# Change detection in monitoring time series

Formose - Changes Workshop

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# Change detection in monitoring series

## Content

- What is a time series?
- What are we monitoring?
- What is a change?
- How can we detect the time series changes?

- Example for streams/rivers
- Example for landslides

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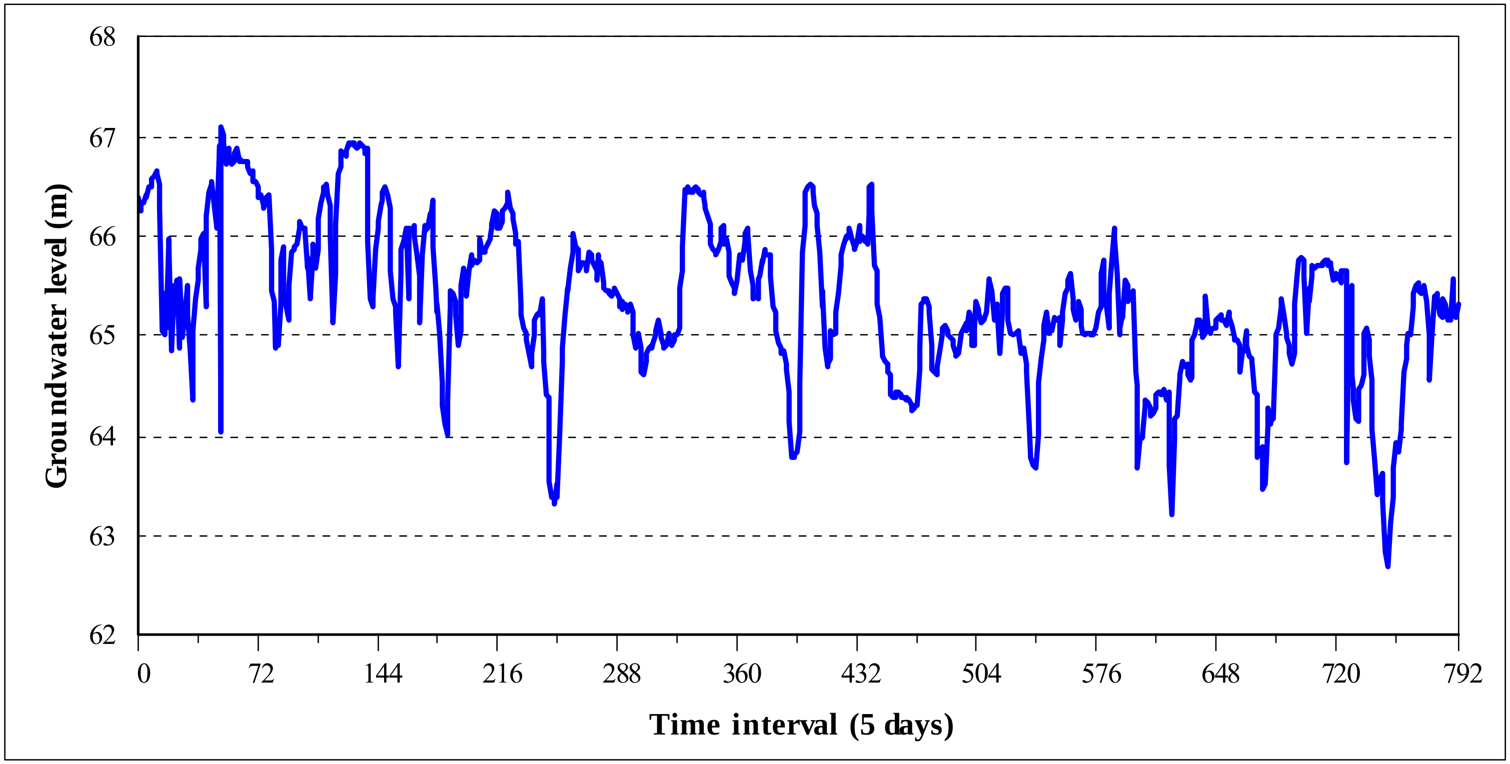
# What is a time series?

**time series** is a sequence of data points, measured typically at successive points in time spaced at uniform time intervals

**Time series *analysis*** comprises methods for analyzing time series data in order to extract meaningful statistics and other characteristics of the data

# Characteristics of time series

Plot of hydrograph




Observation interval = 5 days
Observation frequency = 6 times / month

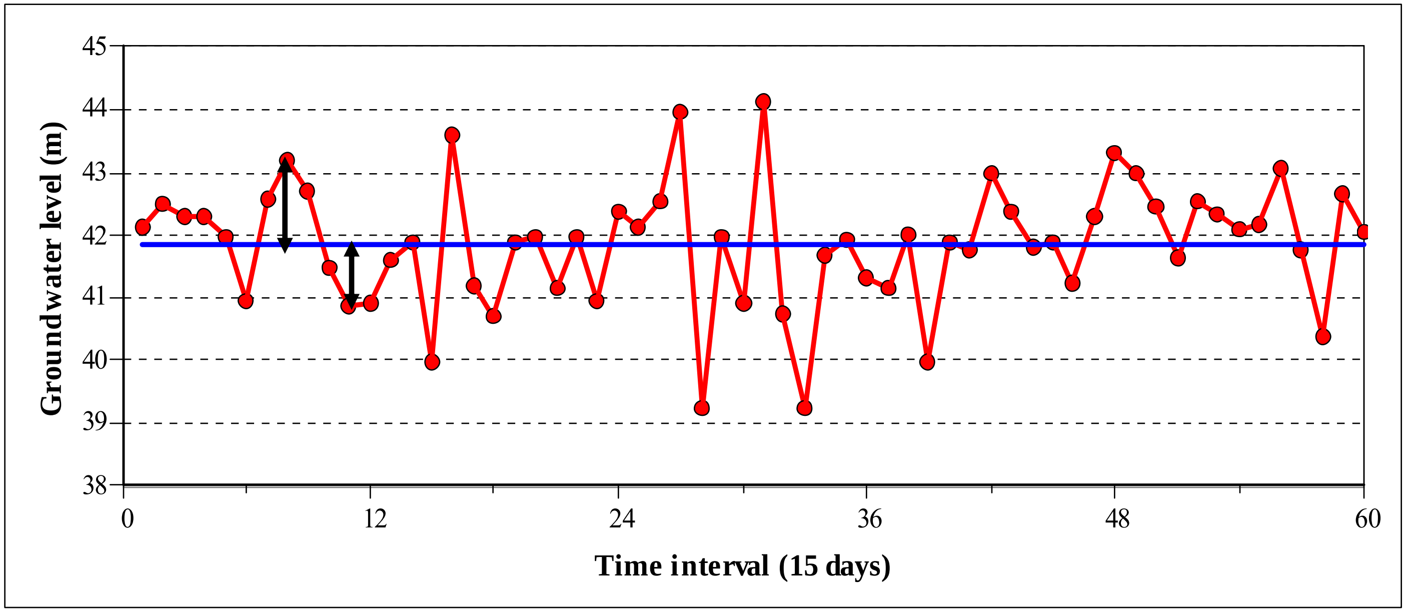
# Characteristics of time series

Mean: central tendency

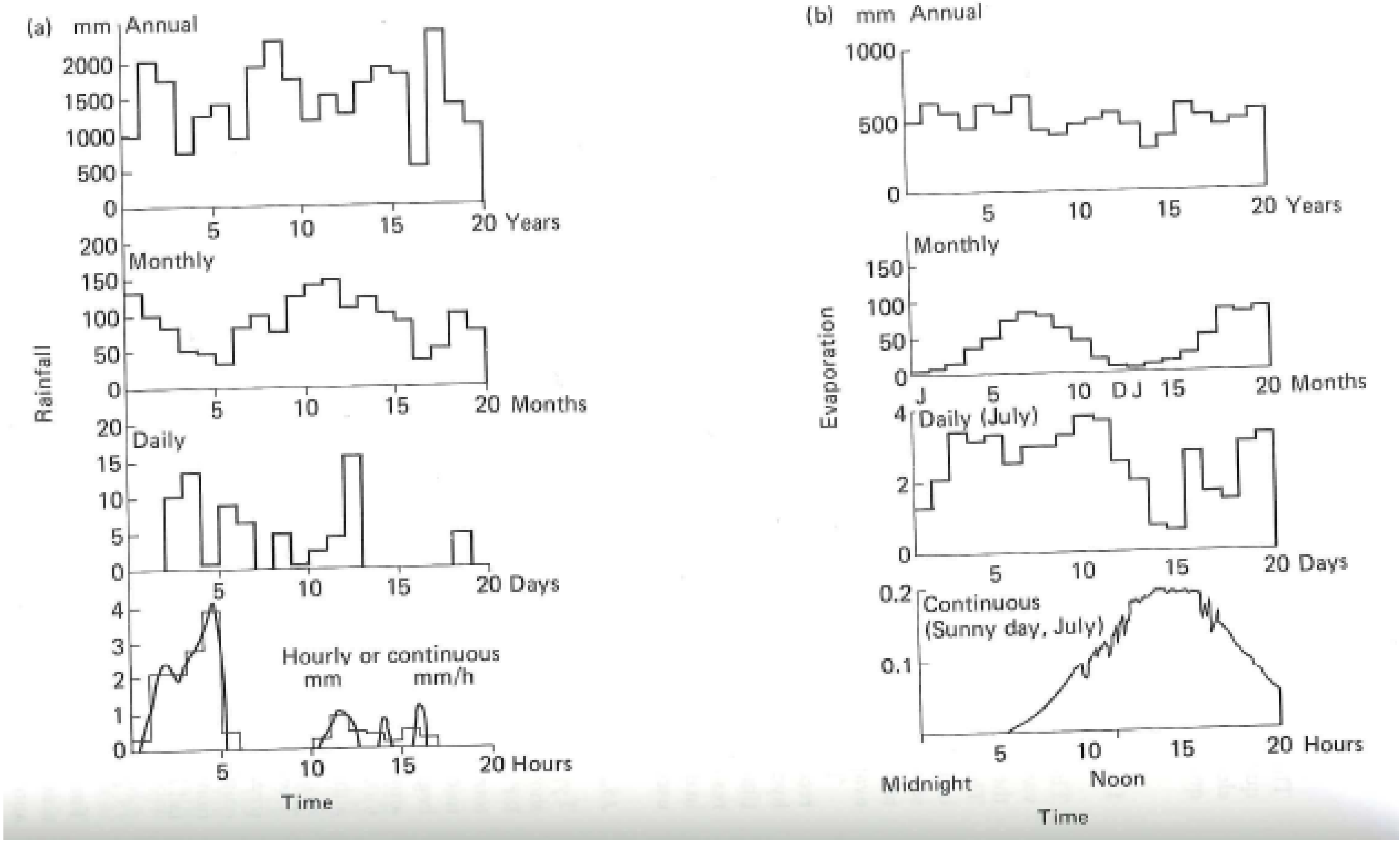
$$\bar{h} = \frac{1}{n}\sum_{i=1}^{n} h_i$$

