Supporting information for Grid-to-Grid model estimates of monthly mean flow and soil moisture for Great Britain: weather@home2 (climate model) driving data [MaRIUS-G2G-WAH2-monthly]

Bell VA, Rudd AC, Kay AL and Davies HN (2018). Grid-to-Grid model estimates of monthly mean flow and soil moisture for Great Britain: weather@home2 (climate model) driving data [MaRIUS-G2G-WAH2-monthly]. NERC Environmental Information Data Centre.
https://catalogue.ceh.ac.uk/documents/3b90962e-6fc8-4251-853e-b9683e37f790

Brief summary of the dataset

MaRIUS (Managing the Risks, Impacts and Uncertainties of drought and water Scarcity) was a UK NERC-funded research project (2014–2017) which developed a risk-based approach to drought and water scarcity (http://www.mariusdroughtproject.org/).

The MaRIUS-G2G-WAH2-monthly dataset provides Grid-to-Grid (G2G) model estimates of monthly mean hydrological variables on a 1km x 1km grid across Great Britain. The variables provided are

- Flow (m^3s^{-1}),
- Soil moisture (mm water/m soil).

Both variables are monthly means of daily (midnight to midnight) values, and are provided for historical (1900–2006), near-future (2020–2049) and far-future (2070–2099) periods.

To aid interpretation, two additional spatial datasets are provided:

- Digitally-derived catchment areas on a 1km x 1km grid,
- Estimated locations of flow gauging stations on a 1km x 1km grid and as a csv file.

The meteorological data used to drive the G2G model are from the MaRIUS weather@home2 (WAH2) regional climate model (RCM) dataset. This dataset provides multiple simulations (ensembles) of historical and projected future climates, and has allowed construction of matching sets of historical and projected future hydrological simulations.

Hydrological model – Grid-to-Grid (G2G)

The G2G is a national-scale hydrological model for Great Britain that runs on a 1km x 1km grid (aligned with the GB national grid), at a 15-minute time-step, and is parameterised using digital datasets (e.g. soil types, land-cover) (Bell et al. 2009). The effect of urban and suburban land-cover on runoff and downstream flows is accounted for in the model. G2G has been shown to perform well for a wide range of catchments across Britain (Bell et al. 2009), particularly those with more natural flow regimes as it currently does not include the effect of artificial influences such as abstractions and discharges on river flows. It has recently been shown to perform well specifically for low flows and for drought identification (Rudd et al. 2017). The G2G generally uses spatial datasets in preference to parameter identification via calibration, and where model parameters are required (such as the kinematic wave speeds used in lateral routing) nationally-applicable values are used. Thus calibration has not been used to identify separate model parameters for individual catchments.

G2G requires input time-series of precipitation and potential evaporation (PE). The optional snow module (Bell et al. 2016) is not used here, thus precipitation input to G2G is assumed to be rain. Although this needs to be borne in mind, its effect on drought is likely to be limited.

G2G simulations are produced for 100-member ensembles covering four periods, corresponding to available WAH2 climate simulations:

- Historical Baseline (HISTBS: 1900–2006)
- Baseline (BS: 1975–2004)
- Near-Future (NF: 2020–2049)
- Far-Future (FF: 2070–2099)

} 100 G2G simulations are available for each period

Note that the Baseline period (BS), against which the Near-Future (NF) and Far-Future (FF) periods should be compared, is a 30-year subset of the longer Historical Baseline (HISTBS) period. For the first two years of the HISTBS, NF and FF simulations the G2G was being "spun up", thus flow and soil moisture estimates from the first two years should be ignored in analyses, or used only for follow-on model spin-up. Drought-focussed analyses of the G2G hydrological simulations are provided by Kay et al. (2018) and Rudd et al. (in prep.).

G2G flow estimates are provided as monthly averages of daily mean natural flows (m^3s^{-1}). G2G soil moisture estimates are provided as monthly averages of daily mean soil moisture (mm water/m soil). The latter can also be interpreted as 1000 θ, where θ has units of m water/m soil ($0 \leq \theta \leq 1$). The G2G model assumes that soil properties, including soil depth, vary spatially across Britain. Soil depth can vary from a few centimetres to several metres, and G2G model soil moisture estimates should be interpreted as depth-integrated values for the whole soil-column. Both flow and soil moisture estimates are provided for every non-sea 1km x 1km grid box, and flows are provided for every 1km land grid box whether there is a river located in the grid box or not.

