 14(6), 1125-1138.

Examples

```
## Not run:
options(
    calibration.end=as.POSIXct('1972-12-31', tz='GMT')
)
analogues <- ClimDown::ca.netcdf.wrapper('./tiny_gcm.nc', './tiny_obs.nc')

## End(Not run)
```

---

ci.netcdf.wrapper *High-level NetCDF wrapper for Climate Imprint (CI)*

Description

CI performs several steps. For the GCM input it calculates daily climate anomalies from a given calibration period (default 1951-2005). These daily GCM anomalies are interpolated to the high-resolution observational grid. These interpolated daily anomalies constitute the "Climate Imprint". The high resolution gridded observations are then grouped into months and a climatology is calculated for each month. Finally the observed climatology is added to the GCM-based climate imprint and the final result is saved to output.file.

Usage

```
ci.netcdf.wrapper(gcm.file, obs.file, output.file, varname = "tasmax")
```

Arguments

`gcm.file`	Filename of GCM simulations
`obs.file`	Filename of high-res gridded historical observations
`output.file`	Filename to create (or overwrite) with the climate imprint outputs
`varname`	Name of the NetCDF variable to downscale (e.g. 'tasmax')

References

Hunter, R. D., & Meentemeyer, R. K. (2005). Climatologically aided mapping of daily precipitation and temperature. Journal of Applied Meteorology, 44(10), 1501-1510.

Ahmed, K. F., Wang, G., Silander, J., Wilson, A. M., Allen, J. M., Horton, R., & Anyah, R. (2013). Statistical downscaling and bias correction of climate model outputs for climate change impact assessment in the US northeast. Global and Planetary Change, 100, 320-332.

Examples

```
## Not run:
ci.nc <- tempfile(fileext='.nc')
ClimDown::ci.netcdf.wrapper('./tiny_gcm.nc', './tiny_obs.nc', ci.nc)
unlink(ci.nc)

## End(Not run)
```

ClimDown *ClimDown: PCIC's daily Climate Downscaling library*

Description

This package includes PCIC's routines and techniques for downscaling coarse scale Global Climate Models (GCMs) to fine scale spatial resolution.

Details

At present, the package only exports high-level wrapper function that perform each of three downscaling steps: CI, CA, QDM, and rerank as well as one wrapper that runs the entire pipeline: BCCAQ. In general, each wrapper simply takes four arguments: GCM file, gridded observation file, output file, and variable name. However, see the specific function documentation for specifics.

The package also provides five wrapper scripts that allow the user to run each step from the command line (plus the whole pipeline) with Rscript.

References

Werner, A. T., & Cannon, A. J. (2016). Hydrologic extremes - an intercomparison of multiple gridded statistical downscaling methods. Hydrology and Earth System Sciences, 20(4), 1483-1508. doi: 10.5194/hess-20-1483-2016

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options *User-configurable options*

Description

ClimDown has a number of global options with sensible defaults pre-set. Options must be configured using R's `options` function. They can be set by using an .Rprofile file, or on the R session prompt prior to executing any **ClimDown** wrapper functions.

Arguments

`max.GB`
: An *approximate* measure of how much RAM to use in the chunk I/O loop. In reality, R does a lot of copying data, so if you have a firm RAM threshold, it's best to set this to about 1/3 to 1/4 of what you want the high-water mark to be. (default=1)

`trimmed.mean`
: Undocumented and not recommended to change. (default=0)

`delta.days`
: Undocumented and not recommended to change. (default=45)

`n.analogues`
: The number of temporal analogues that the CA algorithm will search for and match. The higher this number, the longer the execution time of the reordering step. (default=30)

`calibration.start`
: A POSIXct object that defines the beginning of the calibration period. (default=`as.POSIXct('1971-01-01',tz='GMT')`)

`calibration.end`
: A POSIXct object that defines the end of the calibration period. (default=`as.POSIXct('2005-12-31',tz='GMT')`)

`tol`
: Undocumented and not recommended to change. (default=0.1)

`expon`
: Undocumented and not recommended to change. (default=0.5)

`multiyear`
: Undocumented and not recommended to change. (default=TRUE)

`expand.multiyear`
: Undocumented and not recommended to change. (default=TRUE)

`multiyear.window.length`
: Undocumented and not recommended to change. (default=30)

`trace`
: Undocumented and not recommended to change. (default=0.005)

`jitter.factor`
: Undocumented and not recommended to change. (default=0.01)

`tau`
: Undocumented and not recommended to change. (default=`list(pr=1001,tasmax=101,tasmin=101)`)

`seasonal`
: Undocumented and not recommended to change. (default=`list(pr=TRUE,tasmax=FALSE,tasmin=FALSE)`)

`ratio`
: Undocumented and not recommended to change. (default=`list(pr=TRUE,tasmax=FALSE,tasmin=FALSE)`)

`check.units`
: A boolean value that determines whether to check the input units and convert them to the target output units. The *safe* option is to leave this set to TRUE, but if know for sure that the units match, modest performance gains can be made by not checking and performing this conversion. (default=TRUE)

`check.neg.precip`
: A boolean value that determines whether to check for and eliminate negative precipitation values. Like check.units, modest performance gains can be achieved if you are certain that no negative precipitation values exist. (default=TRUE)

`target.units`
: A list containing the units that should be used for the output file (default=`c(tasmax='celsius',tasmin='celsius',pr='kg m-2 d-1')`)

parallelization — *Parallelization*

Description

ClimDown uses the **foreach** package to support parallelization where possible. In general, most of **ClimDown**'s computations contain an outer I/O chunk loop and an inner computational loop. The outer chunk loop serially reads in as much data from input files as it feasibly can, and then the inner loop will execute in parallel if the user has configured a parallel engine.