Variance: variation around mean

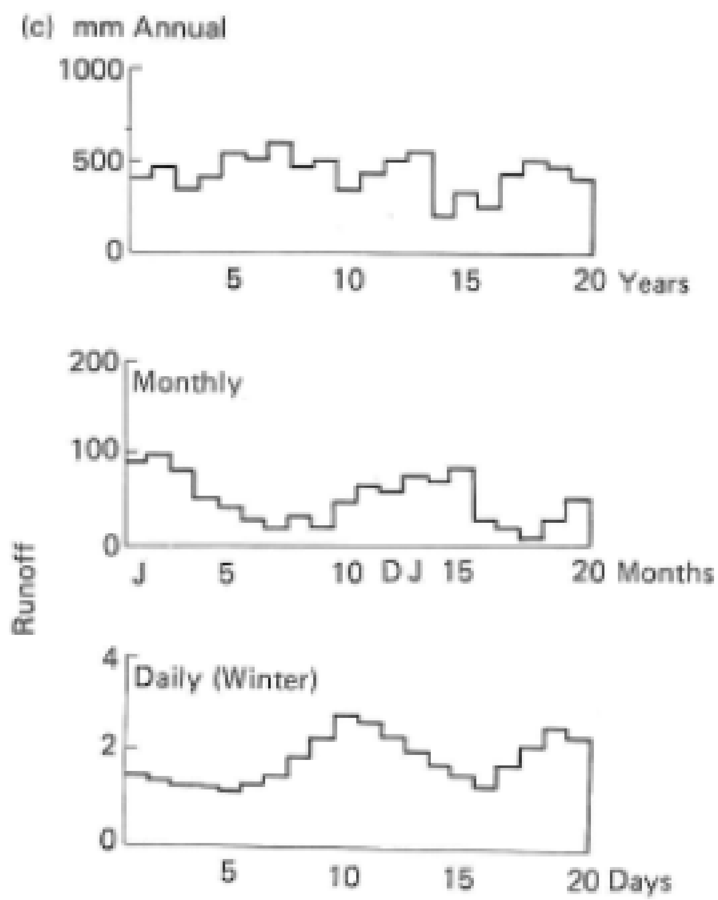
$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(h_i - \bar{h})^2$$

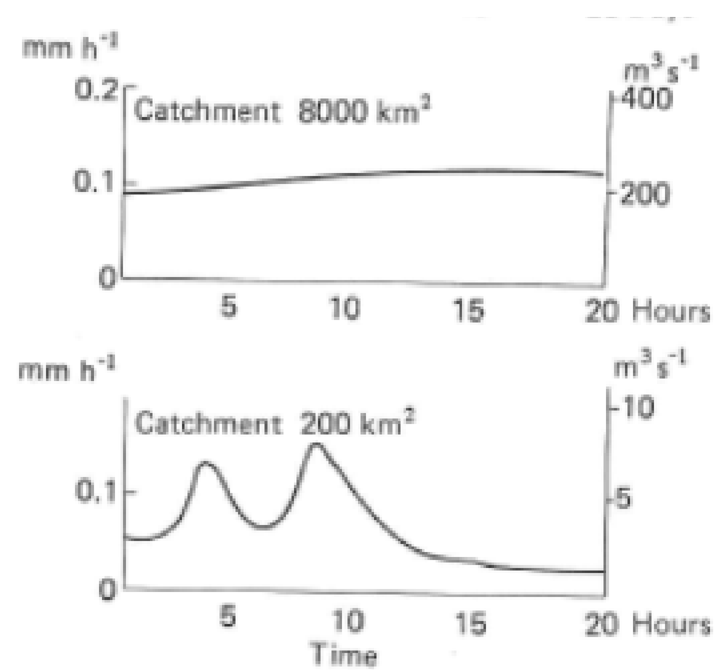


# Time scale effect on time series

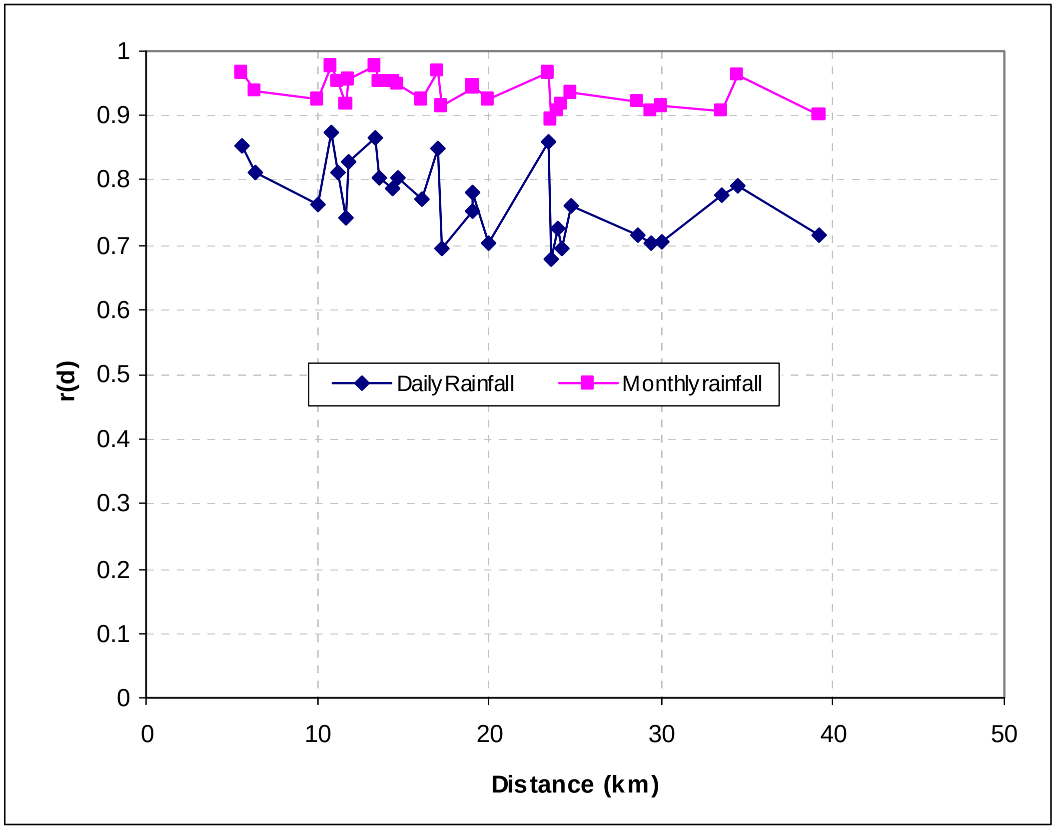


# Time and spatial scale effect on discharge time series

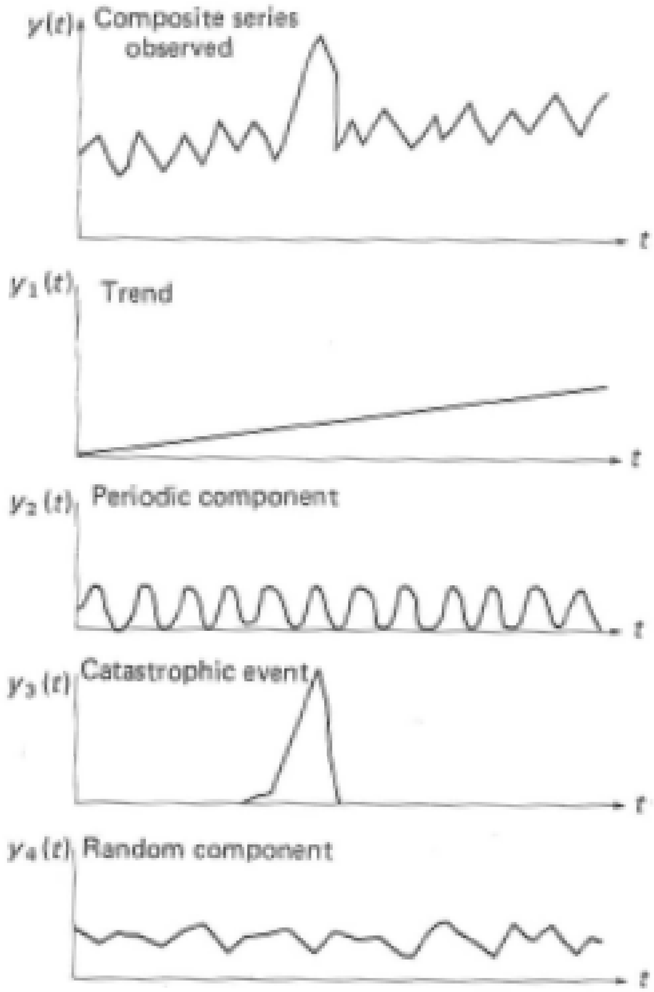


# Scale effect on rainfall time series
# Example of 9 rain gauges Luxembourg



# Decompose a time series




Time series

Trend

Periodicity

Catastrophic event

Noise (random)

