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UKCP18 Guidance:
Bias correction

This document provides an introduction to bias-correction which you may wish to consider before using UKCP18 data. It covers:

1. What is bias-correction?
2. What do I need to be aware of?
3. What bias correction methods are there?
4. What is different from UKCP09?
5. What about downscaling?
6. Where can I get more information?

1. What is bias-correction?

If you would like to carry out climate impacts studies using the UKCP18 land projections datasets, then you need to consider whether to modify the datasets for systematic differences between model results and observations. This technique is called bias-correction and is an established approach used by many researchers and climate data users. Take care when applying these methods, as debatable assumptions are often required. We present four common bias-correction methods, summarising what they are, their advantages and disadvantages and examples of their use. The choice of method will depend on your particular application.

Impacts studies often require running climate impacts models (e.g. hydrological, habitats, building energy performance) or analysing how often climate thresholds are crossed (e.g. how many days surface air temperature is greater than 30°C). These analyses require absolute values rather than relative changes to a reference (or baseline) period and it is common practice to bias-correct climate model data before using them. Essentially, these methods calculate the differences between the model results and observations for a particular statistic, e.g. the mean or variance, and then apply this to the future dataset. Many bias-correction methods are available in the peer-reviewed literature and although widely used, they are often contested, context specific and require strong assumptions as outlined below.

The bias-correction methods presented below also include implicit downscaling (i.e. they correct for biases as well as downscale from a coarser to a finer spatial scale). This is relevant as the detailed physio-geographic properties of the target site are not represented in the climate models. This may include land-use, topography with shadowing and wind-channelling effects, nearby lakes or coastlines, etc.

There are limitations in our understanding of physical processes, the representation of these processes in models, uncertain historical forcing, and imperfect initialization of models. These factors mean that whilst climate models can replicate many observed features of climate the simulations of present-day climate from models do not precisely match observations. Simplifications need to be made when modelling the climate and can lead to systematic differences between model results and observations (or biases). Also there are small-scale climatic variations – even a perfect model (at grid resolution) would exhibit differences in climate relative to single-station observations.

2. What do I need to be aware of?

Before embarking on any bias-correcting, you need to consider the following:

- Bias-correction methods assume that the causes of the biases do not change in the future.
  The peer-reviewed literature has severely criticised this assumption (e.g. Maraun, 2016, Ehret et al, 2012). Nevertheless, many studies choose to use bias correction/ downscaling methods rather than raw model output.
- Bias-correction methods require sufficient observational data to characterize the reference climatology. In practice, this is at least 10 years of data (often 30 years) in order to include some variations at the decadal timescale.
- The quality of the observed dataset affects the quality of bias-corrected data and how well the climate model is able to represent the relevant physical processes that govern the variable of interest.
- The physical consistency of the different climate variables may not be maintained if they are bias-corrected independently. For example, bias-correcting temperature may result in sub-zero values, whereas rainfall does not convert to snowfall. Negative values for diurnal temperature range may be generated from daily minimal and maximal temperatures. This will be important in some applications but not others.
- Do not bias-correct if the biases are large, e.g. the Met Office Hadley Centre Model (HadGEM3-GC3.05) subset of the global projections show significant bias in winter surface air temperature in large parts of the Northern Hemisphere, although not over the UK (see Section 3.4 of Land Science Report. Murphy et al, (2018). You should disregard the members that show these large biases in your analysis.

Interpretation of any bias-corrected data needs to take into account the assumptions above. Please seek technical advice before using bias-corrected data for decision-making.

Carrying out bias-correction is a pragmatic choice that allows impacts modellers to carry out analyses using existing impacts models. The benefits are that you can use familiar models to understand the changing risk of climate impacts. However, the assumption that the behaviour of the bias is stationary (or constant with time) has been criticised, as there is evidence that the climate response to a warming world can change in the future (i.e. non-stationary) such as in extreme precipitation and evapotranspiration Maraun et al, (2016).

Observations datasets for the variable or metric of interest is essential if you are to carry out any bias-correction. For the UK, you can find further information on data availability and the quality of the dataset in the State of the UK Climate report (https://www.metoffice.gov.uk/climate/uk/about/state-of-climate). Some evaluation work has already been carried out to assess the UKCP18 climate models' ability to simulate physical processes, further information can be found in the UKCP18 land projections science report and the variable factsheets.

3. What bias correction methods are there?

There are many bias-correction methods available depending on your application. You can find four commonly used methods summarised in Table 1 with links to examples of their use in the UK. The methods are characterised by the statistic that it attempts to correct, i.e. the mean, the variance, the distribution and the long-term trend. Please note that this is not an exhaustive list and their inclusion does not mean that they are supported by the UKCP18 project.

You can find other methods described in more detailed overviews (Maraun et al, 2016; Teutschbein et al, 2012; Themeßl et al, 2011; Watanabe et al, 2012) but suffice to say that different methods applied to the same dataset can yield different results. For example, Gohar et al, (2017) found that different methods can change the timing of reaching a 2°C or 4°C world; for RCP4.5 differences could be on the order of 5-10 years for Europe for passing the 2°C warming compared to pre-industrial. Also, Lafon et al, (2012) found that results were sensitive not only to the method but also the baseline period for the quantile mapping method. Take care to understand the possible effects of using bias-correction and the robustness of the results.