Users can configure a parallel engine before execution using either the **doParallel** or **doMPI** packages.

If the user does not configure a parallel backend, the inner loops will simply run serially and issue a warning.

See Also

doParallel and **doMPI**

Examples

```
## Not run:
library(doParallel)
registerDoParallel(cores=4)
bccaq.netcdf.wrapper(...)
stopImplicitCluster()
## End(Not run)
```

qdm.netcdf.wrapper — *High-level wrapper for Quantile Delta Mapping (QDM)*

Description

This function performs the QDM algorithm on a cell-by-cell basis for each cell in the spatial domain of the inputted high-res gridded observations. It uses the gridded observations plus the GCM-based output of CI as input to the algorithm and then performs a quantile perturbation/quantile mapping bias correction. The output is written out to out.file.

Usage

```
qdm.netcdf.wrapper(obs.file, gcm.file, out.file, varname = "tasmax")
```

Arguments

`obs.file`	Filename of high-res gridded historical observations
`gcm.file`	Filename of GCM simulations interpolated to the obs.file grid
`out.file`	Filename to create (or overwrite) with the bias corrected outputs
`varname`	Name of the NetCDF variable to downscale (e.g. 'tasmax')

References

Cannon, A. J., Sobie, S. R., & Murdock, T. Q. (2015). Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes?. Journal of Climate, 28(17), 6938-6959. doi: 10.1175/JCLI-D-14-00754.1

Examples

```
## Not run:
ci.file <<- tempfile(fileext='.nc')
ClimDown::ci.netcdf.wrapper('./tiny_gcm.nc', './tiny_obs.nc', ci.file, 'tasmax')
out.nc <- tempfile(fileext='.nc')
options(
    calibration.end=as.POSIXct('1972-12-31', tz='GMT'),
    cend=as.POSIXct('1972-12-31', tz='GMT')
)
ClimDown::qdm.netcdf.wrapper('./tiny_obs.nc', ci.file, out.nc, 'tasmax')
unlink(ci.file)
unlink(out.nc)

## End(Not run)
```

`rerank.netcdf.wrapper` *High-level NetCDF wrapper for Quantile Reranking*

Description

Quantile Reranking is the final, critical step in the BCCAQ pipeline. Its purpose is this: since Climate Analogues (CA) gets its high resolution information by using a linear combination of historical daily time series for the domain as a whole, it ends up reintroducing some bias. This is because the quantile mapping bias correction step was performed only at course resolution (of the GCM). Quantile Reranking fixes this by re-applying a simple quantile mapping bias correction at each grid box. The advantage of doing this as a final step is that the downscaling method retains the primary advantage of BCCA: high spatial consistency (e.g. when a storm or a heat wave hits a specific area, it probably also hits neighboring areas, etc.).

Usage

```
rerank.netcdf.wrapper(
  qdm.file,
  obs.file,
  analogues,
  out.file,
  varname = "tasmax"
)
```

Arguments

`qdm.file`	The output file from the QDM script
`obs.file`	Filename of high-res gridded historical observations
`analogues`	Temporal analogues. This is a list of two arrays: the index values and the fractional weights. Each array is the length of the number of timesteps by k (typically 30).
`out.file`	The file to create (or overwrite) with the final NetCDF output
`varname`	Name of the NetCDF variable to downscale (e.g. 'tasmax')

Details

All input files (save for the analogues_file) should have the same spatial domain.

References

Schefzik, R., Thorarinsdottir, T. L., & Gneiting, T. (2013). Uncertainty quantification in complex simulation models using ensemble copula coupling. Statistical Science, 28(4), 616-640.

Wilks, D. S. (2015). Multivariate ensemble Model Output Statistics using empirical copulas. Quarterly Journal of the Royal Meteorological Society, 141(688), 945-952.

Examples

```
## Not run:
options(
    calibration.end=as.POSIXct('1972-12-31', tz='GMT')
)
ci.file <- tempfile(fileext='.nc')
ClimDown::ci.netcdf.wrapper('./tiny_gcm.nc', './tiny_obs.nc', ci.file, 'tasmax')
qdm.file <<- tempfile(fileext='.nc')
ClimDown::qdm.netcdf.wrapper('./tiny_obs.nc', ci.file, qdm.file, 'tasmax')
unlink(ci.file)
analogues <<- ClimDown::ca.netcdf.wrapper('./tiny_gcm.nc', './tiny_obs.nc')
out.file <- tempfile(fileext='.nc')
ClimDown::rerank.netcdf.wrapper(qdm.file, './tiny_obs.nc', analogues, out.file, varname='tasmax')
unlink(qdm.file)
unlink(out.file)

## End(Not run)
```

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