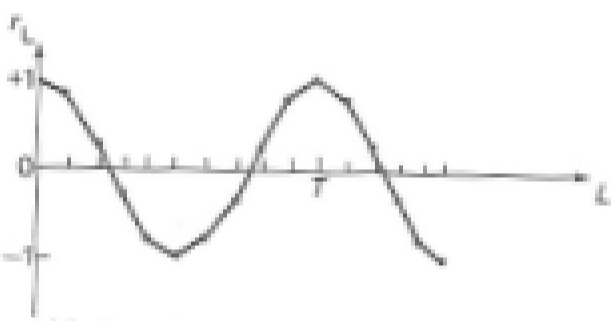
# How to test periodicity?
# Serial correlation

(a) Random, independent noise

Random

(b) Autoregressive, Markov process

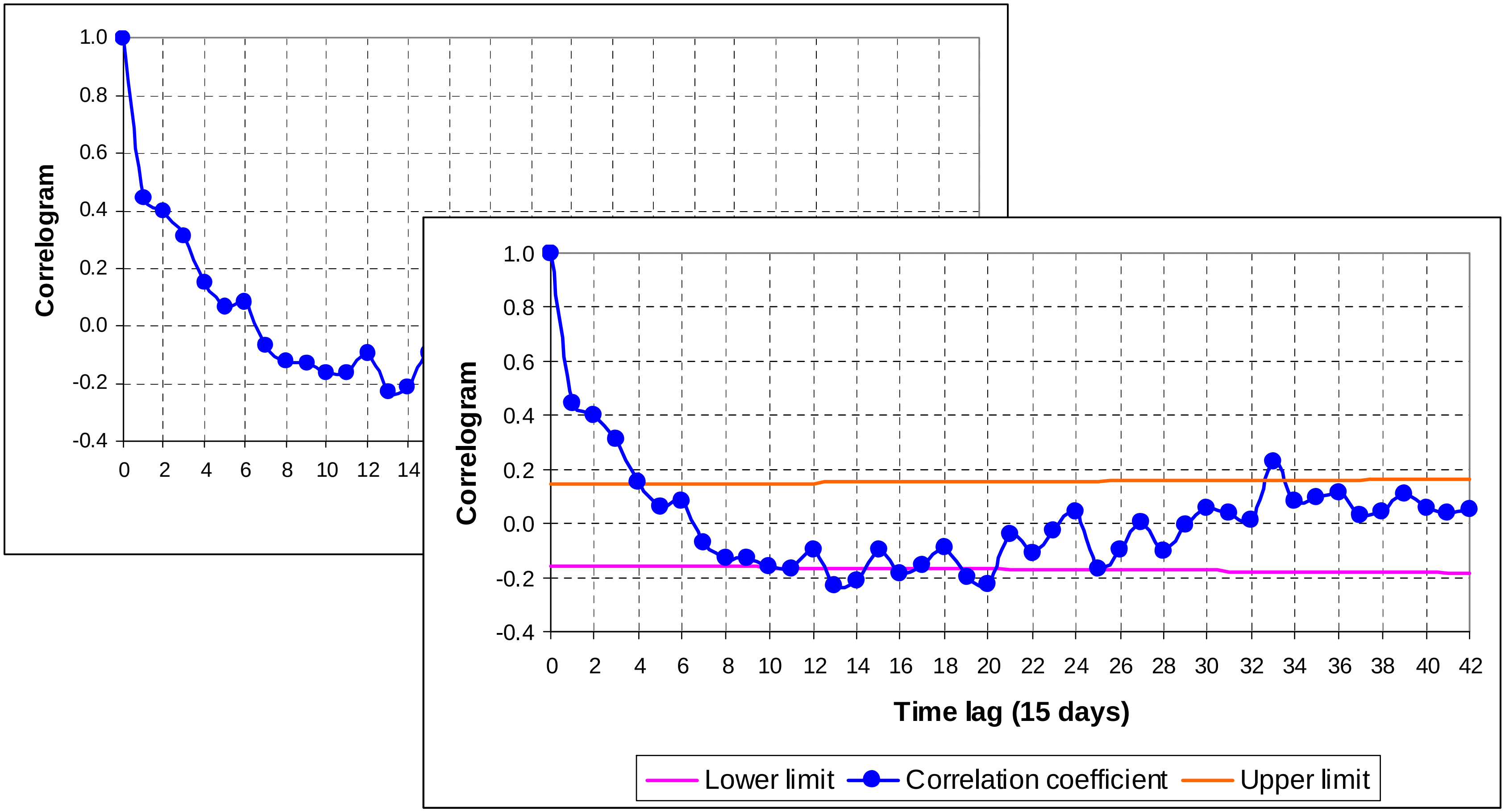
Autoregressive, Markov process



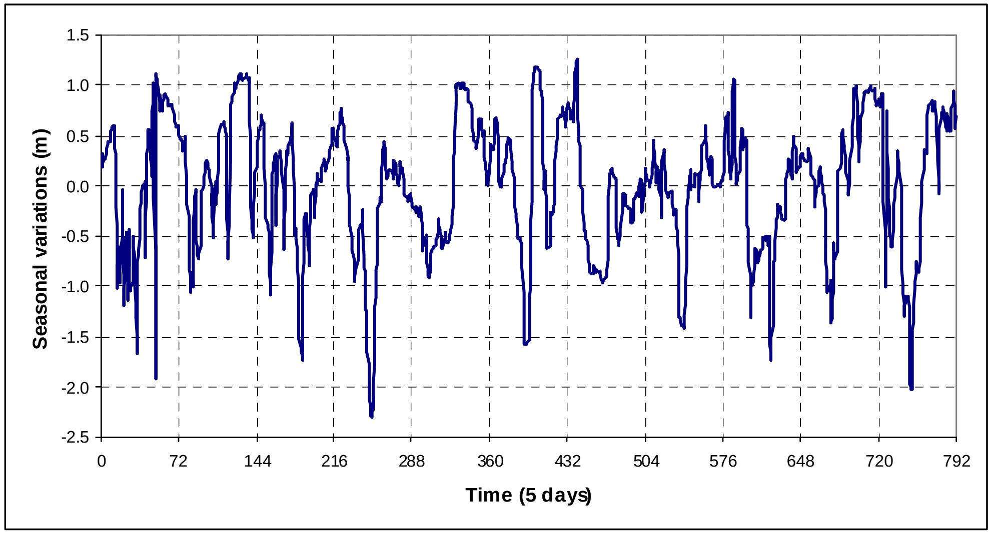
(c) Pure sine wave

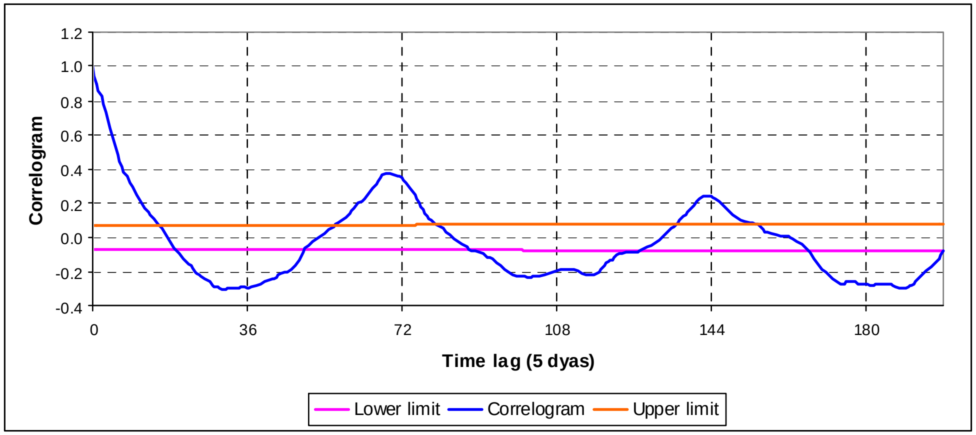
Periodicity

# How to test periodicity?
# Serial correlation and confidence limits



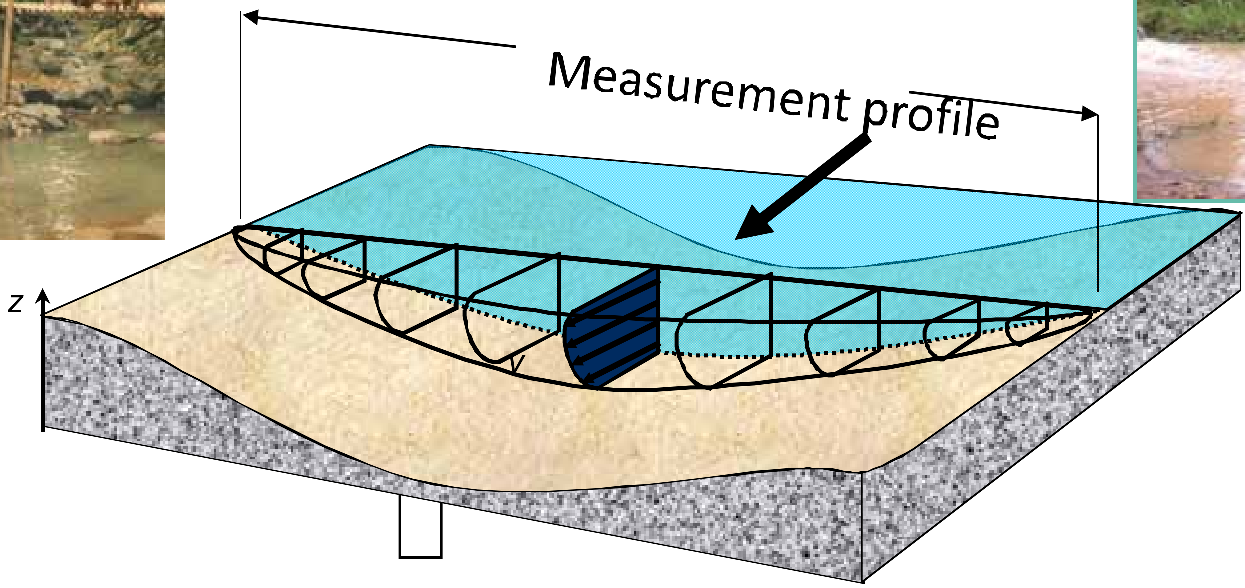
