A global map of mean annual runoff based on discharge observations from large catchments

Hylke E. Beck (hylke.beck@gmail.com)

January 15, 2016

Abstract

This report describes the development of a global map of mean annual runoff (MAR) based on discharge observations from 1651 large catchments (10 003 to 4 691 000 km^2) around the globe. The map was produced based on the assumption that the mean annual volumetric discharge difference between a station and its upstream neighbor(s) represents the MAR generated in the interstation region. The produced map represents a unique spatial estimate of MAR at a global scale useful for, among other things, the spatial evaluation of macro-scale hydrological models. Compared to an equivalent map developed at the University of New Hampshire, the new map (i) is based on substantially more catchments (1651 versus 663), (ii) has a higher resolution ($\sim$0.04° versus 0.5°), (iii) covers a larger portion of the hydrologically-active, ice-free land surface (58.9 % versus 56.5 %), and (iv) agrees considerably better with a completely independent MAR map based on small catchments.

1 Introduction

Discharge is one of the major components of the hydrologic balance that, together with precipitation, can be directly measured with relative ease. Accordingly, discharge observations are frequently used to ensure that hydrological models accurately partition precipitation into runoff, evaporation, and storage. This report describes the development of a global, observation-based map of mean annual runoff (MAR) which can be used, among other things, to spatially evaluate macro-scale hydrological models. This new map can be considered an updated version of the one produced by the University of New Hampshire (UNH; Fekete et al., 2002).

2 Data and methodology

The discharge observations used to produce the MAR map originate from four sources. First, we downloaded observed discharge for 9322 USA stations part of the Geospatial Attributes of Gages for Evaluating Streamflow (GAGES)-II database (Falcone et al., 2010) from the U.S. Geological Survey (USGS) National Water Information System

(NWIS; http://waterdata.usgs.gov/nwis). Second, mean annual discharge values for 3843 stations were taken from the Global Runoff Data Centre (GRDC) website (http://grdc.bafg.de; GRDC, 2011). Third, observed discharge for 841 stations around the globe were requested from the GRDC. Fourth and last, we used observed discharge for 321 Australian stations from the compilation of Peel et al. (2000). Corresponding catchment boundaries were provided by the data suppliers. This resulted in an initial dataset comprising 14 327 stations, of which only those with record length > 5 yr (not necessarily consecutive) and catchment area > 10 000 km^2 were retained. From the remaining 2155 stations, those with interstation region (defined as the catchment of the station excluding the subcatchments of its upstream neighbors) < 5000 km^2 were excluded to avoid artifacts in the MAR map due to systematic biases in the discharge observations. The final dataset consisted of 1651 stations with corresponding catchment areas ranging in size from 10 003 to 4 691 000 km^2 (median 31 468 km^2) and interstation areas ranging in size from 5026 to 1 736 000 km^2 (median 16 745 km^2). Fig. 1 shows the locations of the stations and the corresponding interstation regions.

The global MAR map (~0.04° resolution) was produced based on the assumption that the mean annual volumetric discharge difference between a station and its upstream neighbor(s) represents the MAR generated in the interstation region. The same approach was used by Arnell (1995) and Fekete et al. (2002) to produce MAR maps for Europe and the globe, respectively. Specifically, MAR was computed following:

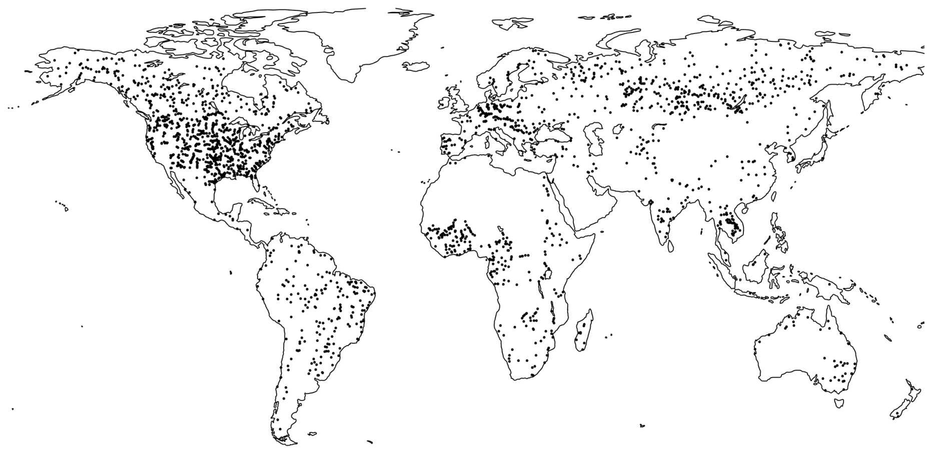
$$\mathrm{MAR}_x = \left(\frac{365.25 \times 24 \times 3600}{1000}\right) \times \left(\frac{Q_x - \sum_{i=1}^{k} Q_i}{A_x - \sum_{i=1}^{k} A_i}\right), \quad (1)$$

