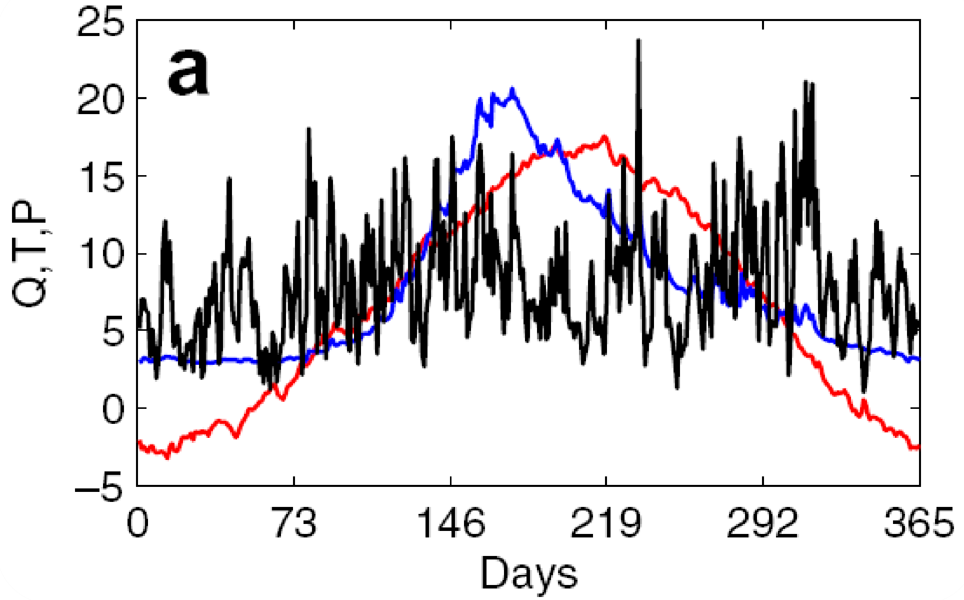
Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course



Lecture 6-1: Data analysis, tzpe of time series, determinism vs stochasticity

Prof. P. Perona
Platform of hydraulic constructions

Complexity of river basin systems

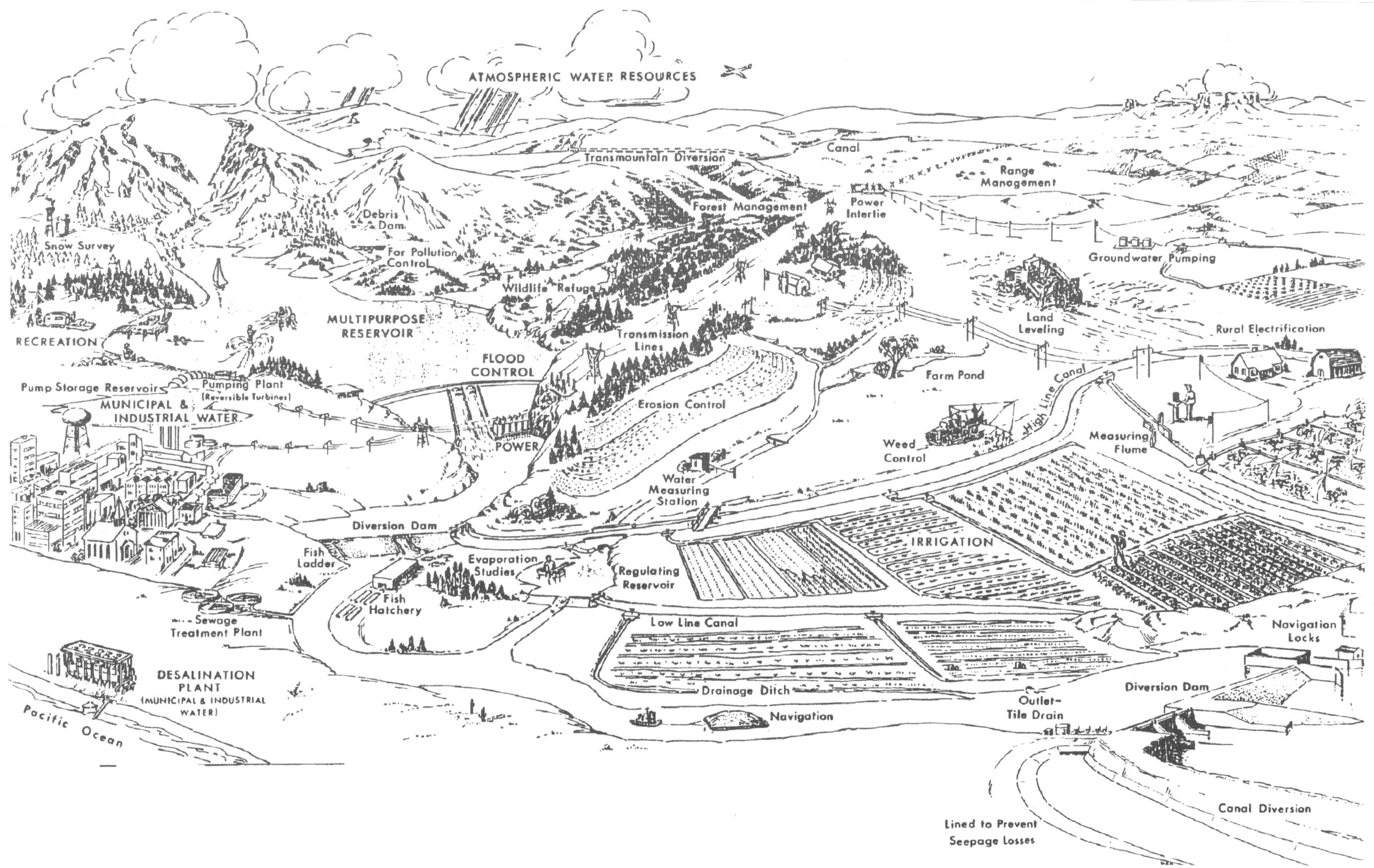
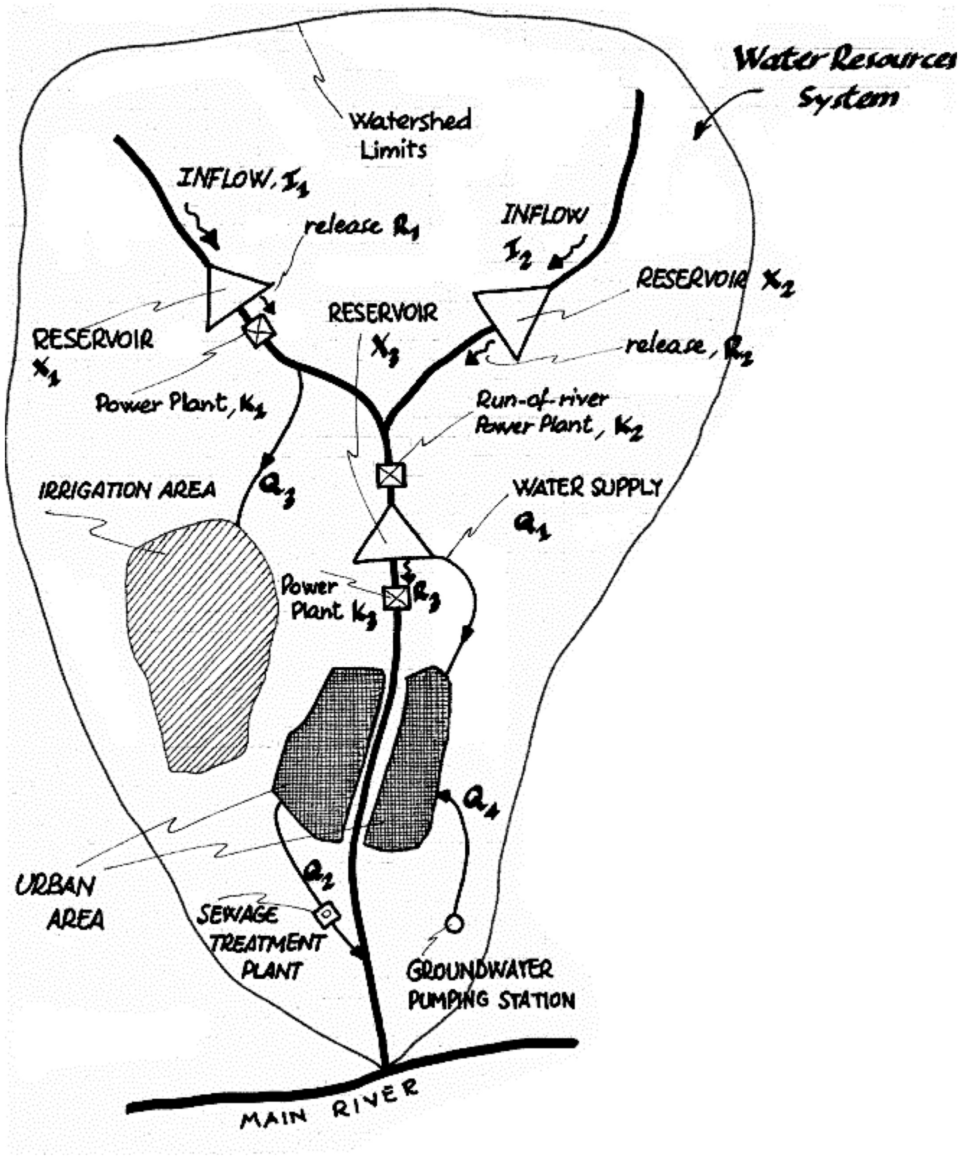
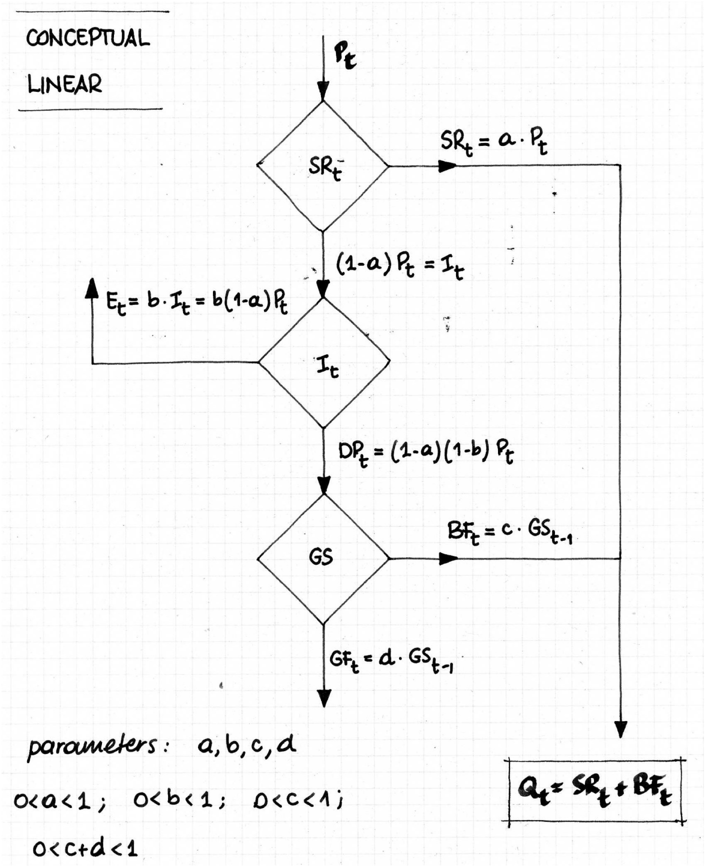