# Correlogram of seasonal time series



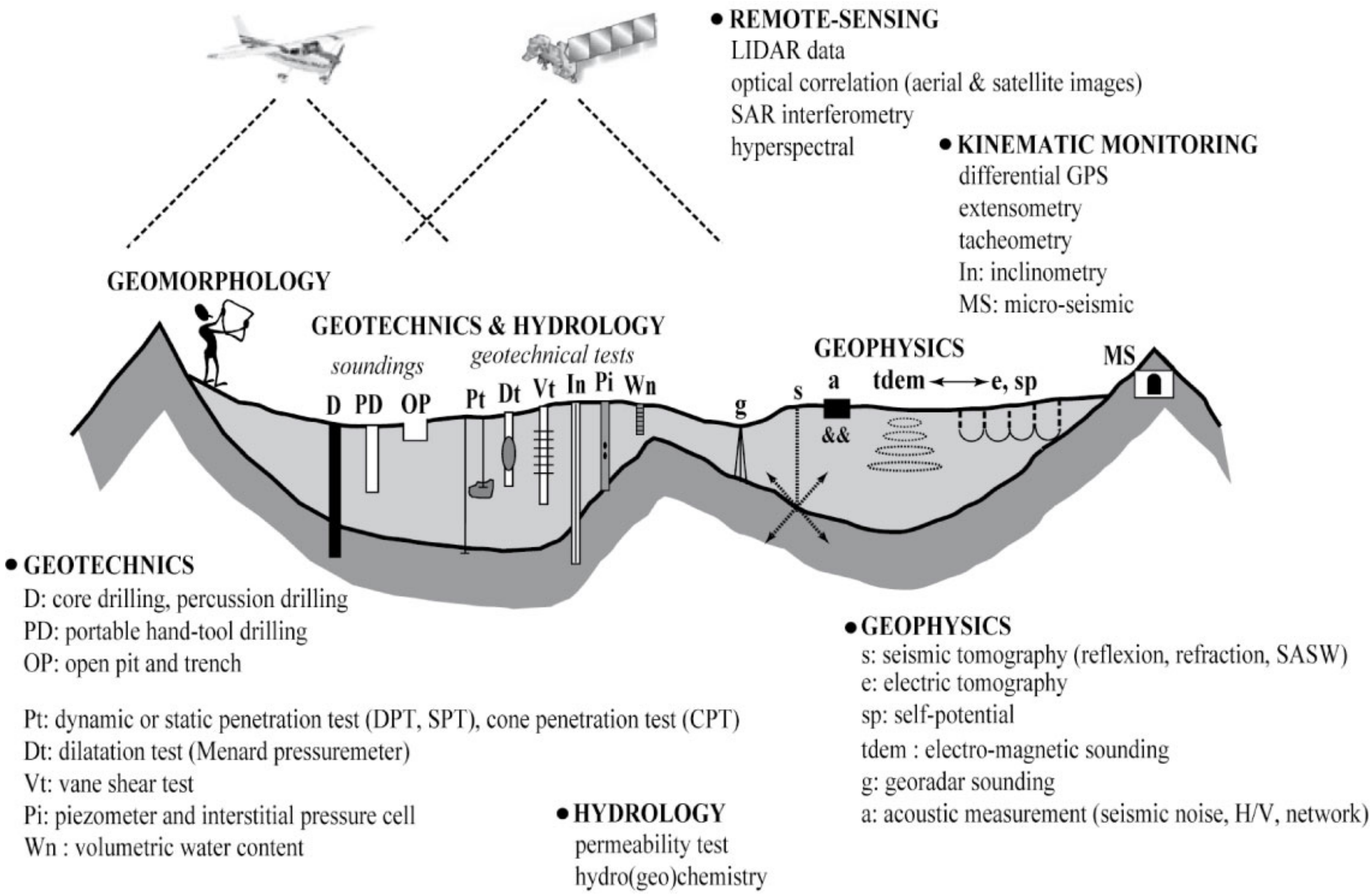



# What are we monitoring in natural hazards?

Floods: discharge, water level height, bed topography, ...

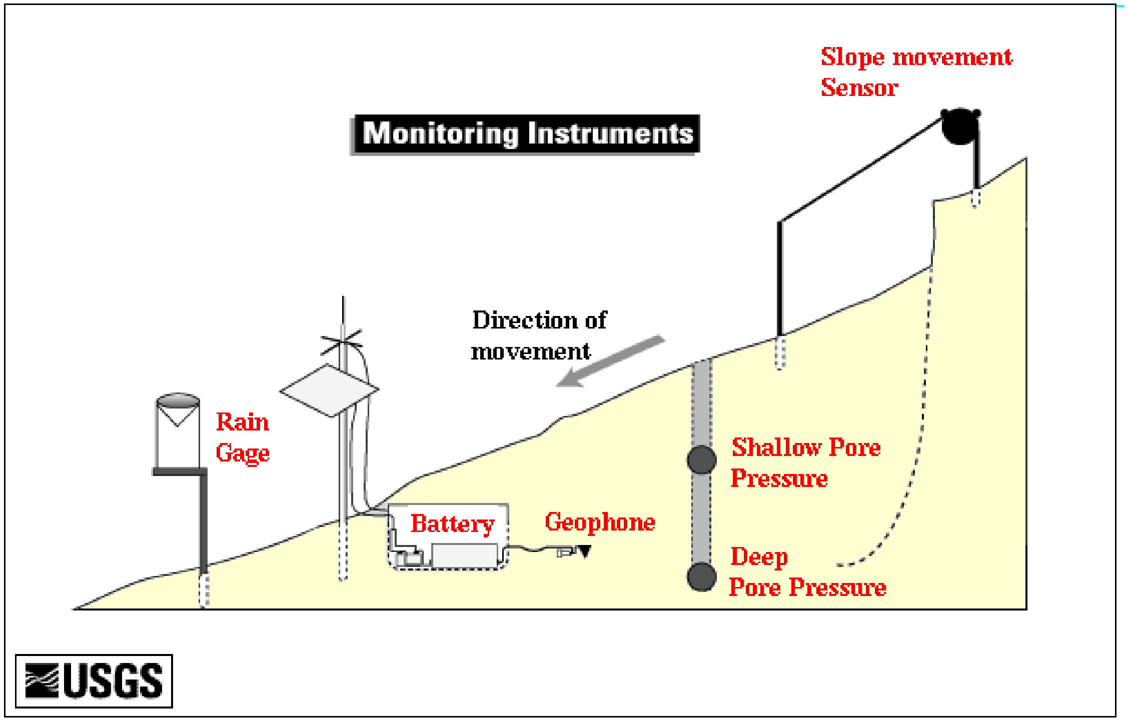



# What are we monitoring in natural hazards?



# What are we monitoring in natural hazards?

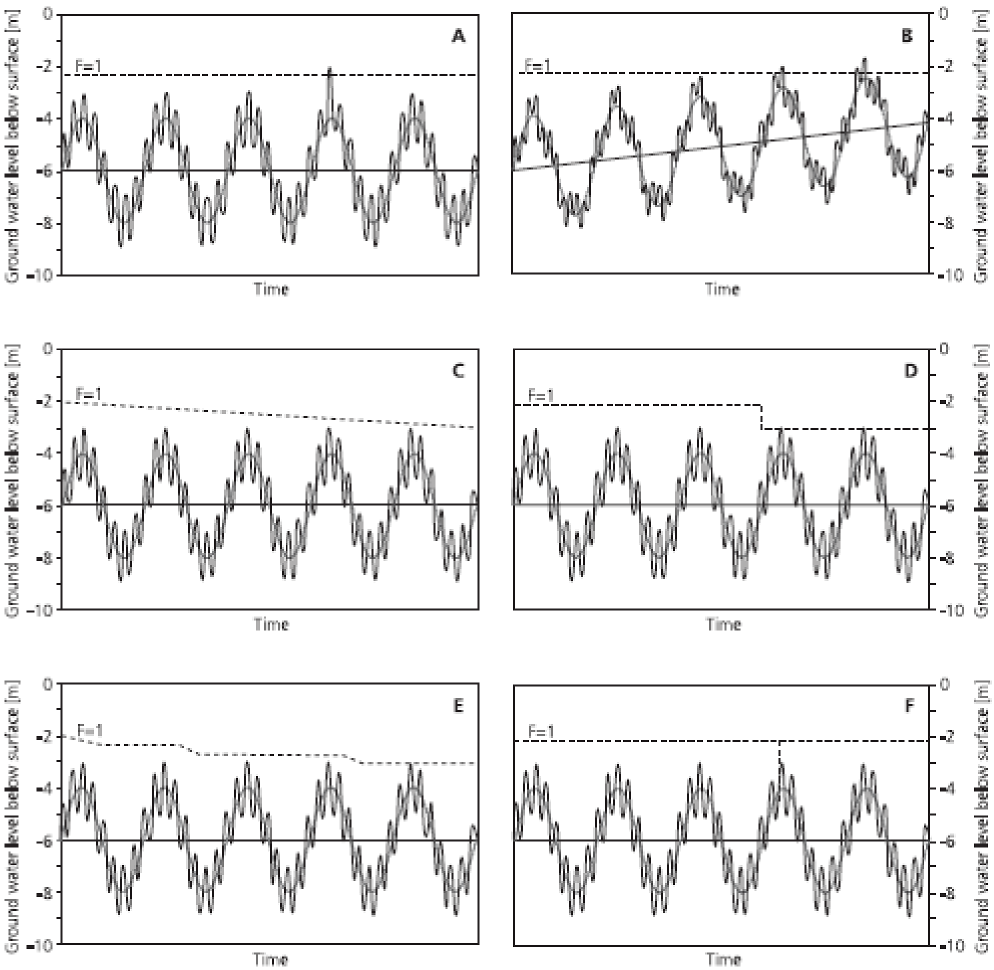
Landslide: displacement, groundwater level, precipitation