where MAR_x is the mean annual (specific) runoff (mm yr^{-1}) for the interstation region of station x, Q is the observed mean annual volumetric discharge (m^3 s^{-1}), A is the catchment area (km^2), and $i = 1, 2, ..., k$ denote the upstream stations neighboring station x. To reduce potential biases due to seasonal gaps in the observed discharge record, for each station Q was computed only if at least five annual mean values were available. Annual mean values were computed only if at least ten monthly mean values were available, while monthly mean values were computed only if at least twenty days with flow data were available.

3 Results and discussion

Fig. 2a shows the global MAR map produced in this study. The map should be useful for various large-scale hydrological applications, notably the spatial evaluation of large-scale hydrological models. However, there are some caveats worth mentioning. First, since the discharge observations are affected by water withdrawals (Döll et al., 2003) and transmission losses (Lange, 2005), the MAR estimates may be underestimated and may even become negative when the observed discharge decreases downstream. Second, channel diversions will cause neighboring interstation regions to respectively overestimate and underestimate MAR. Third, the map is less reliable in highly heterogeneous regions due to the use of spatially-uniform values for the interstation regions.

(a) Stations



(b) Interstation regions in arbitrary colors

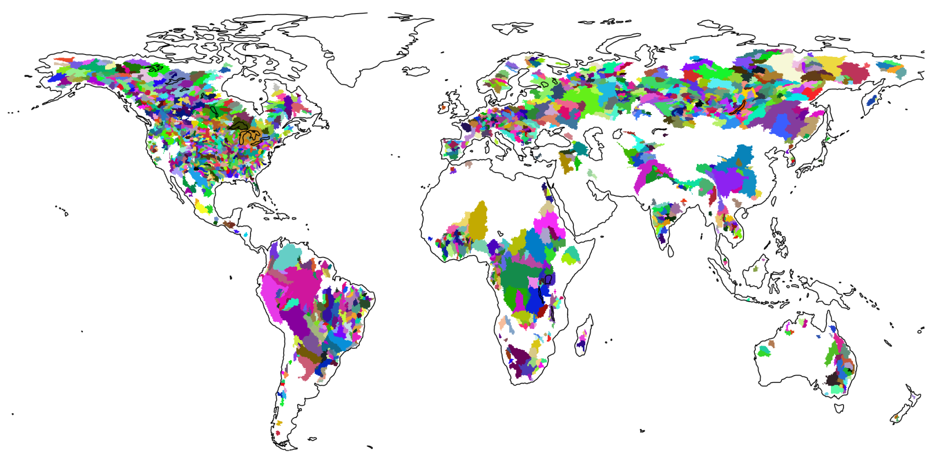


Figure 1: Global maps showing (a) the stations and (b) the corresponding interstation regions used to derive the global MAR map ($n = 1651$).