The methods that we present below only correct the statistical distribution of a target variable (e.g. daily temperatures) and not the statistical properties of time series (i.e. biases in autocorrelation are not actively corrected). The most common application of the methods presented use station data as reference and are not suitable in a multi-site context, as the temporal correlation between neighbouring stations does not enter the method.

4. What is different from UKCP09?

There is no difference in the approach to bias-correction for UKCP18 compared to UKCP09. No bias-corrected raw climate data are being provided.

The focus of the UKCP09 projections over land was the probabilistic projections which provided 30-year mean changes through the 21st century. Underpinning this dataset was a set of 11 regional climate model results that were available for users who were able to use raw climate model data. Many impacts researchers used this latter dataset as they required spatially-coherent daily time series to run their impacts models and often carried out bias-correction (see Table 1 for examples). The UKCP18 projections at 2.2km, 12km and 60km spatial resolutions are similar to this dataset and you may choose to consider bias-correction.

5. What about downscaling?

In UKCP09, a weather generator provided site-specific statistically downscaled and bias-corrected daily and monthly data. UKCP18 will not provide an updated weather generator. In its place, a set of high-resolution climate models at 2.2km and 12km provide dynamically downscaled, physically consistent information at a finer spatial and temporal scale.

For further information in statistical downscaling methods there are a number of papers and textbooks, e.g. Fowler et al, (2007), Wilby et al, (2004) and Wilby et al, (2011).

6. Where can I get more information?

You can find further information in the detailed overviews mentioned above, i.e. Maraun et al, (2016), Teutschbein et al, (2012), Themeßl et al, (2011) and Watanabe et al, (2012).

Many other methods are discussed in the scientific literature, including those that deal with multi-site contexts, e.g. Harpham and Wilby (2005) and Brissette et al, (2007). Also, Rajczak et al, (2016) extends the quantile mapping method so that it can be applied with short observational data records.

Open-source scripts are available online which can be used at your own risk (i) from the ISIMIP project (www.isimip.org) to carry out trend-preserving quantile-mapping (TPQM) https://github.com/ISI-MIP/BC in GDL/IDL (ii) from the Santander Meteorology Group, Spain, to carry out the TPQM as well as other types of bias-correction (https://github.com/SantanderMetGroup/downscaleR/wiki) in R.

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	Linear scaling	Variance scaling	Quantile mapping	Trend-preserving quantile-mapping
Description	Simple method that only adjusts for mean bias	A popular method that adjusts mean and variance bias	A method often used for precipitation as it preserves the distribution and can inform extreme values	A method endorsed by the ISIMIP project (www.isimip.org). It combines two steps: (1) linear scaling approach for the long-term trend and (2) quantile mapping approach for variability
Pros	Simple method	■ Simple method that many have previously used ■ Retains climate change signal	■ Considers entire distribution ■ Useful for changes in extreme values and where variability is important	Same as quantile mapping method but also preserving climate change signal
Cons	Only corrects for the mean	■ Variability follows that of observed ■ Restricted to range of observed anomalies	■ Climate change signal can be altered ■ Assumes correction increments are the same as in the current climate ■ Extreme values restricted to observed	■ As with other methods, variables corrected independently. Can lead to physical inconsistency ■ Many more steps involved
When to use it	■ Not often used on its own. See Trend-Preserving Quantile Mapping column ■ Unsuitable for extreme events such as floods	■ Often used for any variable at monthly to annual timescales ■ Unsuitable for extreme events such as floods	■ Often used for precipitation when considering hydrological applications	■ Often used in hydrological applications
UK examples	Lafon et al, (2013), Guillod et al, (2018)	Dutch example available from Leander and Buishand (2017)	Prudhomme et al, (2012), Lopez et al, (2009), Brown et al, (2009)	Hutchins et al, (2018) who used ISIMIP data (Hempel et al, 2013)
Formulae	For additive adjustments (e.g. for temperature): $X(t) = \overline{O_{base}} - \overline{X_{base}} + X_{fut}(t)$ For relative adjustments (e.g. for precipitation): $X(t) = \frac{\overline{O_{base}}}{\overline{X_{base}}} \bullet X_{fut}(t)$	$X(t) = \frac{\sigma_{Xfut}}{\sigma_{Xbase}} \bullet (O_{base}(t) - \overline{X_{base}}) + \overline{X}_{fut}$	$X(t) = F_O^{-1}\left(F_X\left(X_{fut}(t)\right)\right)$	$X(t) = C + X_{fut}(t) + \Delta\, \tilde{X}_{fut}(t)$ Step 1: $C = \overline{O}_{base} - \overline{X}_{base}$ Step 2: $\Delta\, \tilde{X}_{fut}(t) = \overline{B} \bullet \Delta\, X_{fut}(t)$

where X is the bias-corrected model data, O are observations, subscripts refer to baseline and future periods, t is time, σ is the variance, F is the cumulative distribution function mapping modelled data to observations, C is the long term trend, $\Delta\tilde{x}$ is the anomaly, B is the slope of the quantile mapping curve

Table 1. Characteristics and UK examples of four bias-correction methods that could be used for UKCP18 (based on Gohar et al, 2017).