Figure 19.1 Comprehensive watershed diagram. (*Source: U.S. Bureau of Reclamation.*)

Some typical questions: assessment from historical data



How much is the inflow to the reservoir and which reliability?

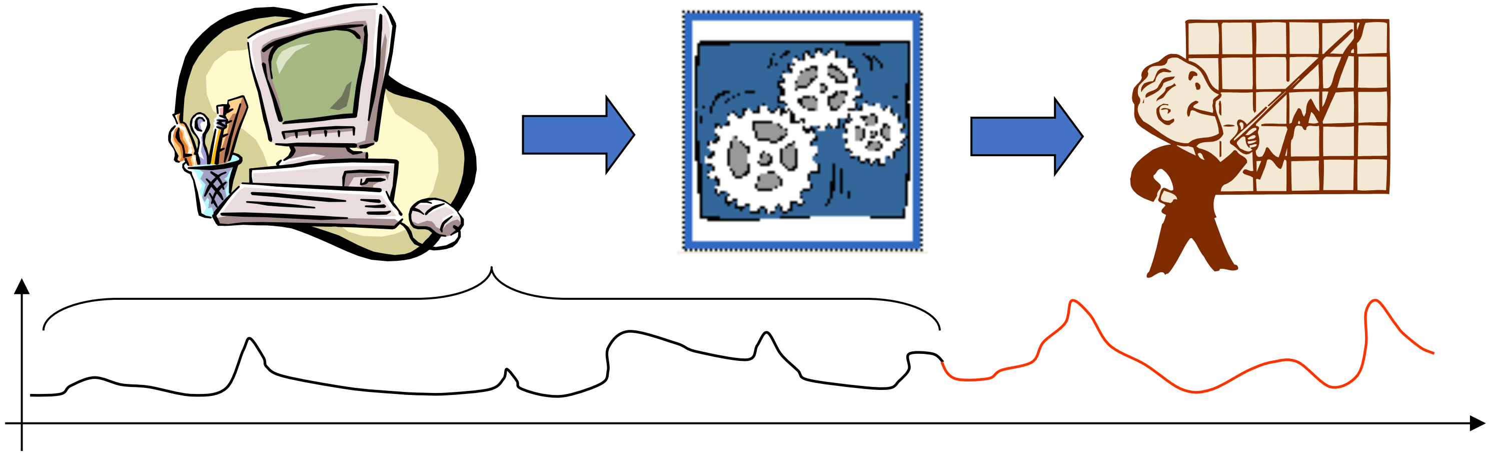


Data analysis of time series and modelling (Time Series Analysis)

Reference books:
“Handbook of hydrology, edited by D.R. Maidment, in particular, Ch. 19 by J. Salas (on Moodle)
“Applied statistics for civil and environmental engineers”, Kottegoda & Rosso, 2007

