A Statistical Approach to Resolve Incompatibilities Between Measured Runoff Data and Daily Estimates of Spatially Averaged Rainfall

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1. Objectives

In the case of catchments covered by a single raingauge (i.e. a frequent case for medium and large- sized catchments in Greece), one approximates spatially averaged rainfall intensities using point rainfall measurements. Since the statistics of the two processes are quite different, one faces important problems when calibrating hydrological models and calculating annual water-budgets.

We develop an approach to adjust point rainfall measurements to better resemble the statistical structure of spatial rainfall averages. This is done by developing a statistical tool that:

- identifies and corrects incompatibilities between daily rainfall measurements and river discharges,
- accounts for the increase of wet days when passing from point rainfall measurements, I, to spatial rainfall averages, $\bar{I}$, (i.e. on average $P[\bar{I} > 0 | I = 0] > 0$), and
- allows for water budget corrections at an annual level.

2. Case study: Glafkos river basin

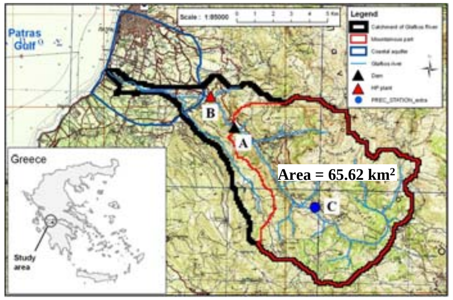

Figure 1: Rainfall measuring locations (daily resolution) at Glafkos river basin for the period 1st October 1975 – 30th September 1993. Daily river discharges are available at the location of the hydroelectric plant (B).

2.1 Rainfall-runoff incompatibilities at an annual level

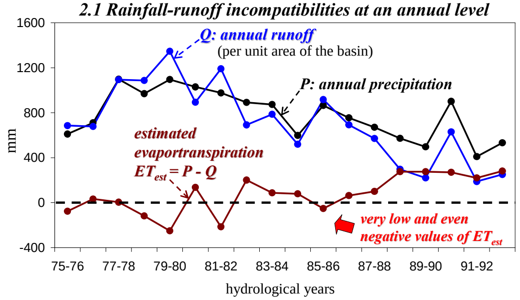

Figure 2: Annual precipitation (P) and river discharges (Q) per unit area of the basin at the location of the hydroelectric plant (B); see Figure 1.

2.2 Rainfall-runoff incompatibilities at a daily scale

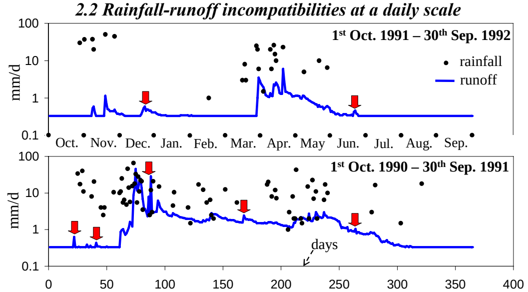

Figure 3: Measured precipitation depths and daily river discharges per unit area of the basin at the HP of Glafkos river basin for the period 1st Oct. 1990 – 30th Sep. 1992. The arrows indicate abrupt changes of the river discharge in the absence of rain.

3. Statistical framework

Step 1: Formulate a statistical test to identify *"wet"* days that appear as *"dry"* in the historical record of point rainfall measurements.

Linear reservoir model with zero inflow (i.e. no rain for dry days) ⇨ $r(t) = \dfrac{Q(t) - Q(t-1)}{Q(t)} = const. < 0$

river discharge on day t-1

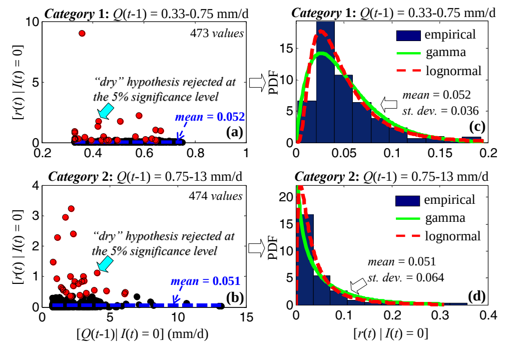

Figure 4: (a, b) Scatter plots of the empirical ratios $[r(t) > 0 | I(t) = 0]$, calculated using daily rainfall and discharge data for the period 1st Oct. 1975 – 30th Sep. 1993, and split into 2 equally populated categories with respect to the previous-day river discharge $Q(t$-1). (c, d) Empirical histograms of the ratios in (a) and (b) fitted by a gamma (solid lines) and lognormal (dashed lines) distribution models.