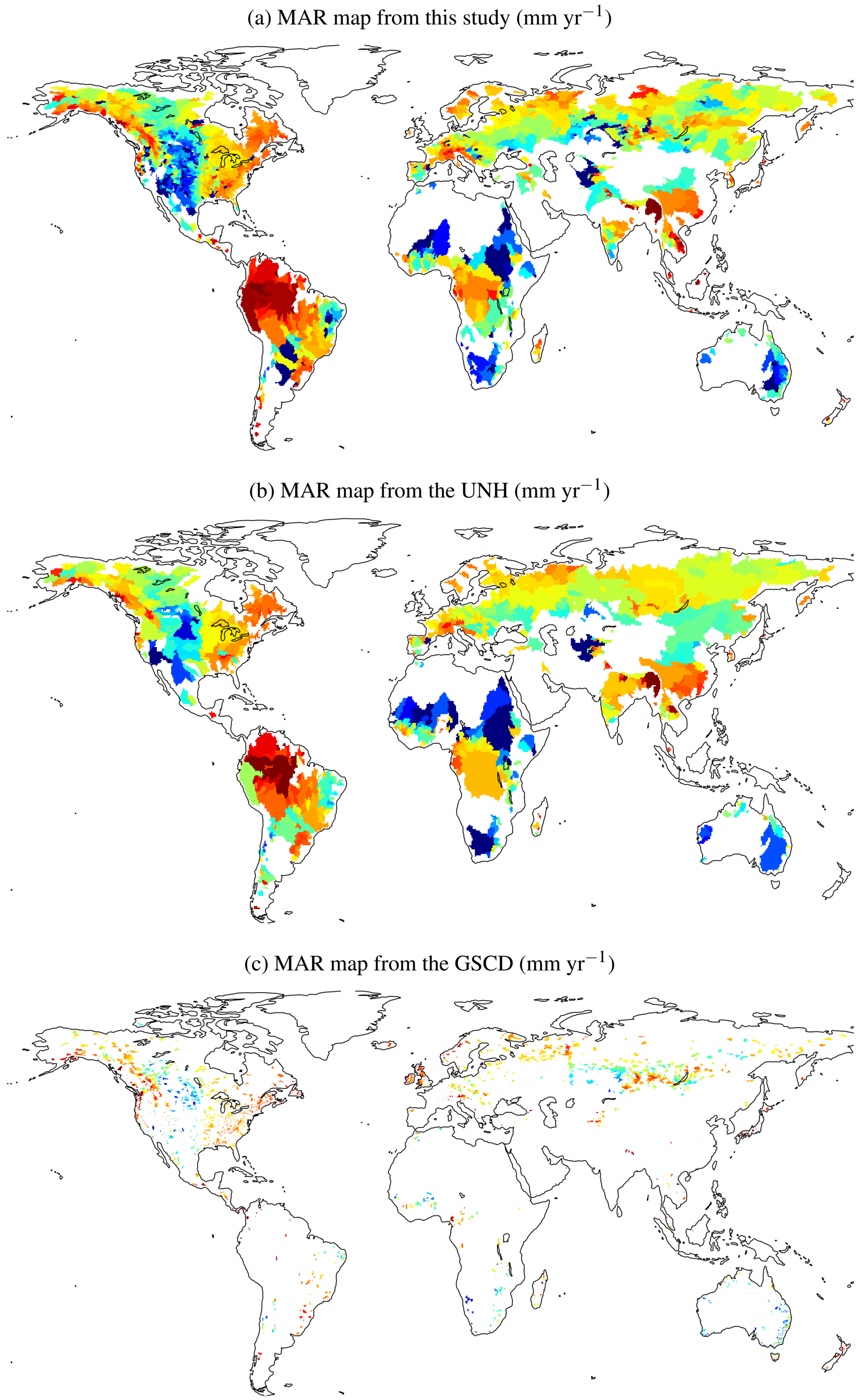


Figure 2: Global, observation-based MAR maps from (a) this study, (b) the UNH, and (c) the GSCD.

Fig. 2b shows the University of New Hampshire (UNH) GRDC Composite Runoff Fields dataset (version 1.0; http://www.grdc.sr.unh.edu; Fekete et al., 2002) MAR map which is similar to the one produced here. Although monthly data and data for ungauged regions are provided along with the UNH MAR map, these are model-based and therefore not of interest here. Their map has a 0.5° resolution and was based on discharge observations from 663 catchments ($>$ 10 000 km^2) across the globe. Our map has a slightly higher spatial coverage—considering only the hydrologically-active, ice-free land surface[1] of the earth (33.5×10^{12} km^2), our map has a coverage of 58.9 % versus 56.5 % for the UNH map. The markedly lower MAR value for the UNH map in the western part of the Amazon Basin is probably due to the use of incorrect observed discharge data for GRDC station 3623100.