Scopes of Time Series Analysis

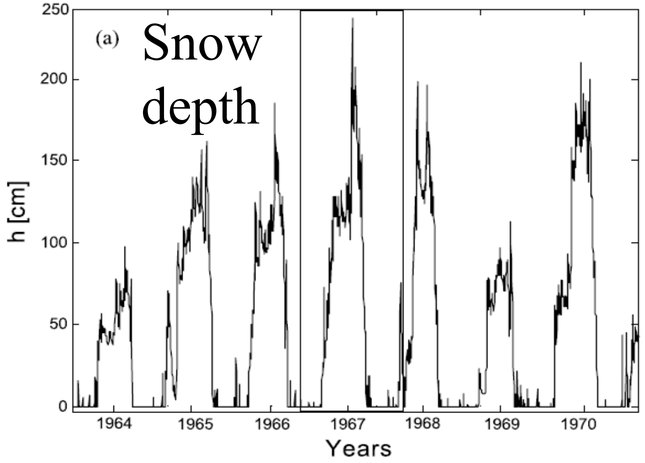
To analyze the statistical properties of a given variable in order to characterize the system‘s behaviour, to understand its dynamics, and to simulate or to predict it N steps ahead



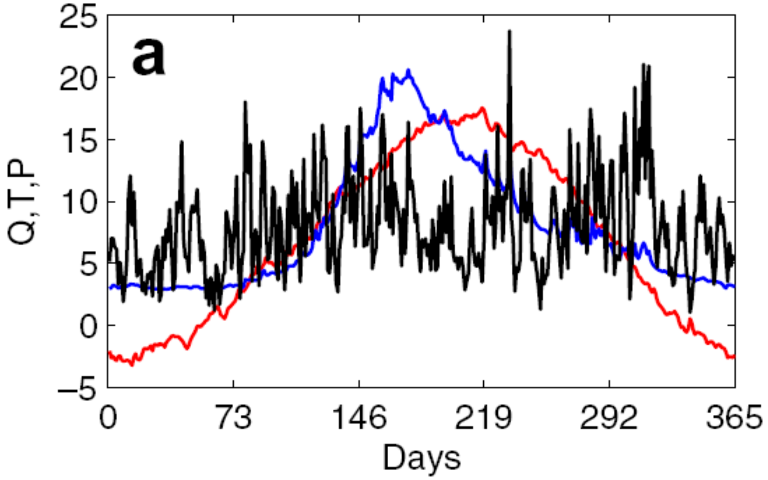
Statistical properties → Mathematical modelling → Data generation for several purposes

Examples: TSA concerns any system

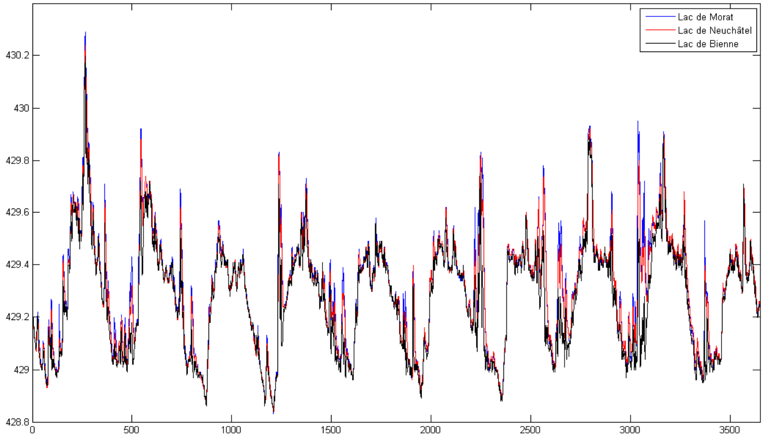
PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES



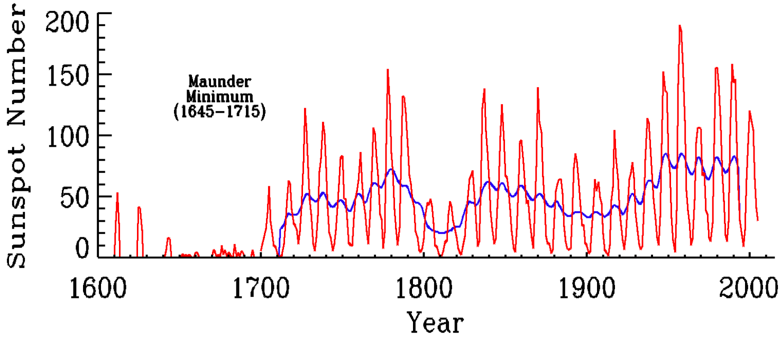
Precip, Temp, Discharge

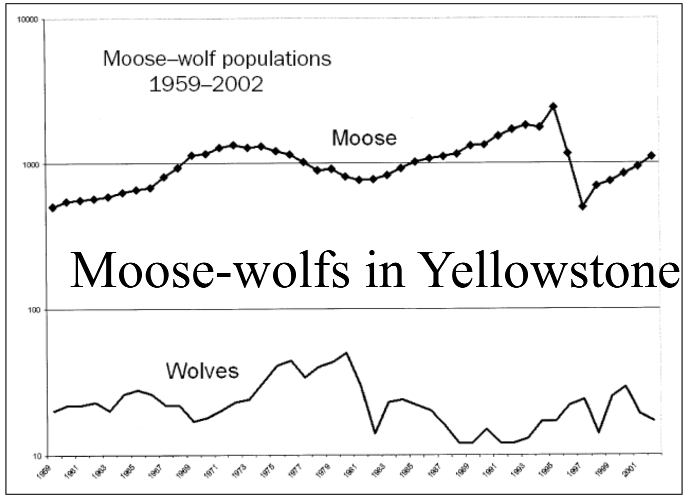


Lake levels

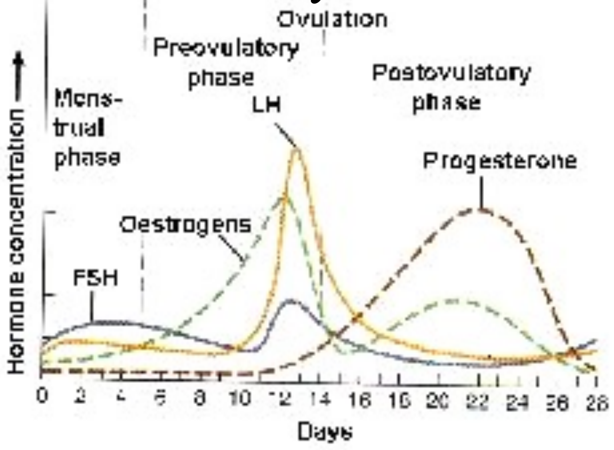


Sunspots number dynamics





Hormonal cycle



Aims of Time Series Analysis

Linear vs Nonlinear Analysis

Deterministic vs Stochastic

Noise Reduction

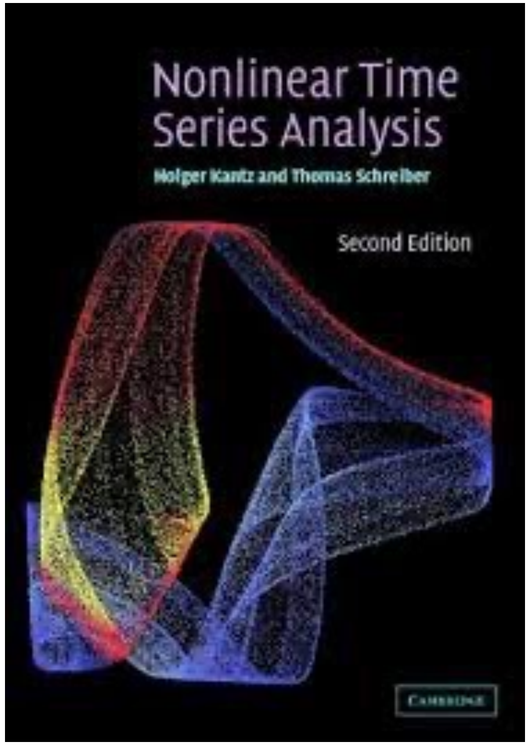
System dynamics reconstruction

Test for stationarity and transient dynamics

Intermittency

Structural stability

Modelling (prediction, syntethic data generation)

