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Return period for time-dependent processes

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Return period

- First introduced by *Fuller* (1914) who pioneered statistical flood frequency analysis in USA: it quantifies hydrologic events rareness (e.g. floods, draughts, etc.)

- Hypotheses commonly assumed in hydrology as necessary conditions for conventional frequency analysis
  1. Events arise from a **stationary** distribution
  2. Events are **independent** of one another

- Considerations
  - Dependence has been recognized to be the rule rather than the exception (e.g. *Hurst*, 1951; *Mandelbrot*, 1968)
  - Non-stationarity may be confused with dependence in time (e.g. *Montanari and Koutsoyiannis*, 2014)

Definitions and properties

- Traditional methods define return period as the mean of

  $T_W \Rightarrow$ the mean of the **waiting time** to the next event

  $T_N \Rightarrow$ the mean of the **interarrival time** between successive events

- Independent events: both definitions lead to the same formula

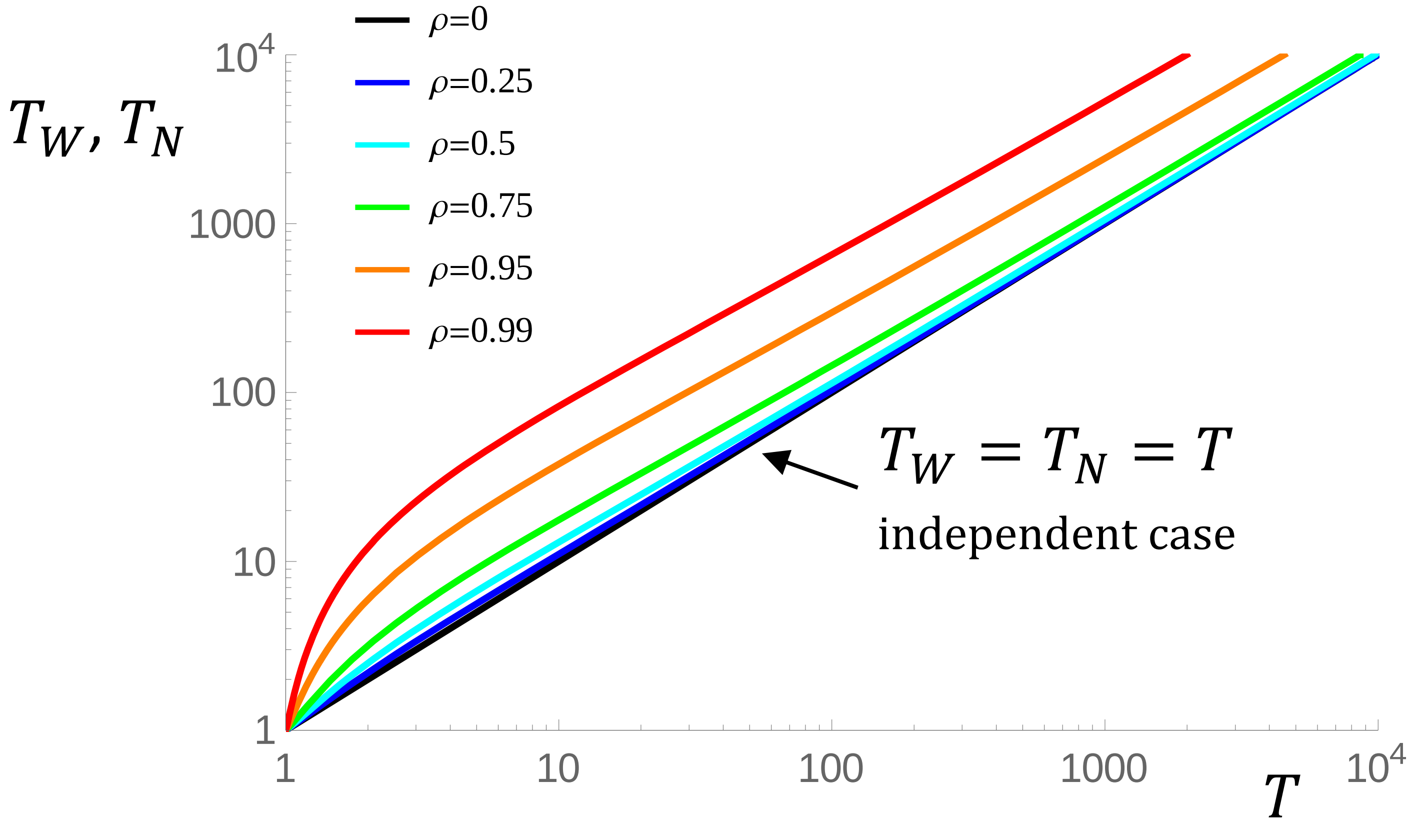
$$T = \frac{1}{1-p}$$

- Dependent events (*Volpi et al.,* 2015)
  1. Mean waiting time: T_W is affected by the autocorrelation structure of the process
  2. Mean interarrival time: $T_N = T$ whatever the time-dependence structure of the process Z_t is

Volpi, E., A. Fiori, S. Grimaldi, F. Lombardo, and D. Koutsoyiannis (2015), *One hundred years of return period: Strengths and limitations*, Water Resour. Res., 51, doi:10.1002/2015WR017820.

1. Mean waiting time, T_W

Z_t, two state Markov-dependent model, 2Mp
$\Pr(Z_t, Z_{t+1}) = \mathrm{N}_2(\mathbf{0}, \mathbf{1}; \rho)$
ρ, lag-1 correlation coefficient of the parent process