G2G model input data

The meteorological variables used by G2G are precipitation and PE from the MaRIUS WAH2 RCM dataset (http://catalogue.ceda.ac.uk/uuid/0cea8d7aca57427fae92241348ae9b03). The WAH2 system uses volunteer computing time to do large numbers of runs of the HadRM3P RCM nested in the HadAM3P atmospheric global climate model (Guillod et al. 2018). Data are available for the historical and future periods listed above. Five alternative sets of NF and FF ensembles were produced, with varying SST warming patterns and magnitudes; only the NF and FF sets based on the median patterns and warming are used here. The future periods use the RCP8.5 emissions scenario.

A simple bias-correction scheme, based on monthly multiplicative factors, was applied to precipitation (Guillod et al. 2018). PE was derived from other WAH2 meteorological variables (Guillod et al. 2018) using the Penman-Monteith scheme (Monteith 1965).

- For the historical baseline periods, the PE calculation uses monthly stomatal resistance (r_s) values from MORECS (Hough and Jones 1997).
- For the future periods two alternative versions of PE are available: one using the same r_s values as the historical periods, and one using values adjusted to allow for closure of stomata under increased carbon dioxide concentrations. The datasets provided here only use the adjusted r_s PE. The low flow analysis of Kay et al. (2018) found that using a PE calculation that accounts for changes in stomatal resistance moderates the projected future decreases in low flows.
- Unlike precipitation, PE is not bias-corrected (see Guillod et al. (2018) for more details).

For use by G2G, the WAH2 precipitation and PE data are re-projected from the 0.22° (~25km) rotated lat-lon RCM grid to the 1km x 1km G2G grid. Following re-projection, spatially distributed weights based on standard average annual rainfall patterns are used to provide a non-uniform distribution of precipitation within each RCM box (Bell et al. 2007). Note that the WAH2 RCM assumes 360-day years (twelve 30-day months).

The spatial data, such as topography and soil data, used to configure G2G are as in Bell et al. (2009).

How to use the MaRIUS-G2G-WAH2-monthly dataset

- G2G river flow and soil moisture estimates for the baseline time slices (HISTBS and BS) can be compared to estimates from G2G driven by observational input data (e.g. from MaRIUS-G2G-Oudin-monthly; https://catalogue.ceh.ac.uk/documents/f52f012d-9f2e-42cc-b628-9cdea4fa3ba0), or to observed river flow (for example from the National River Flow Archive, NRFA; http://nrfa.ceh.ac.uk/) and soil moisture. However, comparisons in either case should only be made statistically, not by

time-series equivalence. For example, WAH2 BS river flows for 1976 will not directly resemble observed reality in 1976; only statistics over long (multi-decadal) periods should be compared. Comparison of MaRIUS-G2G-WAH2-monthly simulations to an observation-based G2G run will indicate how biases in the WAH2 data affect the results for the baseline periods; comparison to observational data themselves will be additionally affected by the accuracy of the G2G model simulations.

- G2G flow and soil moisture estimates for future time slices (NF and FF) can be compared to the Baseline (BS) time slice estimates, NOT to observed time series or G2G simulations with inputs of observed precipitation and PE.
- Results from impacts models (e.g. economic, ecological, agricultural) based on G2G river flow and soil moisture estimates for future time slices (NF and FF) should be compared to those from the Baseline (BS) time slice, NOT to observed "real world" impacts.
- Each of the 100 historical (HISTBS and BS) and future (NF and FF) ensemble members are plausible realisations of the climate of these periods, and analyses of projected future changes should look at differences between historical and future statistical distributions, rather than between individual ensemble members.
- Although each of the historical (HISTBS and BS) and future (NF and FF) ensemble members is numbered from 1 to 100, historical and future ensemble members with the same ensemble number bear no relation to each other and should not be directly compared. Thus flows from BS1 (Baseline ensemble member 1) should not be directly compared to NF1 (Near-Future ensemble member 1), any more than they should to NF2 or NF35.
- An additional dataset of flow gauging station locations identifies a 1km x 1km G2G grid cell chosen to best represent the location of each NRFA gauging station. The most appropriate G2G grid cell is identified as the one that is closest in terms of geographical location and catchment area, and additional checks have been undertaken to ensure that the G2G flows are for the correct river tributary, and not for a nearby river with a similar catchment area. Despite these checks, in some cases the derived catchment area draining to the 1km x 1km river grid cell will be different to the "observed" NRFA catchment area. This problem can particularly affect small catchments for which discretisation to a 1km x 1km grid leads to proportionally larger errors.