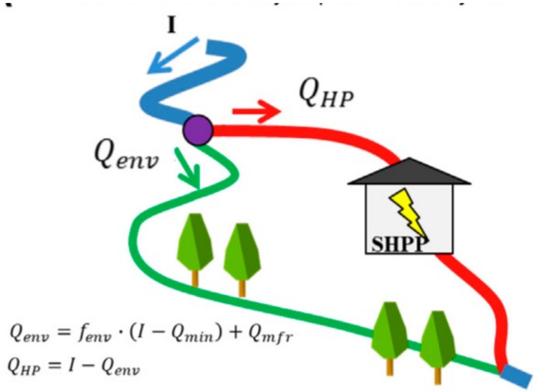


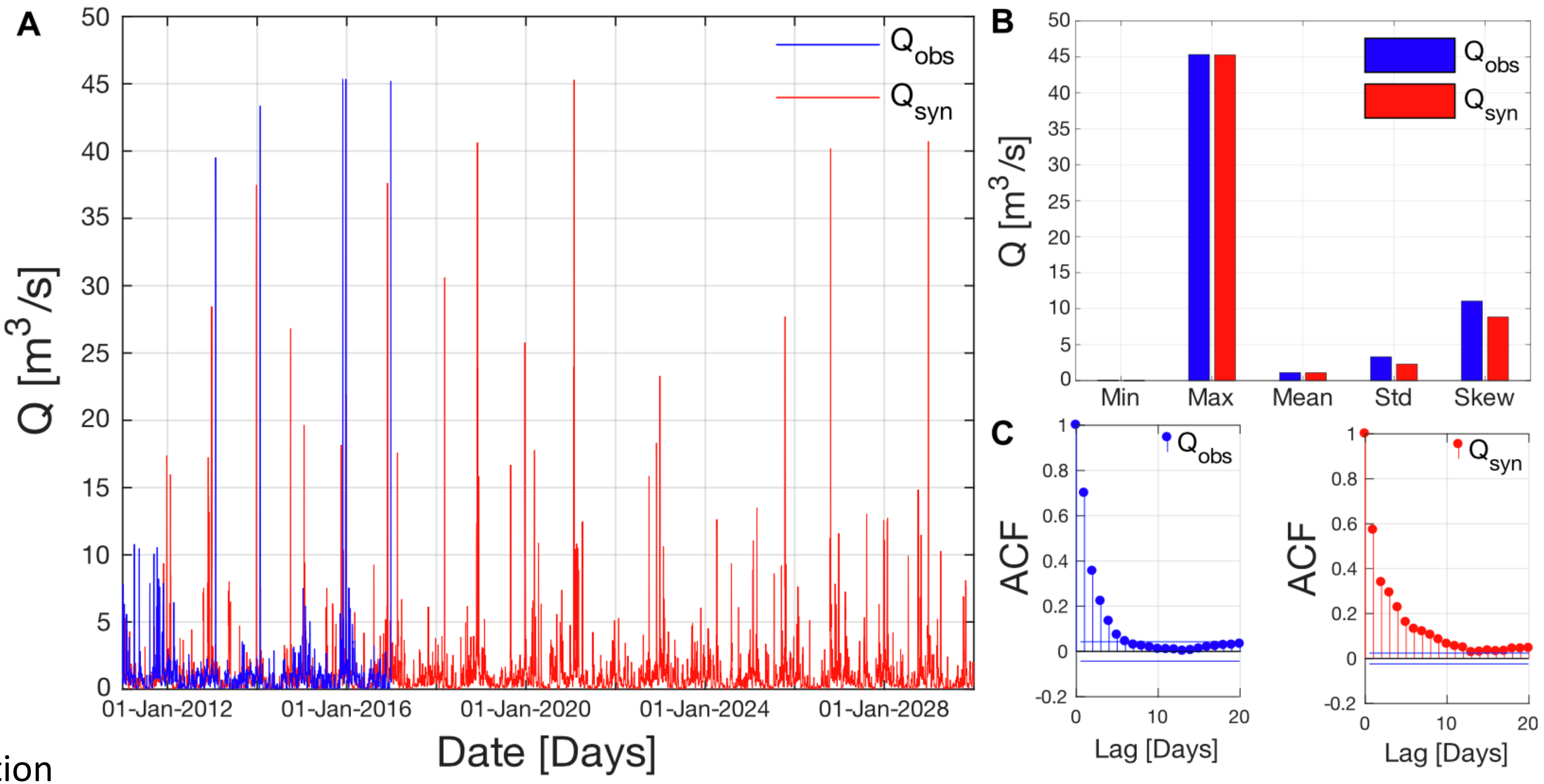
R or Octave package of nonlinear methods

https://www.pks.mpg.de/tisean/

Example: Synthetic data generation for Inveliver PP

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES





STEPS:

1. historical data analysis
2. Partitioning in components
3. Stochastic model identification
4. Use of model for data generation

Source: Perona et al., Frontiers in Env Sci., 2021

Type of time series: definitions

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

a) Continuous or discontinous time series: sequence of a continous or a discrete observation

b) Single time series or *univariate time series:* e.g., one obsersed variable in time

c) Multiple time series *or multivariate time series:* e.g., more observed variables for the same basin are a (multivariate) set

d) Correlated and uncorrelated time series: indicate (linear) dependence of a data at time t on previous data at lag τ

e) Intermittent time series: this sequence are intermittent when the recorded variable shows zero and non-zero values

f) Counting time series: e.g., the count of rainy days in a month or the number of days with snow on the ground

g) Regularly or irregularly spaced time series: a sequence where sampling interval is constant

h) Stationary and non-stationary time series: a sequence that is free of trends, shift or periodicity, etc.