References

Brissette, FP., Khalili, M., and Leconte, R., (2007). Efficient stochastic generation of multi-site synthetic precipitation data, Journal of Hydrology 345(3-4):121-133, DOI: 10.1016/j.jhydrol.2007.06.035.

Brown, S., Boorman, P., Mcdonald, R., and Murphy, J., (2009). Supplement to: Interpretation for use of surface wind speed projections from the 11-member Met Office Regional Climate Model ensemble, UKCP09 technical note, Met Office, December. OPEN ACCESS.

Christierson, BV., Vidal, J-P., and Wade, SD., (2012). Using UKCP09 probabilistic climate information for UK water resource planning, Journal of Hydrology, 424–425: 48-67.

Ehret, U., Zehe, E., Wulfmeyer, V., Warrach-Sagi, K., and Liebert, J., (2012). Should we apply bias correction to global and regional climate model data? Hydrol. Earth Syst. Sci., 16: 3391–3404. doi:10.5194/hess-16-3391-2012.

Fowler, H J., Blenkinsop, S., and Tebaldi, C., (2007). Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling, International Journal of Climatology, 27: 1547–1578.

Gohar, L K., Lowe, J A., and Bernie, D., (2017). The Impact of Bias Correction and Model Selection on Passing Temperature Thresholds, Journal of Geophyiscal Research: Atmospheres Atmospheres, 122: 12 045-12061. https://doi.org/10.1002/2017JD026797

Harpham, C., and Wilby, RL., (2005). Multi-site downscaling of heavy daily precipitation occurrence and amounts, Journal of Hydrology 312(1): 235-255. DOI: 10.1016/j.jhydrol.2005.02.020.

Hempel, S., Frieler, K., Warszawski, L., Schewe, J., and Piontek, F., (2013). A trend-preserving bias-correction - the ISI-MIP approach, Earth System Dynamics, 4: 219 - 236, doi:10.5194/esd-4-219-2013.

Hutchins, M., Absesser, C., Prudhomme, C., Elliiott, JA., Bloomfield, JP., Mansourf, MM., and Hitta, OE., (2018). Combined impacts of future land-use and climate stressors on water resources and quality in groundwater and surface waterbodies of the upper Thames river basin, UK, Science of The Total Environment, 631–632: 962-986. https://doi.org/10.1016/j.scitotenv.2018.03.052

Lopez A, Fung F, New M, Watts G, Weston A and Wilby RL (2009), From climate model ensembles to climate change impacts and adaptation: A case study of water resource management in the South West of England, Water Resour. Res., 45, W08419, doi:10.1029/2008WR007499.

Maraun, D., (2016). Bias Correcting Climate Change Simulations - a Critical Review, Curr Clim Change Rep (2016) 2: 211. https://doi.org/10.1007/s40641-016-0050-x

Prudhomme, C., Dadson, S., Morris, D., Williamson, J., Goodsell., G, Crooks., S, Boelee, L., Davies, H., Buys, G., Lafon, T., and Watts, G., (2012). Future Flows Climate: an ensemble of 1-km climate change projections for hydrological application in Great Britain, Earth Syst. Sci. Data, 4: 143-148. https://doi.org/10.5194/essd-4-143-2012

Rajcak, J., Korlarski, S., Salzmann, N., and Schar, C., 2016. Robust climate scenarios for sites with sparse observations: a two-step bias-correction approach, International Journal of Climatology, 36(3): 1226-1243. https://doi.org/10.1002/joc.4417

Teutschbein, C., and Seibert, J., (2012). Bias-correction of regional climate model simulations for hydrological climate change impact studies: Review and evaluation of different methods. Journal of Hydrology, 456-457: 12–29. https://doi.org/10.1016/j.jhydrol.2012.05.052

Themeßl, MJ., Gobiet, A., and Heinrich, G., (2012). Empirical-statistical downscaling and error correction of regional climate models and its impact on the climate change signal. Climatic Change, 112(2), 449–468. https://doi.org/10.1007/s10564-011-0224-4

Themeßl, MJ., Gobiet, A., and Leuprecht, A., (2011). Empirical-statistical downscaling and error correction of daily precipitation from regional climate models. International Journal of Climatology, 31(10), 1530–1544. https://doi.org/10.1002/joc.2168

Watanabe, S., Kanae, S., Seto, S., Yeh, PJF., Hirabayashi, Y., and Oki, T., (2012). Intercomparison of bias correction methods for monthly temperature and precipitation simulated by multiple climate models, Journal of Geophysical Research, 117, D23114. https://doi.org/10.1029/2012JD018192

Wilby, RL., and Fowler, HJ., (2011), Regional Climate Downscaling, Modelling the Impact of Climate Change on Water Resources, Ed. F. Fung. A. Lopez and M. New, Wiley-Blackwell, 34-85. ISBN: 978-1-405-19671-0.