Format of the MaRIUS-G2G-WAH2-monthly gridded dataset

MaRIUS-G2G-WAH2-monthly 1km x 1km gridded data are stored in NetCDF4 format, following CEH gridded dataset conventions. The dataset is structured as one NetCDF file for each period and each ensemble member. The file naming convention is as follows:

Period	Name of NetCDF file	Years available
Historical Baseline	G2G_WAH_var_HISTBS*.nc	1900–2006 (1900 and 1901 are spin-up)
Baseline	G2G_WAH_var_BS*.nc	1975–2004
Near-Future	G2G_WAH_var_NF*.nc	2020–2049 (2020 and 2021 are spin-up)
Far-Future	G2G_WAH_var_FF*.nc	2070–2099 (2070 and 2071 are spin-up)

* is the ensemble member reference number (1 to 100), var is either "flow" or "soil"

Data are provided for a 700km × 1000km spatial domain on the GB National Grid from lower left corner (0,0) to top right (700000,1000000) (in metres). Values for each 1km x 1km grid box represent the centre of the grid box (i.e. the lower left corner pixel is (500,500)). G2G values are only provided for land grid boxes and set to missing (-9999) for points in the sea. The data have 30-day months due to the "360_day" calendar of the climate model data. The time stamp in the NetCDF is "days since 1900-01-01" and the monthly values are nominally assigned to the first day of the month. Flow, soil-moisture and time are referenced in the files as "flow", "soil" and "time".

To enable identification of NRFA gauging stations on the 1km x 1km G2G grid, two further datasets are provided:

1. Digitally-derived catchment area (km^2) draining to every 1km x 1km grid box (MaRIUS_G2G_CatchmentAreaGrid.nc). This is derived on a 1km resolution across Britain (Davies and Bell, 2009).
2. Estimated locations of river flow gauging stations on the 1km x 1km grid and as a csv file.

i. The 1km x 1km grid (MaRIUS_G2G_NRFAStationIDGrid.nc) provides the best locations corresponding to 1285 gauging stations, referenced by their integer NRFA station number (http://nrfa.ceh.ac.uk/), including the 260 stations for which daily river flow time-series are also provided (https://catalogue.ceh.ac.uk/documents/f6cac471-7d92-4e6d-be8a-9f7887143058). At these locations, the G2G flow estimates can be compared to observed river flows. The (integer) file format sets ID to 0 for land, -9999 for sea, and the NRFA station number at gauging station locations.
ii. A file (MaRIUS_NRFAStationIDs.csv) provides the station IDs of the 1285 NRFA gauging stations for which a corresponding 1km x 1km G2G grid box can be selected.

Figure 1 presents example 1km x 1km G2G flow and soil moisture output over Britain, and shows NRFA gauging station locations and the catchment area 1km x 1km grid over Wales.

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References

Bell VA, Kay AL, Jones RG, Moore RJ (2007). Development of a high resolution grid-based river flow model for use with regional climate model output. Hydrol. Earth Syst. Sci., 11(1), 532–549.

Bell VA, Kay AL, Jones RG et al. (2009). Use of soil data in a grid-based hydrological model to estimate spatial variation in changing flood risk across the UK. J. Hydrol., 377(3–4), 335–350.

Bell VA, Kay AL, Davies HN, Jones RG (2016). An assessment of the possible impacts of climate change on snow and peak river flows across Britain. Clim. Chang., 136(3), 539–553.

Davies HN, Bell VA. (2009). Assessment of methods for extracting low-resolution river networks from high-resolution digital data. Hydrol. Sci. J, 54(1), 17-28.

Guillod BP, Jones RG, Dadson SJ et al. (2018). A large set of potential past, present and future hydro-meteorological time series for the UK. Hydrol. Earth Syst. Sci., 22(1), 611–634.

Hough M, Jones RJA (1997). The United Kingdom Meteorological Office rainfall and evaporation calculation system: MORECS version 2.0 – an overview. Hydrol. Earth Syst. Sci., 1(2), 227–239.

Kay AL, Bell VA, Guillod BP et al. (2018). National-scale analysis of low flow frequency: historical trends and potential future changes. Climatic Change, doi:10.1007/s10584-018-2145-y

Monteith JL (1965). Evaporation and environment. Symp. Soc. Exp. Biol., 19, 205–234.