Let see more in detail

Time series or time sequences: continous and discontinous

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

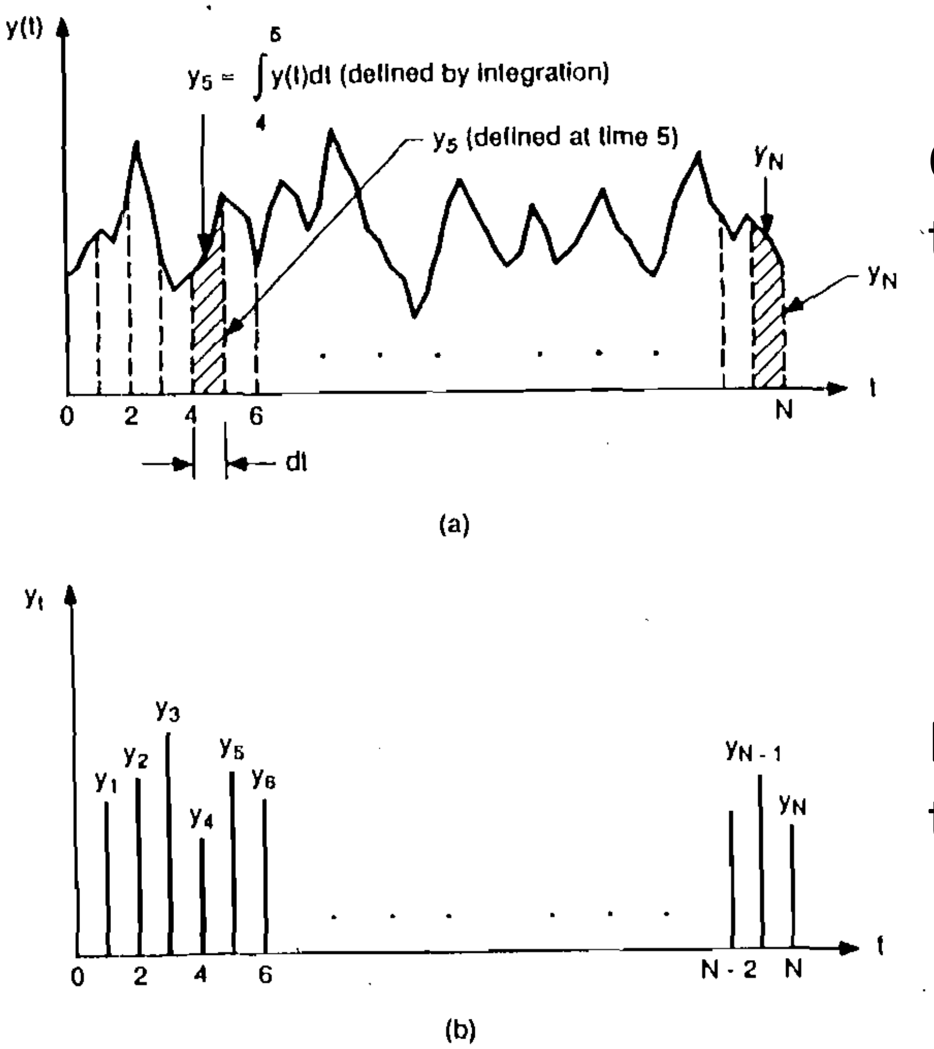


FIGURE 19.1.1 (*a*) A continuous time series $y(t)$. (*b*) A discrete time series y_t derived from the continuous series.

Continuous time series

A quantity (or variable) of a given system evolves (in time) according to the dynamics underlying the system.

i.e., the time series of the measured variable reflects the true system‘s behaviour and can be either **continous** or **discrete**

Discrete time series

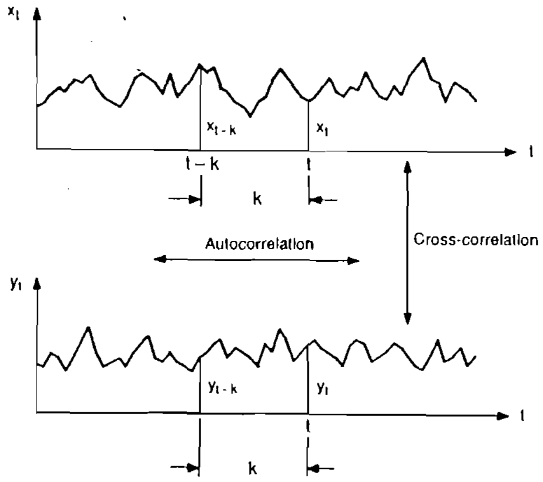
Single Time series (or univariate): a time series of a single variable at a time

Multiple Time series (or multivariate): the time series of more than one (same or different) variable

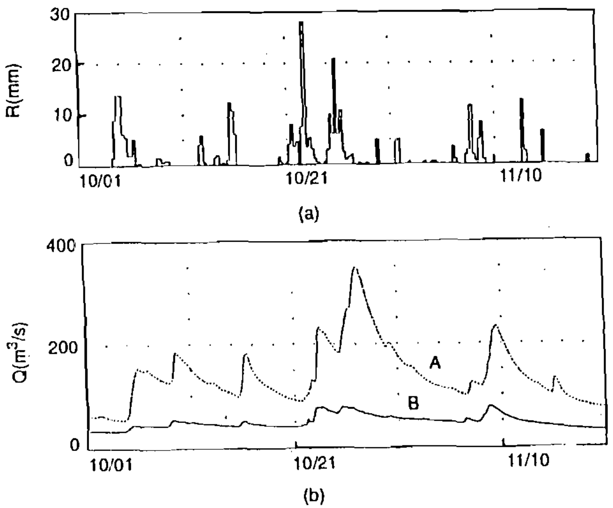
Source: Salas, 1992

Time series or time sequences: correlated and uncorrelated

Source: Salas, 1992

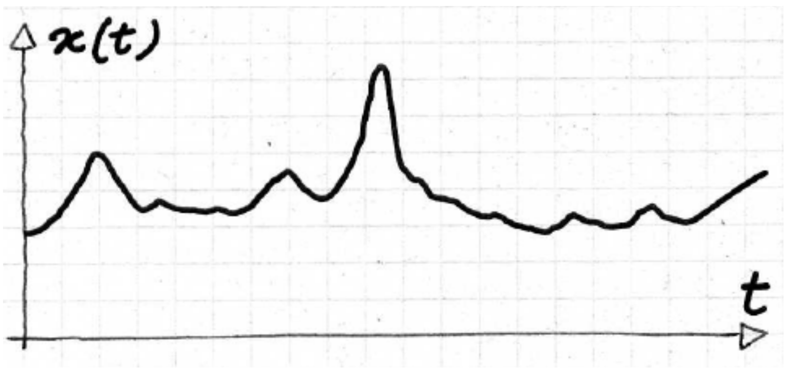


Correlated and uncorrelated time series. The data at time *t* depends on past data values. Correlation in a single time serie can be in time (autocorrelation) or in space with other time series (cross-correlation). We will see how to compute this mathematically

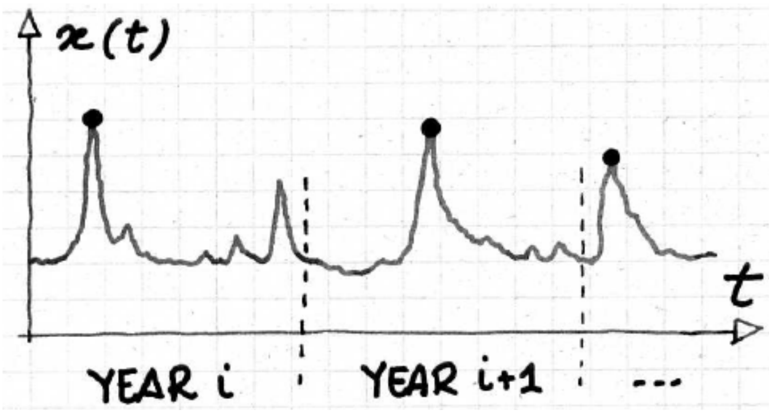


Intermittent vs continuous time series. A time sequence is intermittent when it can take both zero and non-zero values (e.g., precipitation intensity or streamflows in arid regions, which are said ephemeral streams). Intermittency may depend on sampling frequency and aggregation