# What is the difference between a cause and a trigger?

| Process \ Time scale | | Short time scale | Long time scale |
|---|---|---|---|
| Shear strength decrease [Internal] | Increase of pore water pressure | Instantaneous hydrological factors or hydrological triggers<br><br>*Infiltration & percolation* | Long-term hydrological factors<br><br>*Regional ground water flow, Change in land use or climate* |
| | Decrease of material strength | Instantaneous strength factors or strength triggers<br><br>*Artificial freezing-thawing, chemical treatment* | Long-term strength factors<br><br>*Weathering and dissolution Increase strength by roots grow* |
| Shear stress increase [External] | | Instantaneous gravitational factors or gravitational triggers<br><br>*Earthquake, excavation* | Long-term gravitational factors<br><br>*Erosion or Accumulation* |

# What is the difference between a cause and a trigger?



# How to detect a change?

Methods

- Visual inspection
- Double mass (residual mass)
- Statistics
- Physical modelling

# How to detect a change?
## *… data quality and extremes*

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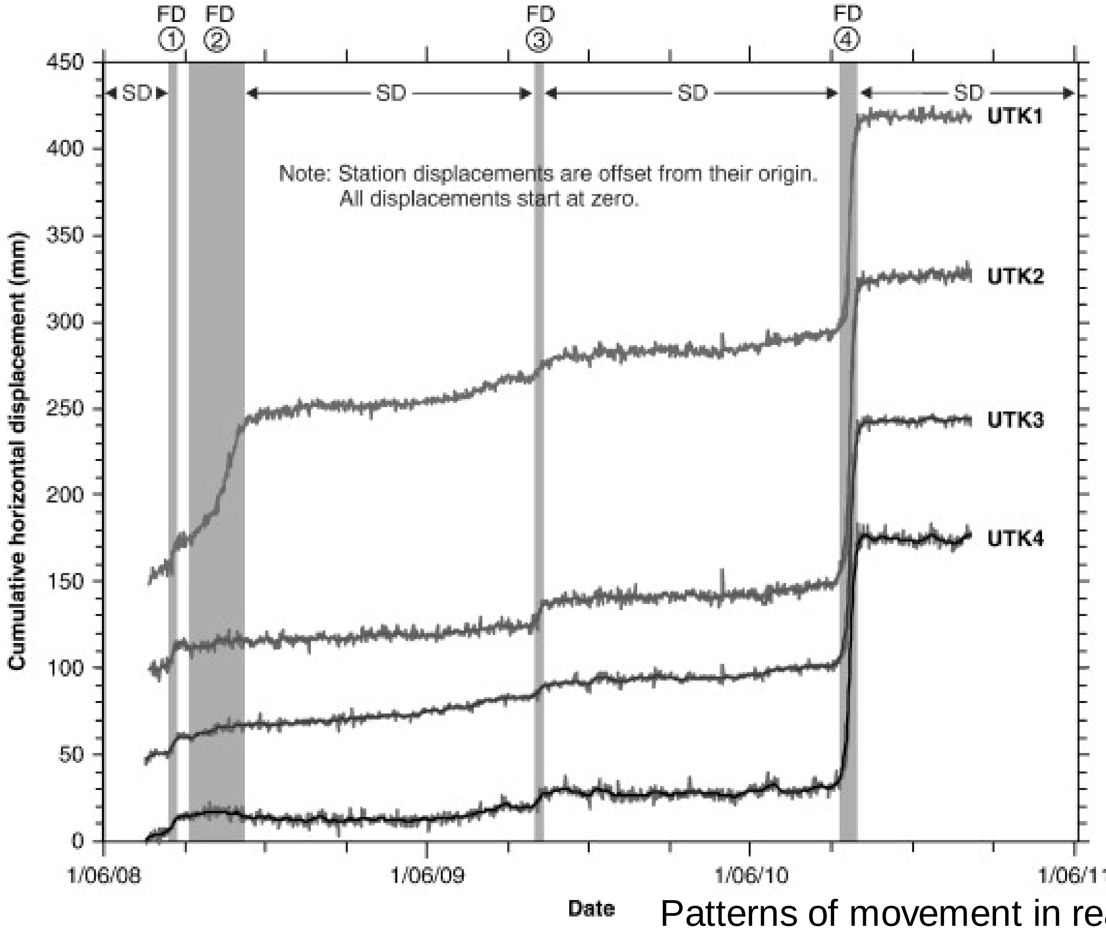
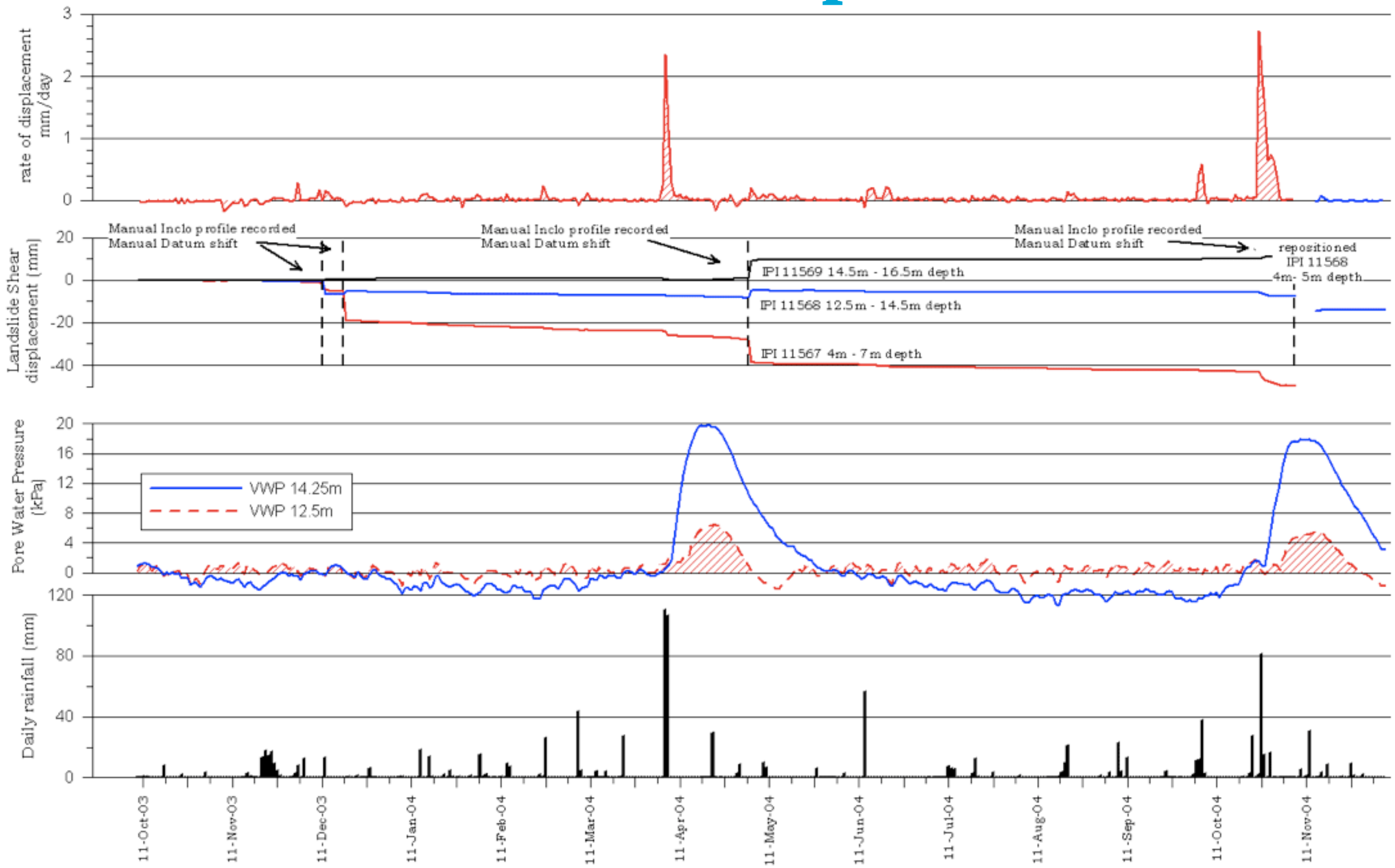
# How to detect a change?
## *… data quality and extremes*

# How to detect a change?
# Visual inspection




Patterns of movement in reactivated landslides
Massey ey al, 2013 Engineering Geology

# How to detect a change?
# Visual inspection




Patterns of movement in reactivated landslides
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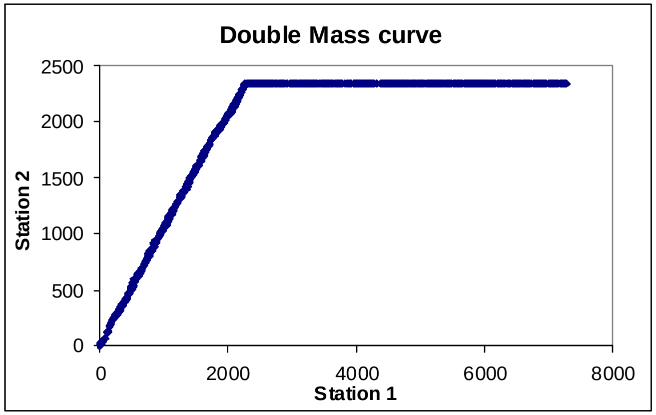
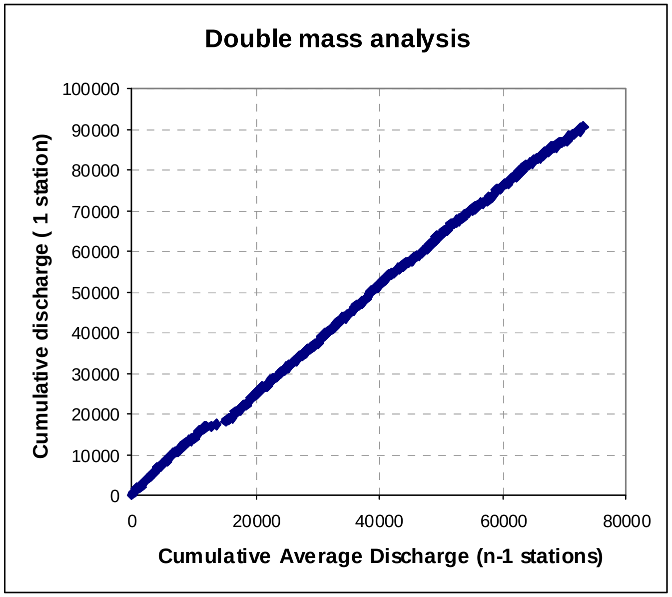
# How to detect a change?