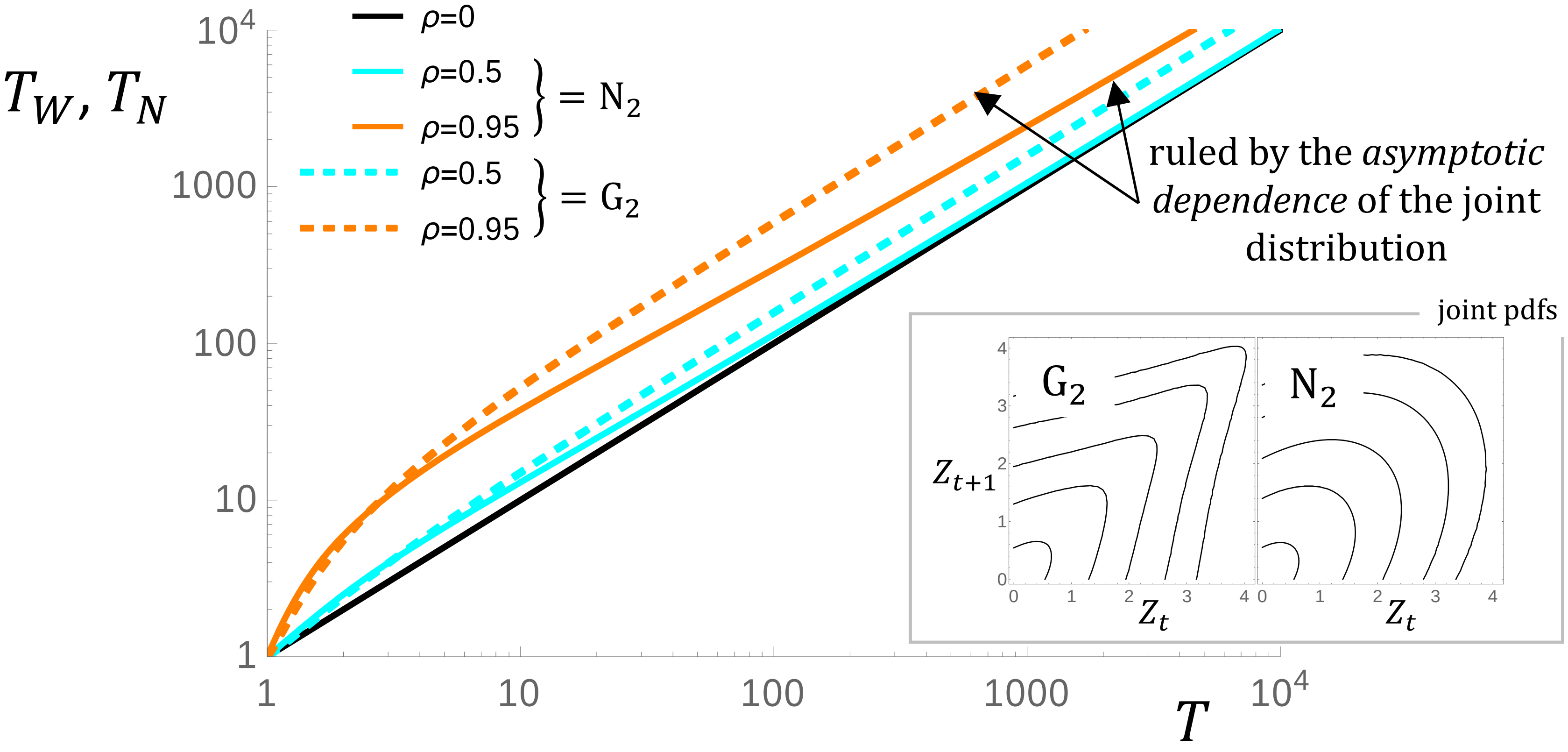


1. Mean waiting time, T_W

Z_t, two state Markov-dependent model, 2Mp

$\Pr(Z_t, Z_{t+1}) = \mathrm{G}_2(\mathbf{0}, \mathbf{1};\ \theta_\rho)$

ρ, lag-1 correlation coefficient of the parent process

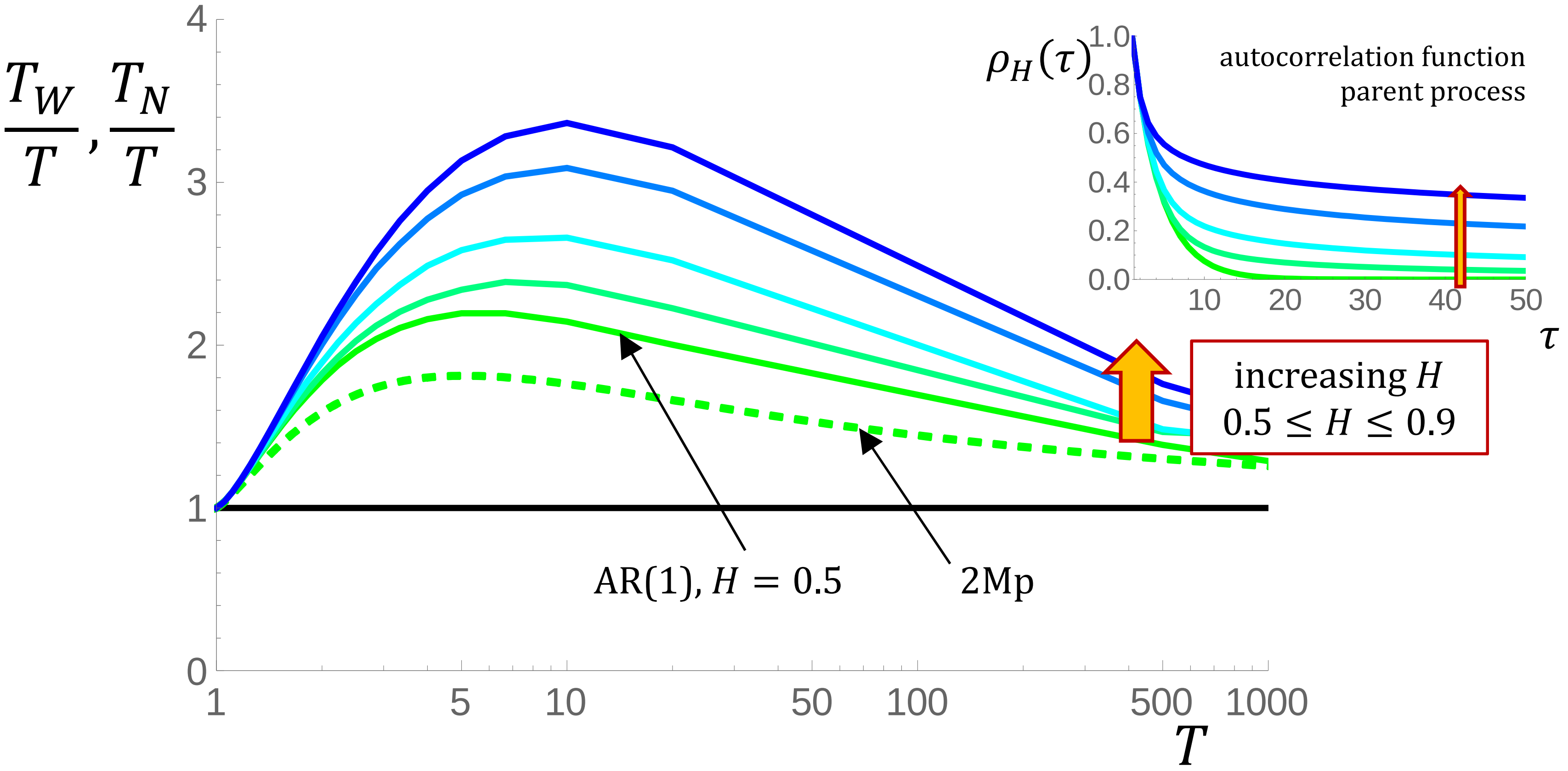


1. Mean waiting time, T_W

Z_t, fractionally integrated autoregressive process, FAR(1,H)

$\Pr(Z_t, .. Z_{t+\tau}) = \mathrm{N}_\tau(\mathbf{0}, \mathbf{1}; \rho_H(\tau))$

$\rho = 0.75$, lag-1 correlation coefficient of the parent process



Probability of failure

$T_N = T$ whatever the time-dependence structure of the process Z_t is

- The probability function $F_N(t)$ <u>is affected</u> by the autocorrelation structure of the process