Time series or time sequences: definitions

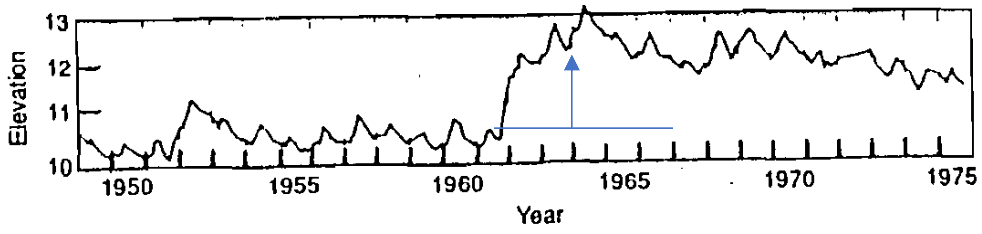


Continuos time and space variables, e.g. Water levels and discharge



Discrete times, continuous space variable, e.g. annual peaks of discharge

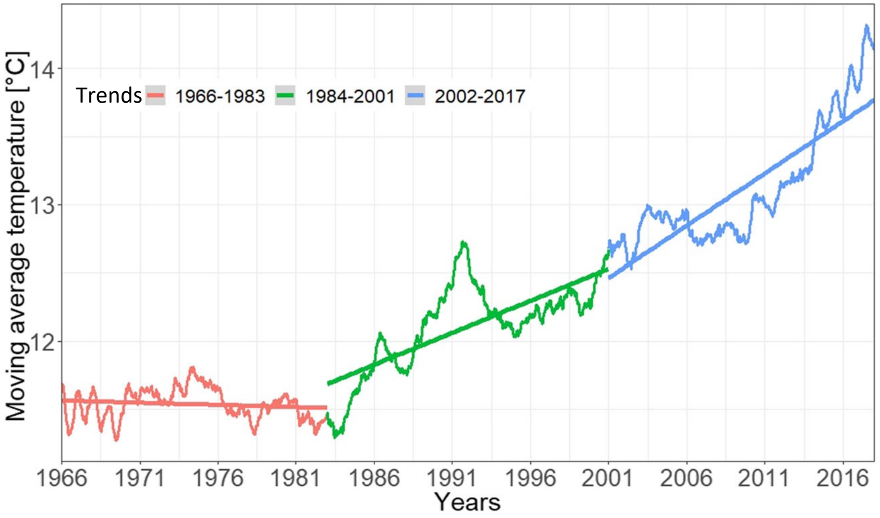
Discrete times, discrete space variables. Eg., the counting of rainy days



Stationary vs non-stationary time series, e.g. trends, shifts, etc.

Examples of trends and shifts

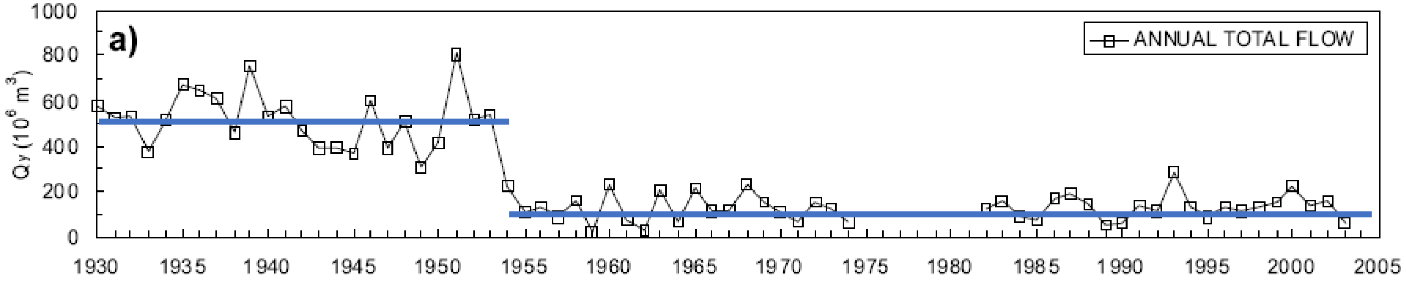
Climatic origin (Greenhouse gases)



Eight years moving average of temperature in Wrocław for 1966–2017, with three linear trends for three homogeneous period

SOURCE: Glogokswi et al., 2020

Anthropogenic origin (catchment impoundment by dam construction)



Maggia river case for the pre- and the post damming period

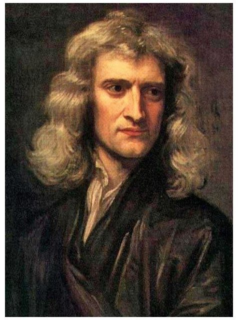
SOURCE: Molnar et al., Peckiana 2008

Determinism vs stochasticity

The ensemble of trajectories or realizations of the system evolution represents a process, which can be modeled as

Deterministic process (Poincaré, Hamilton, Laplace, etc.): data are modeled using a set of mathematical equations corresponding to a quantifiable number of variables (degrees of freedom). Dynamical Systems theory

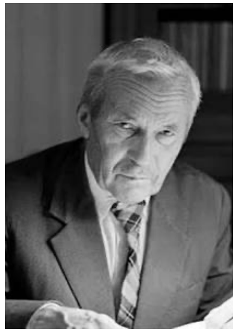
Stochastic process (Langevin, Einstein, Kolmogorov, etc.): data are modeled using mathematical equations affected by „noise“, which intrinsecally increase to infinity the number of variables explaining the system behaviour. Theory of Stochastic Processes



Isaac Newton 1642-1727

Henri Poincaré 1854-1912

Thomas Bayes 1701-1761



Andrej Kolmogorov 1903-1987

Examples of deterministic dynamics

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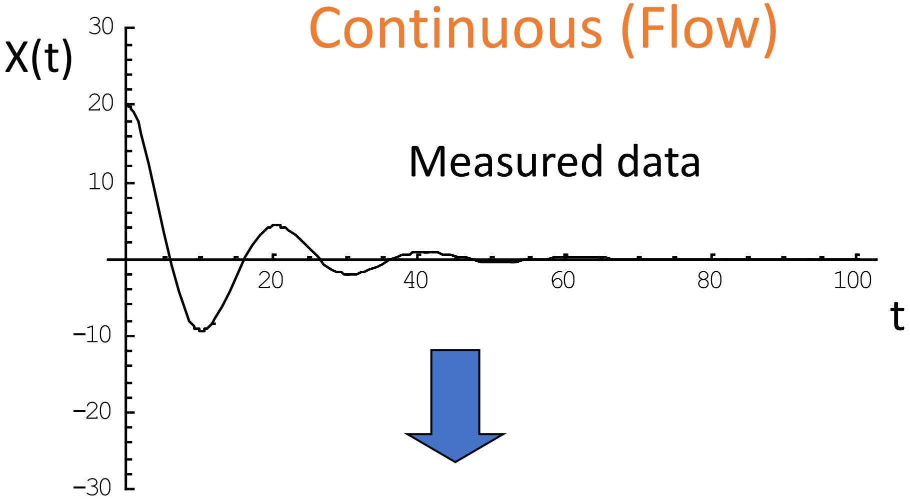
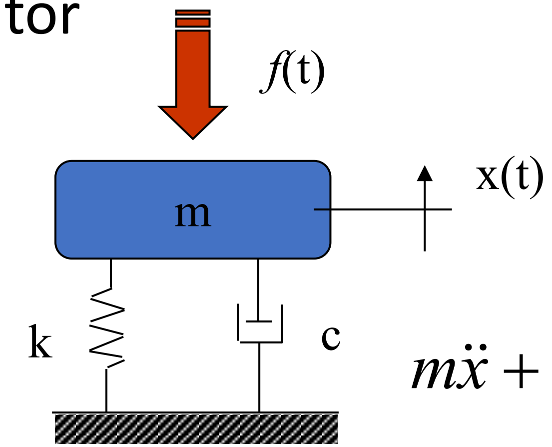
Continuous (Flow)