## Double mass plot

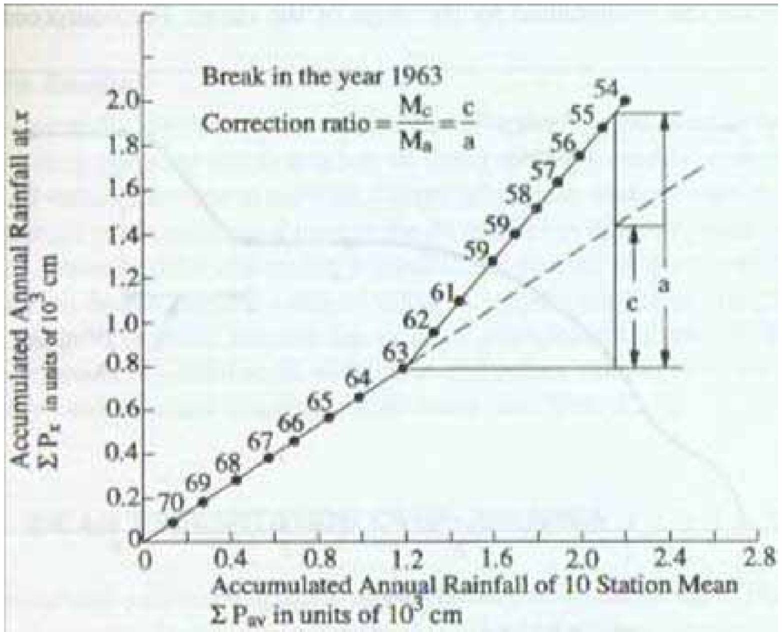
Plot cumulative observation time series against another (averaged) cumulative time series

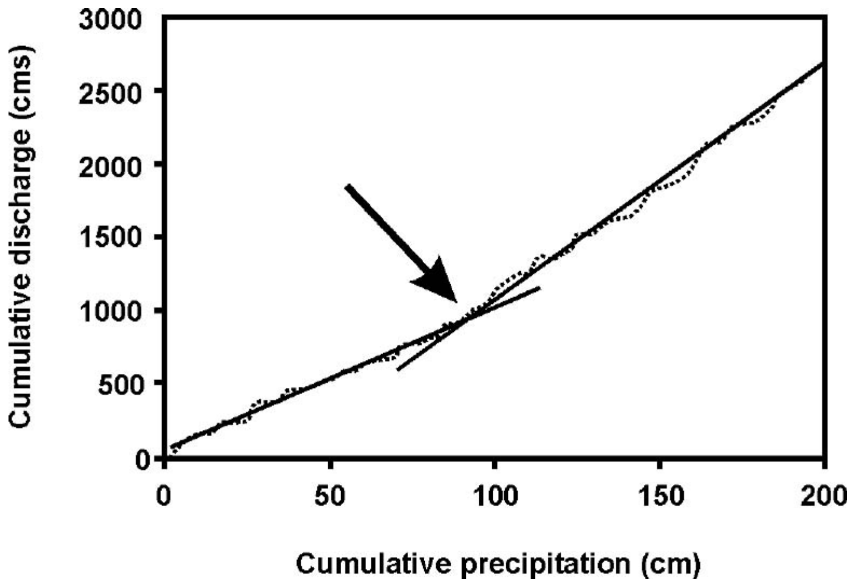


# How to detect a change?

Double mass plot



# How to detect a change?

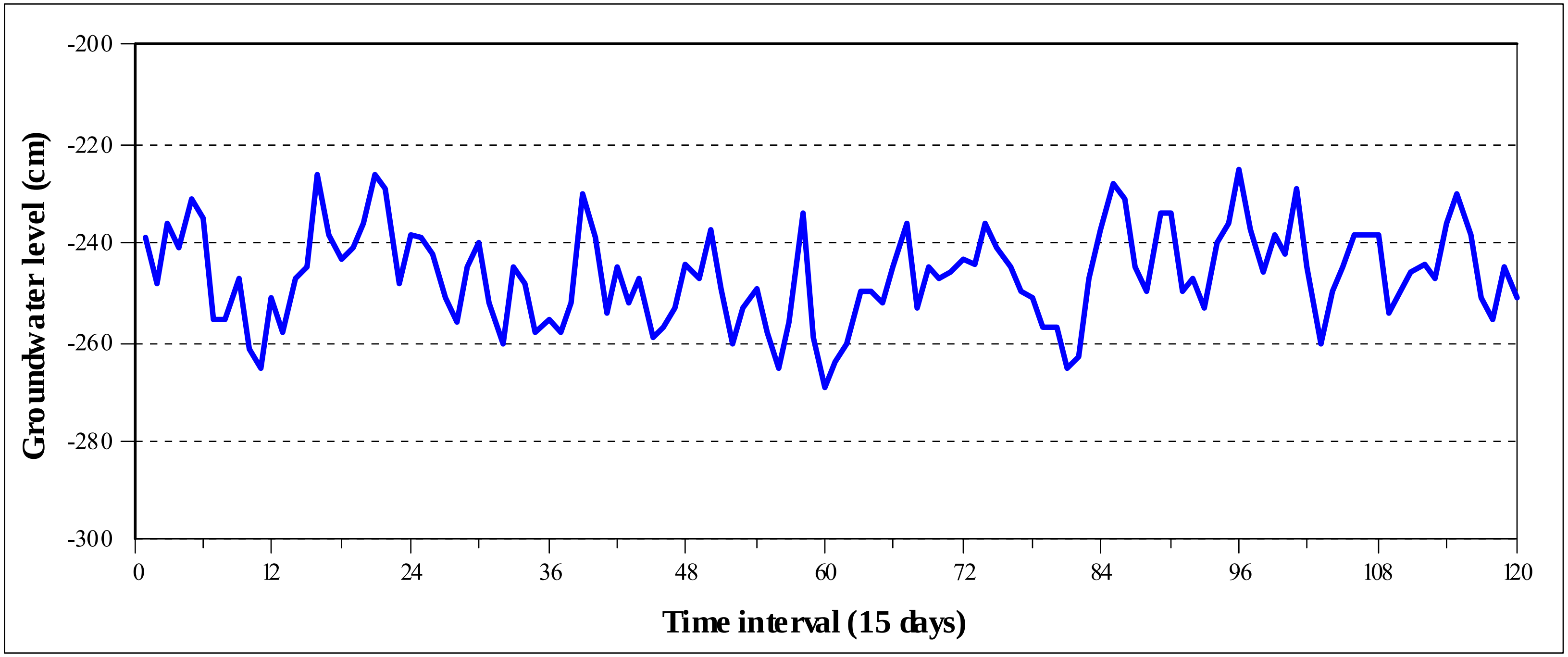
# Characteristics of Time Series

## Stationarity

- Stationary: probability distribution doesn't change with time
- First-order stationary: mean is a constant
- Second-order stationary: mean is a constant and covariance is only a function of time lag, not actual time
- Non-stationary in the mean: presence of a trend or periodicity