- Probability of failure $R(L)$

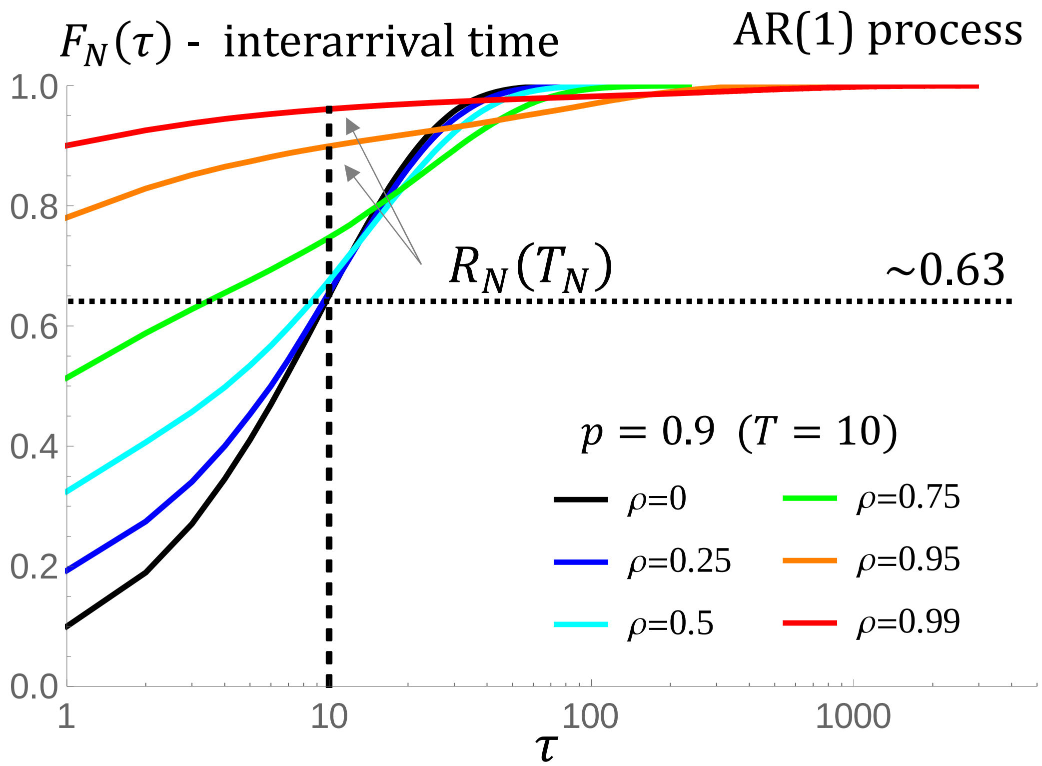
  $R(L) = \Pr\{N \leq L\} = F_N(L)$

  - L, design life of the structure/system

- Probability of failure in T, $R(T)$

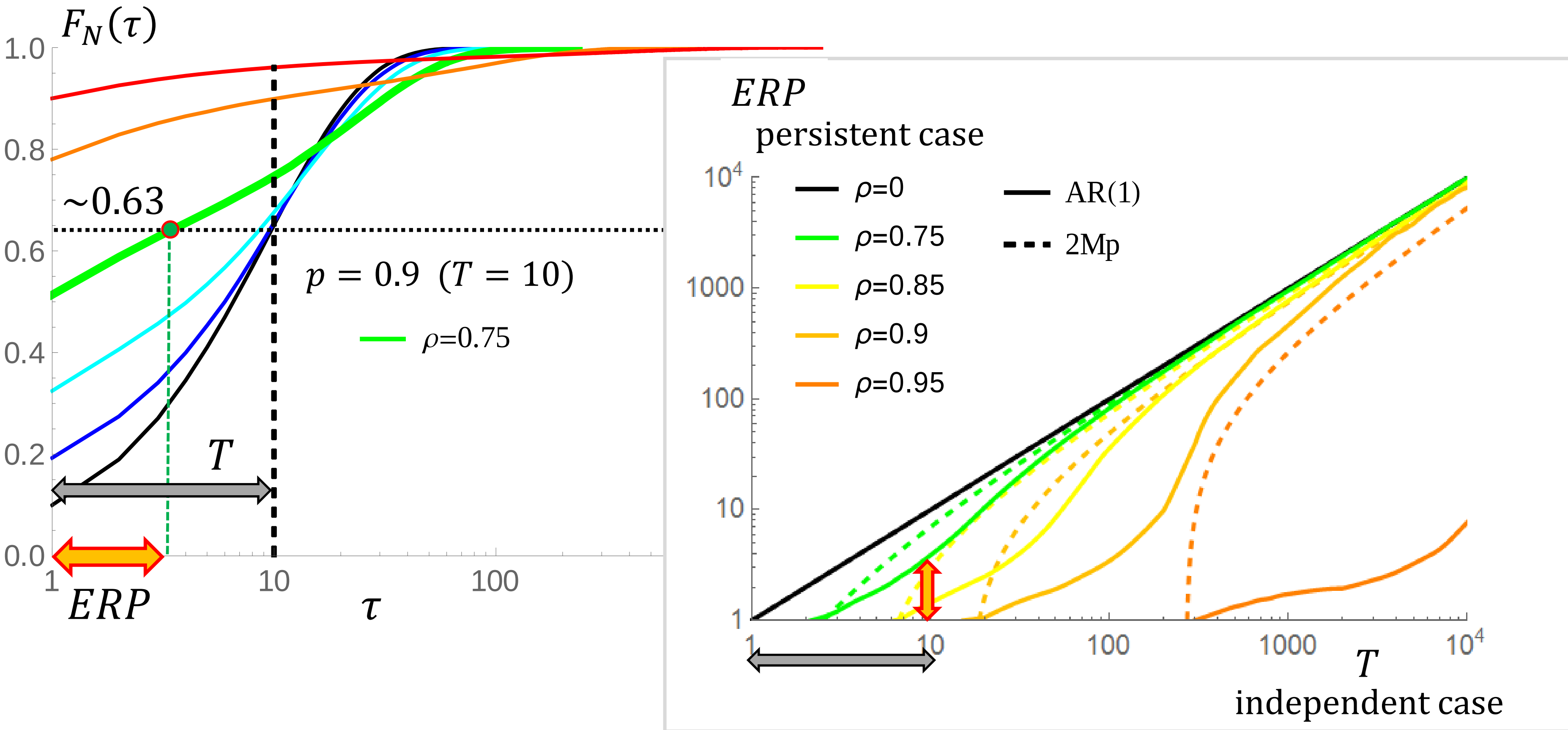
  $R(T) \sim 0.63$

  - for large T (indipendent case)



Equivalent Return Period (ERP)

- ERP: the period that would lead to the same probability of failure pertaining to a given return period T in the framework of classical statistics (independent case)



Conclusions

- Return period properties are generally ruled by the joint probability distribution in time and by the autocorrelation function of the parent process

- The return period based on the concept of waiting time, T_W effectively accounts for the correlation structure of the hydrological process

- The return period T_N (mean interarrival time) is not affected by the time-dependence structure of the process

- The corresponding probability of failure, $R_N(R_T)$, can be larger than that pertaining to the independent case

- We propose the Equivalent Return Period (ERP) for the time-dependent context

Main references

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