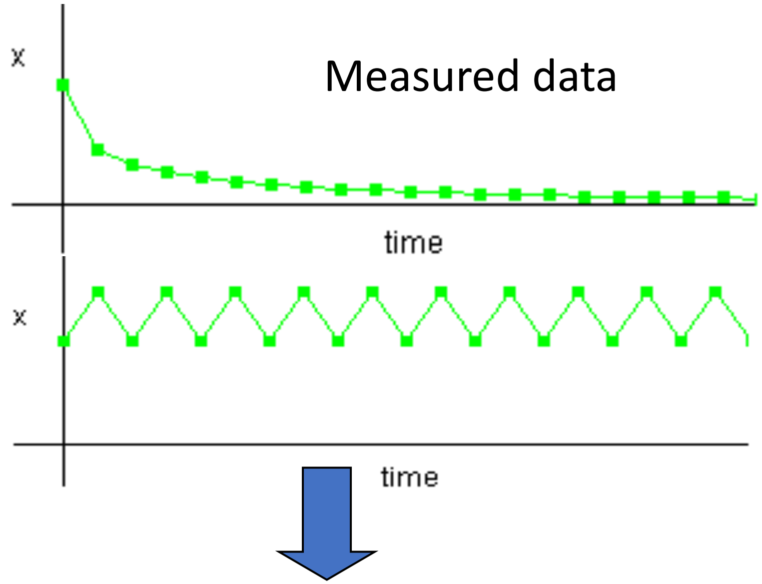


Underlying system: e.g., mech. oscillator



$$m\ddot{x} + c\dot{x} + kx = f(t)$$

Discrete (Map)



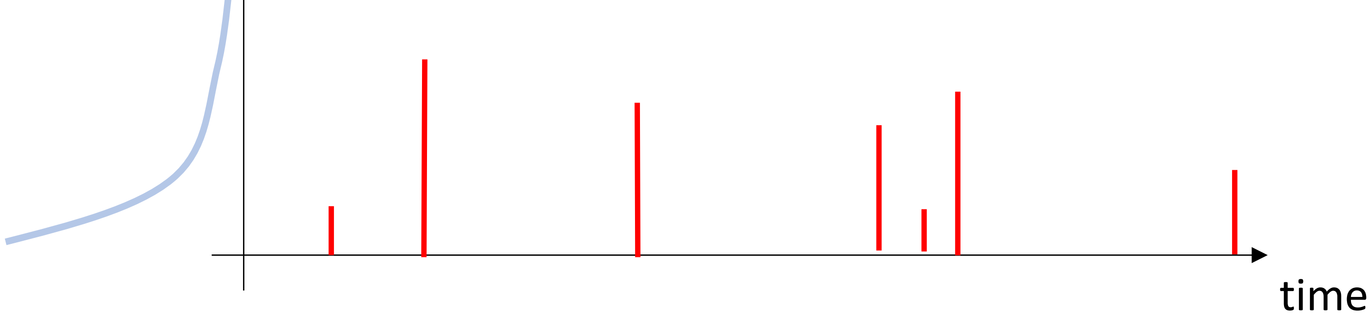
Underlying system: e.g., population dynamics and the logistic map

$$x_{n+1} = a x_n (1 - x_n)$$

$$a = \text{Reduced carrying capacity}$$

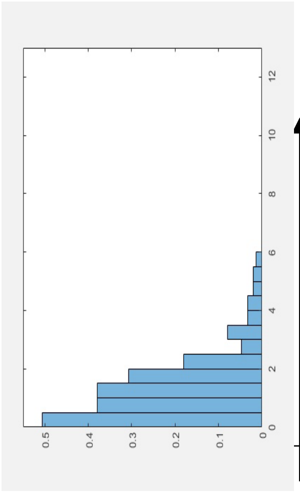
Example of stochastic dynamics

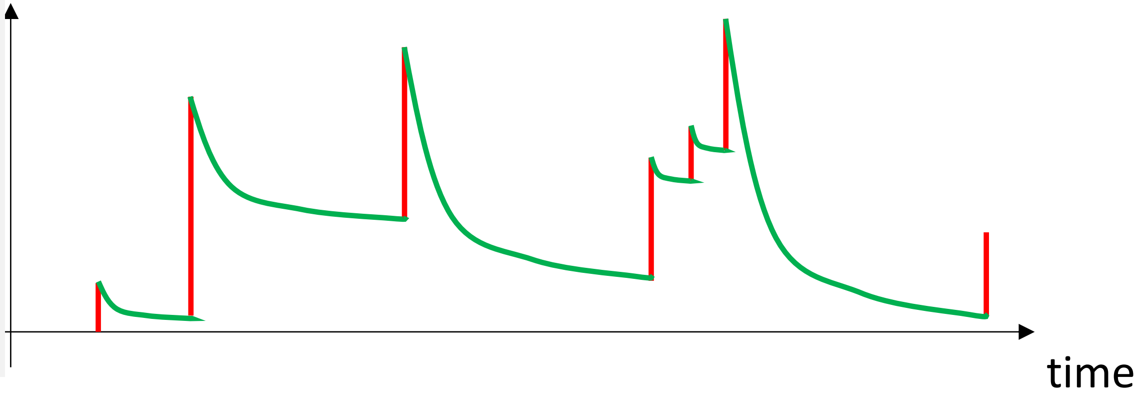
PDF, but NO correlation in time for the state variable N (White noise)



Marked Poisson events, e.g
Cox and Miller (1969)

STOCHASTIC PROCESS: PDF, correlation in time for the state variable N (Colored noise)