Rudd AC, Bell VA, Kay AL (2017). National-scale analysis of simulated hydrological droughts (1891-2015) Journal of Hydrology, 550 (2017) 368–385.

Rudd AC, Kay AL, Bell VA (in prep.). National-scale analysis of future hydrological droughts: potential changes in drought characteristics.

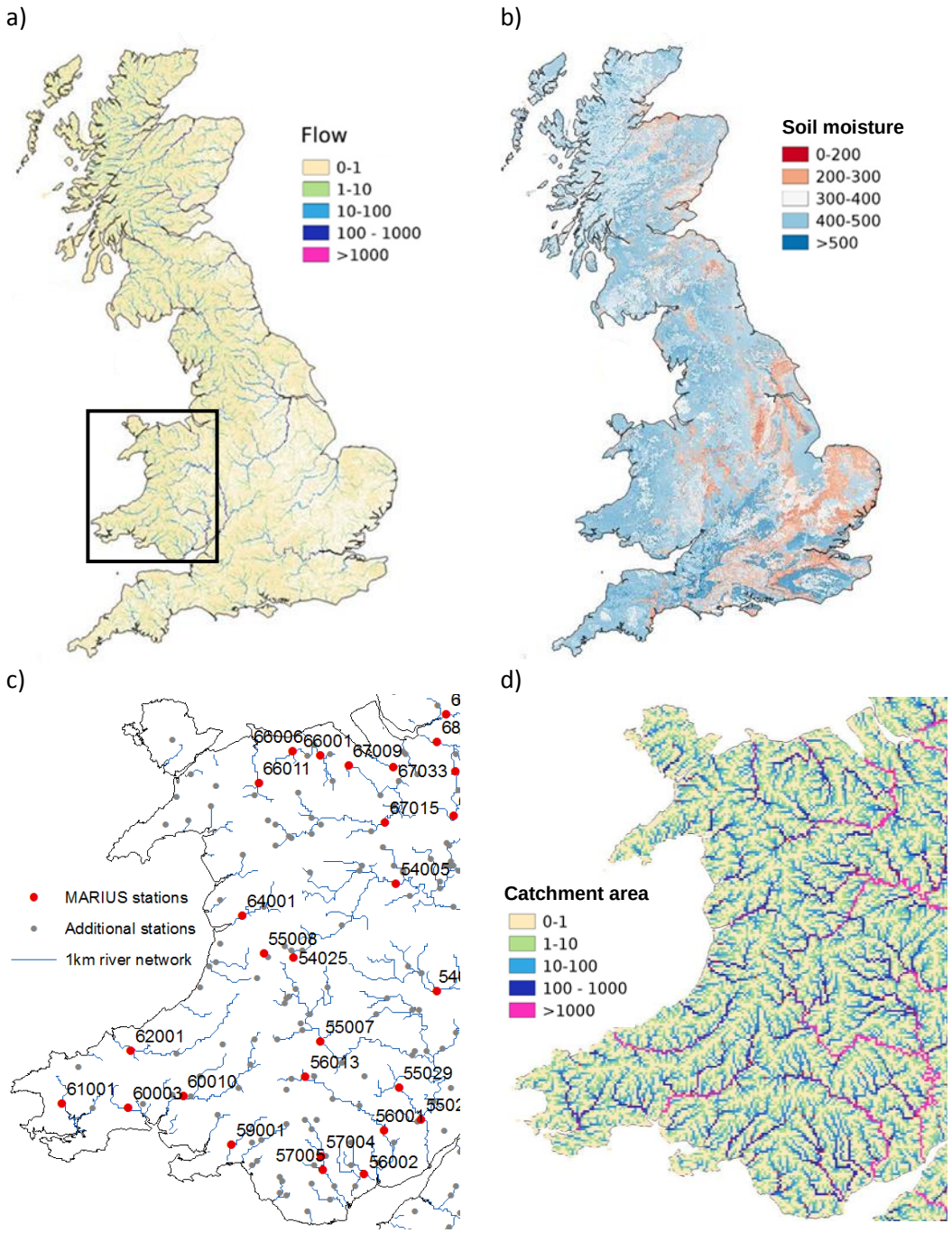

Figure 1. Example grids of a) flow (m^3s^{-1}) and b) soil moisture (mm water / m soil) for Great Britain; and c) gauge names (for MaRIUS stations) and locations and d) catchment area (km^2) for Wales. Black rectangle in a) highlights the location of Wales.