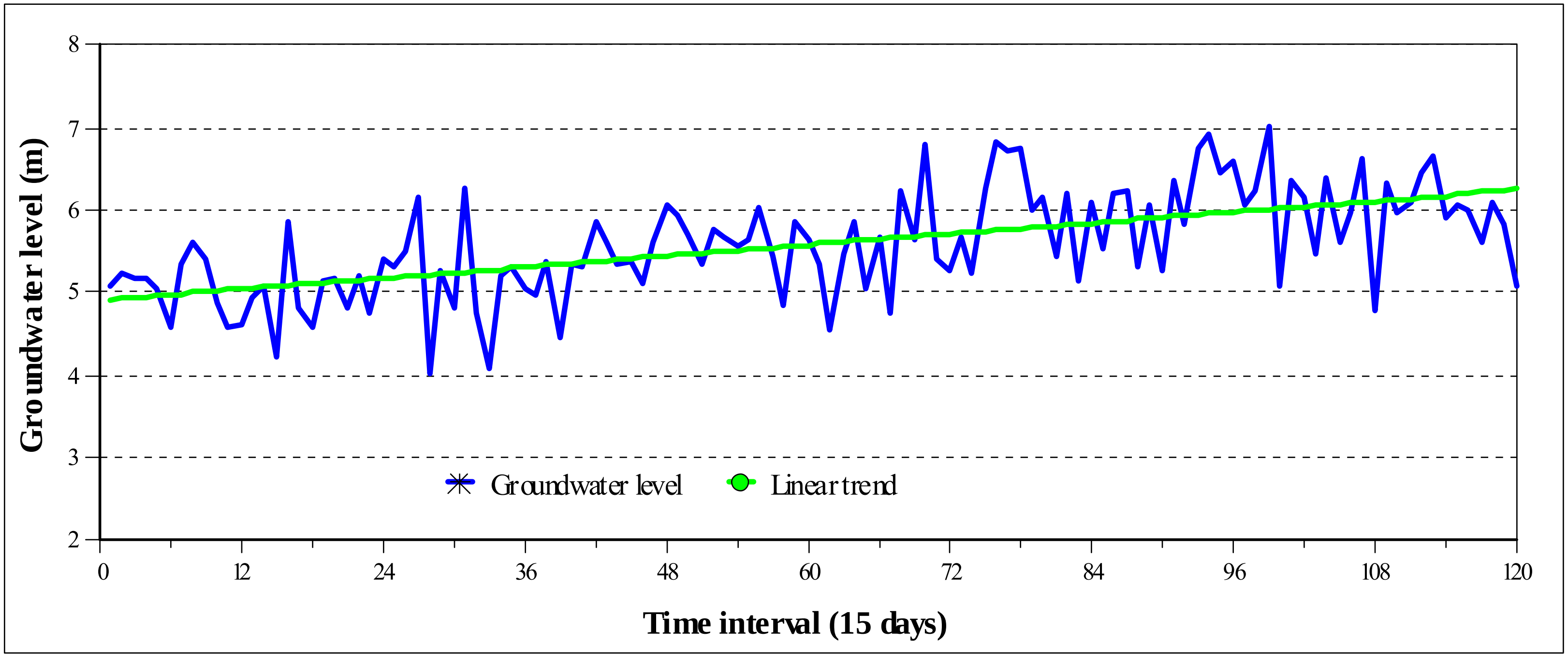
# Characteristics of Time Series

A stationary time series



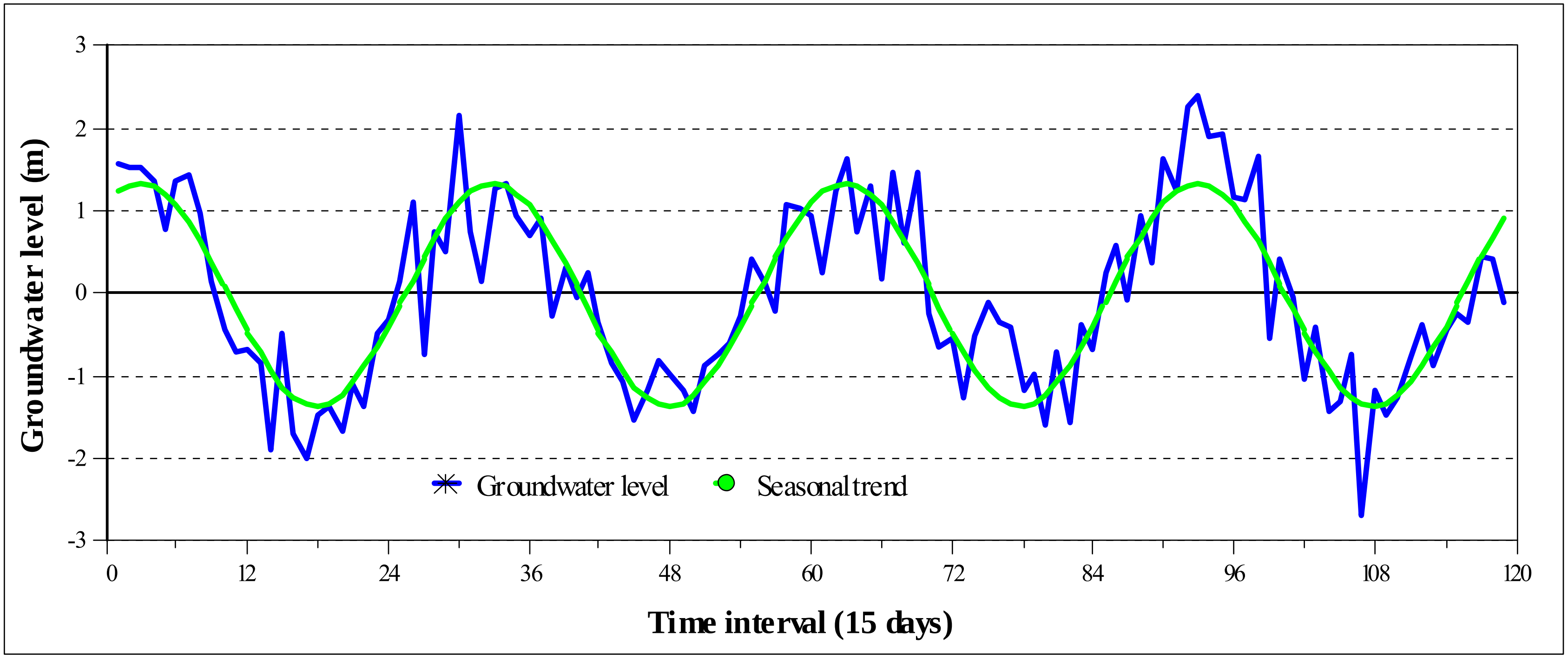
# Characteristics of Time Series

Non-stationary time series with a trend



# Characteristics of Time Series

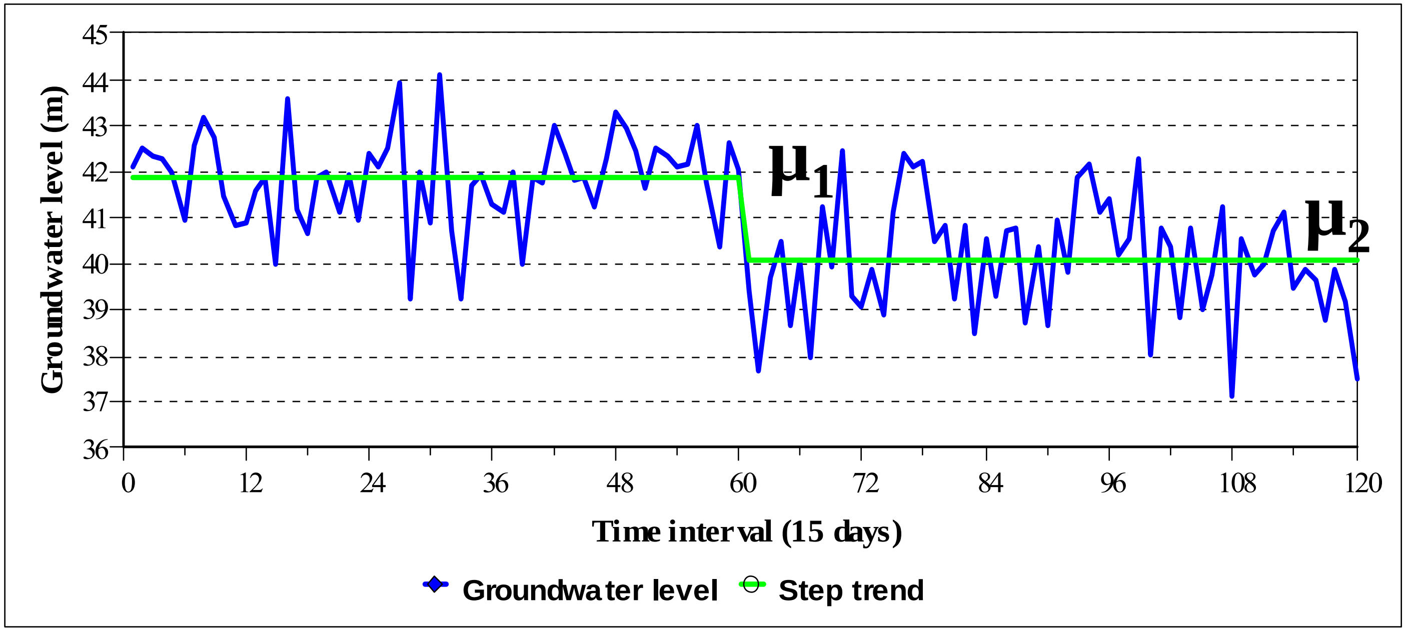
Non-stationary time series with periodic changes



# Detection of a trend

- Step trend

$$h_t = \mu_1 + (\mu_2 - \mu_1)_{t > n_1} + \varepsilon_t$$



# Detection of a step trend

- Hypothesis test

$H_0 \qquad \mu_1 = \mu_2$

$H_a \qquad \mu_1 \neq \mu_2$

t statistic

$$t = \frac{|\overline{x_1} - \overline{x_2}|}{2\, s_p / \sqrt{n}} \propto t(n-2)$$