Compound Poisson Process

Cox and Miller (1969), Iturbe et al. (1999), Ridolfi et al. (2006), Botter et al. (2007)

$$\frac{dh}{dt} = -\frac{h}{\tau} + \zeta(t)$$

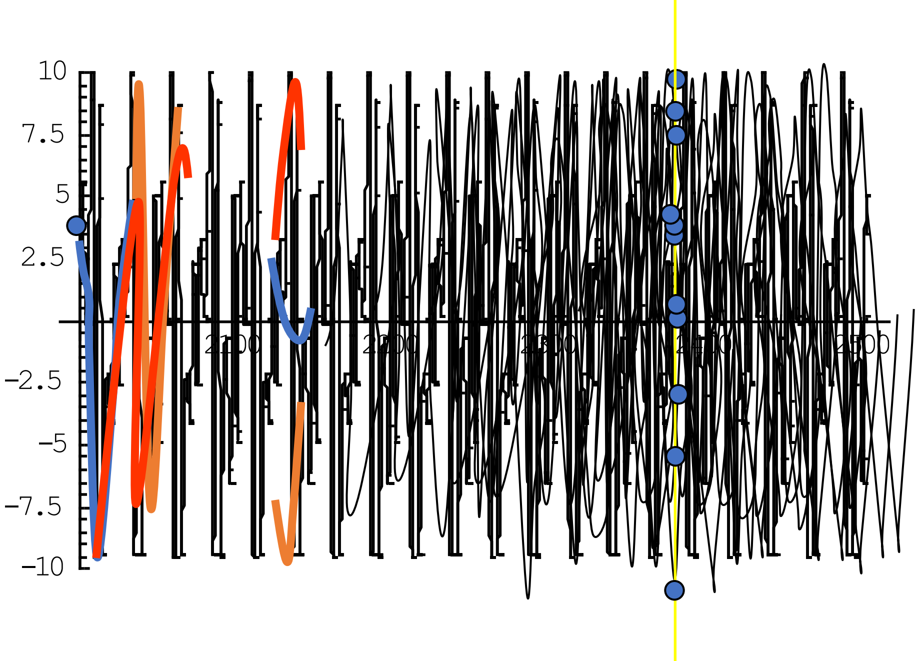
Noise term as “Jumps”

We will return to the use of this simple model

Unpredictable behaviour can occur in nonlinear systems

Continuous (Flow)

$$m\ddot{x} + c\dot{x} + k(x + ax^3) = f(t)$$

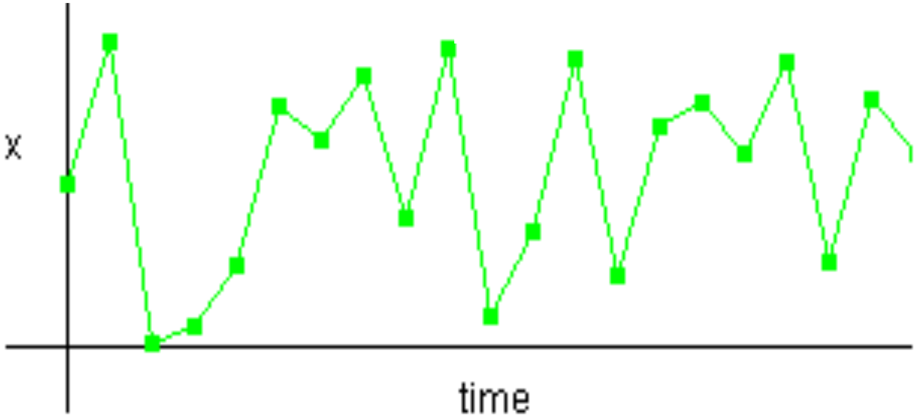


Error in the i.c. propagates (spreading of trajectories)

Determinist nonlinear systems with unpredictable dynamics are named Chaotic systems

Discrete (Logistic map)

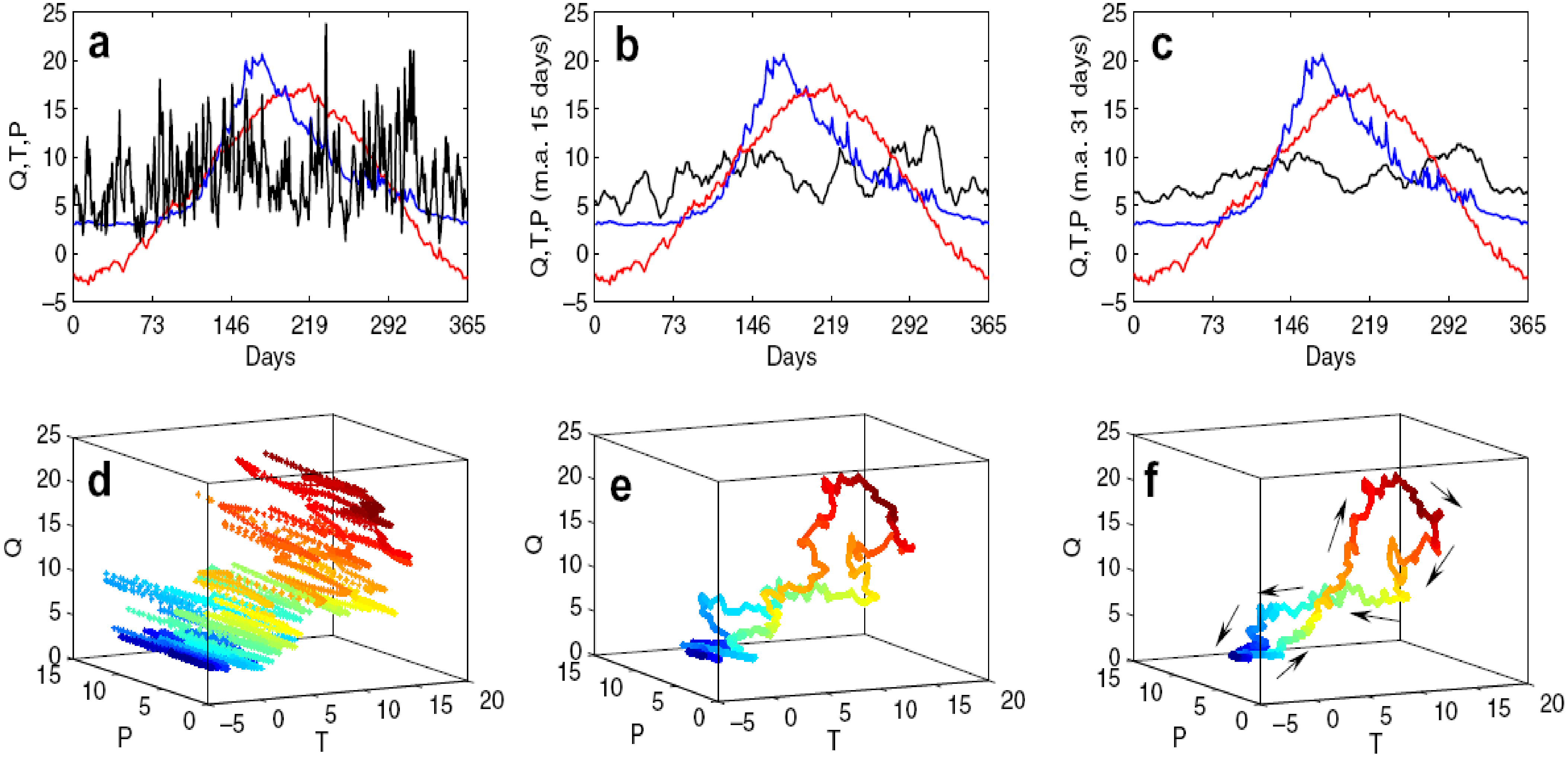
$$x_{n+1} = ax_n(1 - x_n)$$



Too much carrying capacity makes the system „crazy“!

Try with a={0.5; 2.5; 3.1; 3.5; 3.7; 4.2} and x_0=0.5

Is there determinism in hydrology and climatology?



After Perona and Burlando, AWR 2008

It depends at which scale and components one looks at