Fig. 2c shows the Global Streamflow Characteristics Dataset (GSCD; version 1.9; http://water.jrc.ec.europa.eu/GSCD/; Beck et al., 2013; Beck et al., 2015) observation-based MAR map (0.125° resolution) which was used to evaluate the newly produced and UNH maps (Figs. 2a and 2b, respectively). The GSCD MAR map was based on discharge observations from 4072 catchments smaller than 10 000 km^2, hence is completely independent from both the map produced here and the UNH map. To allow quantitative comparisons, the three maps were resampled to a common 1° geographical grid and square-root transformed to give more weight to arid regions. The comparisons revealed that the newly derived map agreed considerably better with the GSCD map than did the UNH map—considering only the regions where all three maps have data, the mean absolute difference was 2.26 for the newly derived map versus 3.21 for the UNH map. These values are unitless due to the applied root square transformation.

4 File details

The dataset consists of the MAR map (global_runoff_map.tif), the interstation region identifier map (ID1.tif), and the stations shapefile (stations.shp). The stations shapefile has fields ID1 (interstation region identifier), ID2 (data provider identifier), Area1 (catchment area in km^2), and Area2 (interstation region area in km^2). The maps are provided in a ∼0.04° (∼5 km at the equator) global geographic grid (WGS 84) in GeoTIFF format.

5 License agreement

By using the dataset you agree to cite the dataset's Digital Object Identifier (10.5281/zenodo.44782) in publications that make use of the map. The dataset is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License. To view a copy of this license, visit http://creativecommons.org/licenses/by-nc-sa/3.0/deed.en_US.

[1]The ice-covered portion of the land surface was identified by climate type EF (polar, frost; using the Köppen-Geiger climate type map of Peel et al., 2007) and the hydrologically-active portion by aridity index (AI) less than five. AI is defined as the ratio of mean annual potential evaporation (PET) to precipitation (P). WorldClim data (Hijmans et al., 2005) were used for P and Consultative Group on International Agricultural Research (CGIAR) data (Trabucco et al., 2008) for PET.

Acknowledgements

The GRDC and USGS are thanked for providing the flow data.

References

Arnell, N. W. (1995). Grid mapping of river discharge. *Journal of Hydrology 167*(1–4), 39–56.

Beck, H. E., A. I. J. M. van Dijk, and A. de Roo (2015). Global maps of streamflow characteristics based on observations from several thousand catchments. *Journal of Hydrometeorology 16*(4), 1478–1501.

Beck, H. E., A. I. J. M. van Dijk, D. G. Miralles, R. A. M. de Jeu, L. A. Bruijnzeel, T. R. McVicar, and J. Schellekens (2013). Global patterns in baseflow index and recession based on streamflow observations from 3394 catchments. *Water Resources Research 49*(12), 7843–7863.

Döll, P., F. Kaspar, and B. Lehner (2003). A global hydrological model for deriving water availability indicators: model tuning and validation. *Journal of Hydrology 270*(1), 105–134.

Falcone, J. A., D. M. Carlisle, D. M. Wolock, and M. R. Meador (2010). GAGES: A stream gage database for evaluating natural and altered flow conditions in the conterminous United States. *Ecology 91*(2), 621.

Fekete, B. M., C. J. Vörösmarty, and W. Grabs (2002). High-resolution fields of global runoff combining observed river discharge and simulated water balances. *Global Biogeochemical Cycles 16*(3), 15–1.

GRDC (2011). Long-term mean monthly discharges and annual characteristics of GRDC station. Technical report, Global Runoff Data Centre (GRDC), Federal Institute of Hydrology (BfG), Koblenz, Germany.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology 25*(15), 1965–1978.

Lange, J. (2005). Dynamics of transmission losses in a large arid stream channel. *Journal of Hydrology 306*(1–4), 112–126.

Peel, M. C., F. H. S. Chiew, A. W. Western, and T. A. McMahon (2000). Extension of unimpaired monthly streamflow data and regionalisation of parameter values to estimate streamflow in ungauged catchments. Report prepared for the Australian National Land and Water Resources Audit. Centre for Environmental Applied Hydrology, University of Melbourne, Australia.

Peel, M. C., B. L. Finlayson, and T. A. McMahon (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences 11*, 1633–1644.

Trabucco, A., R. J. Zomer, D. A. Bossio, O. van Straaten, and L. V. Verchot (2008). Climate change mitigation through afforestation/reforestation: A global analysis of hydrologic impacts with four case studies. *Agriculture, Ecosystems & Environment 126*(1), 81–97.