Step 2: Use *multifractal theory* to relate the probability of zero rainfall over a basin of area A, with that of zero rainfall at a point inside the basin; see Langousis and Kaleris (2012, manuscript in preparation).

$$\bar{P}_{0,s}(A) = a_s(A)\, P_{0,s} - b_s(A)$$

probability of zero rainfall over the basin

probability of zero rainfall at a point

$a_s(A)$, $b_s(A)$: parameters that depend on the area of the basin A and the structure of rainfall (convective vs stratiform) in different months s

⇨ When passing from *point rainfall measurements* to *spatial rainfall averages*, use results from Steps 1 and 2 to estimate the *number* of additional wet days and, also, identify their *probable location*.

Step 3: For those days, use a *lognormal* distribution model with parameters that depend on the *flow conditions* to simulate synthetic rainfall intensities.

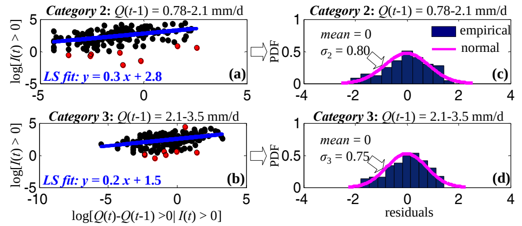

Figure 5: (a-b) Plots of logarithmically transformed daily rainfall intensities on wet days, $\log[I(t) > 0]$, as a function of the observed change of the river discharge $\log[Q(t)$-$Q(t$-1$) > 0]$, for 2 (out of 4) equally populated categories (i.e. 164 point each) of the previous-day river discharge $Q(t$-1). The analysis has been conducted using daily rainfall and discharge data for the same period as in Figure 4. Red dots correspond to outliers of the log-log linear regression at 5% significance level. (c-d) Empirical histograms of the residuals of the log-log linear regression in (a-b) fitted by a normal distribution model with zero mean.

Step 4: Resolve annual water imbalances (see Figure 2), using a constant multiplicative factor for rainfall, calculated at an inter-annual level.

$$C = \sum_{\text{all } j} Q_j \Big/ \left\{(1-\alpha)\sum_{\text{all } j} I_j\right\}$$

multiplicative correction factor for rainfall

river discharge, per unit area of the basin, on day j

semi-empirical estimate of the ratio between actual ET and annual rainfall depth. For Glafkos basin, $\alpha \approx 0.35$)

rainfall depth on day j, from Step 3

4. Results – Statistical validation

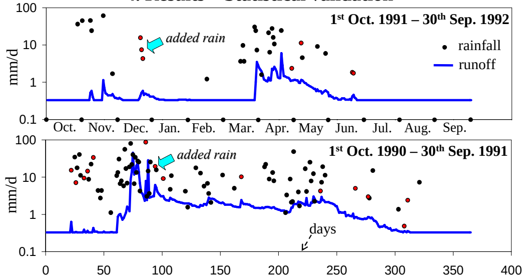

Figure 6: Same as Figure 3. Daily precipitation depths have been adjusted using the procedure described in Section 3.

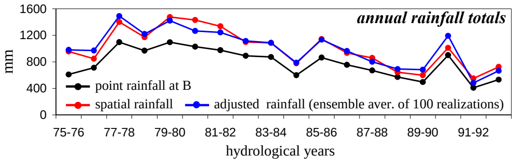

Figure 7: Annual totals for the measured and adjusted precipitation series using the procedure described in Session 3. Spatial rainfall averages (in red) have been calculated by combining point rainfall measurements from points A and C (see Figure 1) using the Thiessen polygons method.

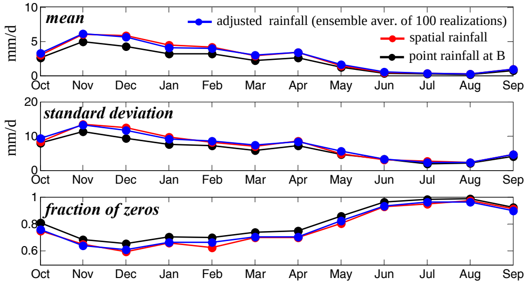

Figure 8: Seasonal statistics for the measured and adjusted precipitation series.

➡ ***The adjusted point rainfall series reproduce well the seasonal and annual statistics of spatial rainfall averages.***

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