- t test result

Given $\alpha$(5%), find $t_{\alpha/2}(n-2)$ from Student table

If $t > t_{\alpha/2}(n-2)$ accept $H_a$, step trend is significant

If $t \leq t_{\alpha/2}(n-2)$ accept $H_0$, step trend is not significant

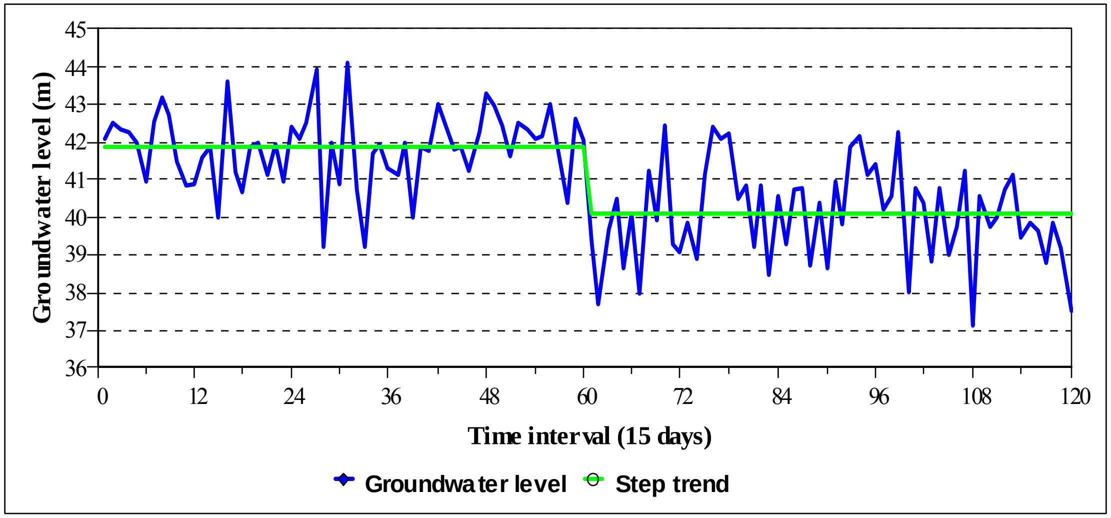
# Detection of a step trend

$$\bar{h}_1 = \frac{1}{60}\sum_{i=1}^{60} h_i = 42.0 \quad \bar{h}_2 = \frac{1}{60}\sum_{i=61}^{120} h_i = 40.0$$

$$s_p^2 = \frac{1}{120-2}\left[\sum_{i=1}^{60}(h_i - 42.0)^2 + \sum_{i=61}^{120}(h_i - 40.0)^2\right] = 1.1$$

$$t = \frac{|42.0 - 40.0|}{2 * 1.1/\sqrt{120}} = 9.89$$

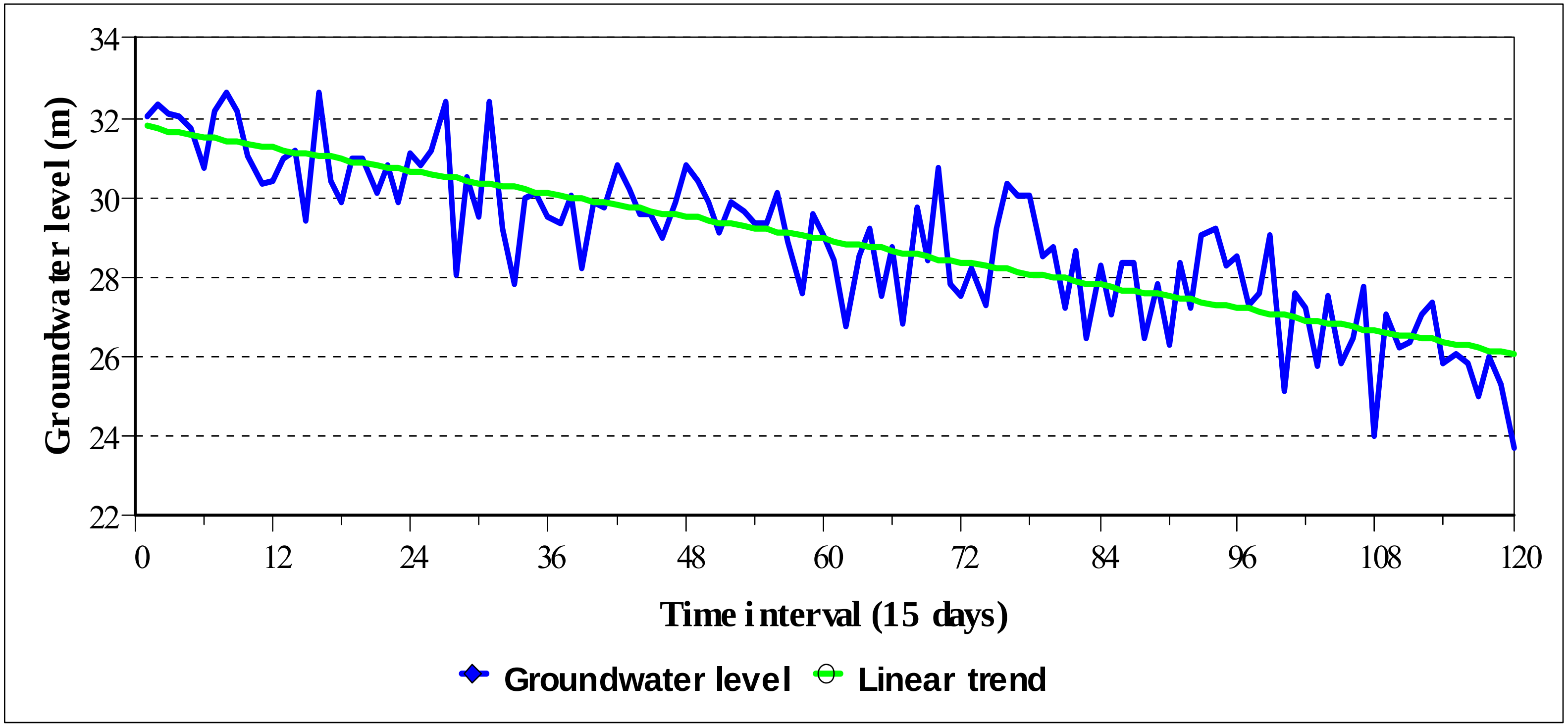
$t_{0.025}(118) = 1.96$



# Detection of a linear trend

$$h_t = \beta_0 + \beta_1 t + \varepsilon_t$$

$$h_t = b_0 + b_1 t$$



# Detection of a linear trend

- Hypothesis test

  $H_0 \quad \beta_1 = 0$

  $H_a \quad \beta_1 \neq 0$

- t statistic

$$t = \frac{|b_1|}{\sqrt{12}\, s_l / \sqrt{n(n+1)(n-1)}} \propto t(n-2)$$

- t test result

  Given $\alpha$(5%), find $t_{\alpha/2}(n-2)$ from Student table

  If $t > t_{\alpha/2}(n-2)$ accept $H_a$, linear trend is significant

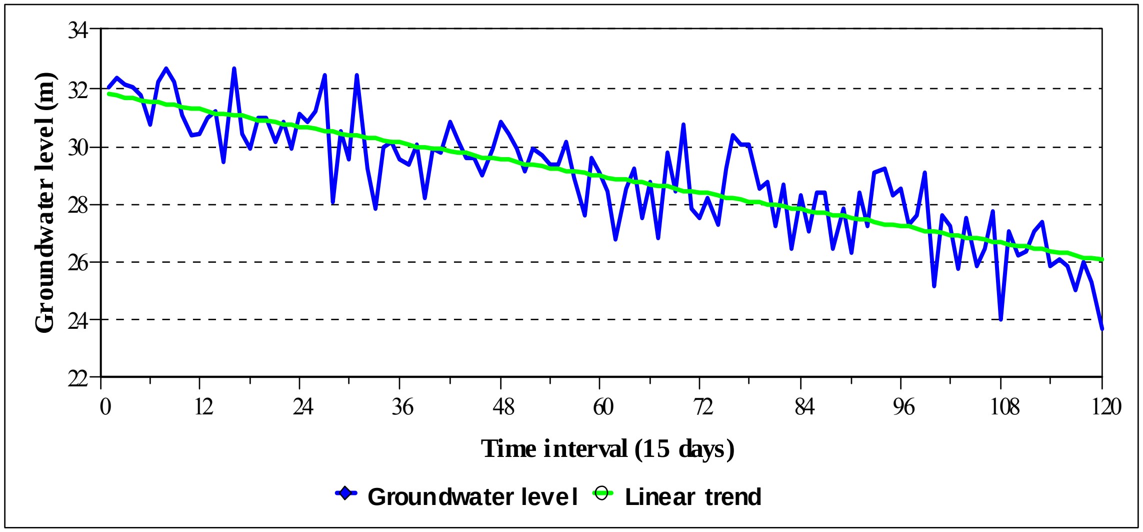
  If $t \leq t_{\alpha/2}(n-2)$ accept $H_0$, linear trend is not significant

# Detection of a linear trend

Example of detecting a linear trend

$$b_1 = \frac{\sum_{t=1}^{n}(h_t - \bar{h})(t - \bar{t})}{\sum_{t=1}^{n}(t - \bar{t})^2} = -0.05$$

$$b_0 = \bar{h} - b_1\bar{t} = 32.0$$

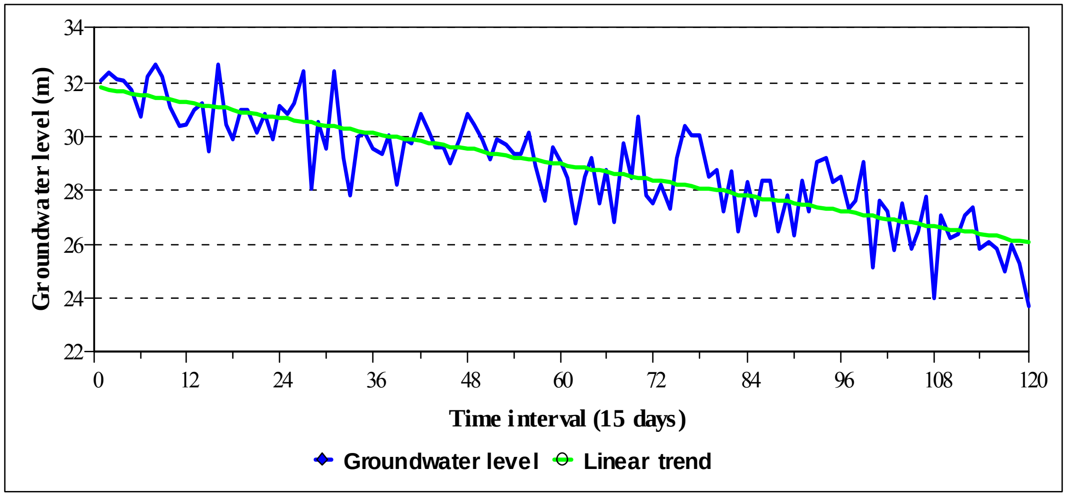


# Detection of a linear trend

Example of detecting a linear trend

$$s_l^2 = \frac{1}{n-2}\sum_{t=1}^{n}(h_t - b_0 - b_1 t)^2 = 1.0$$

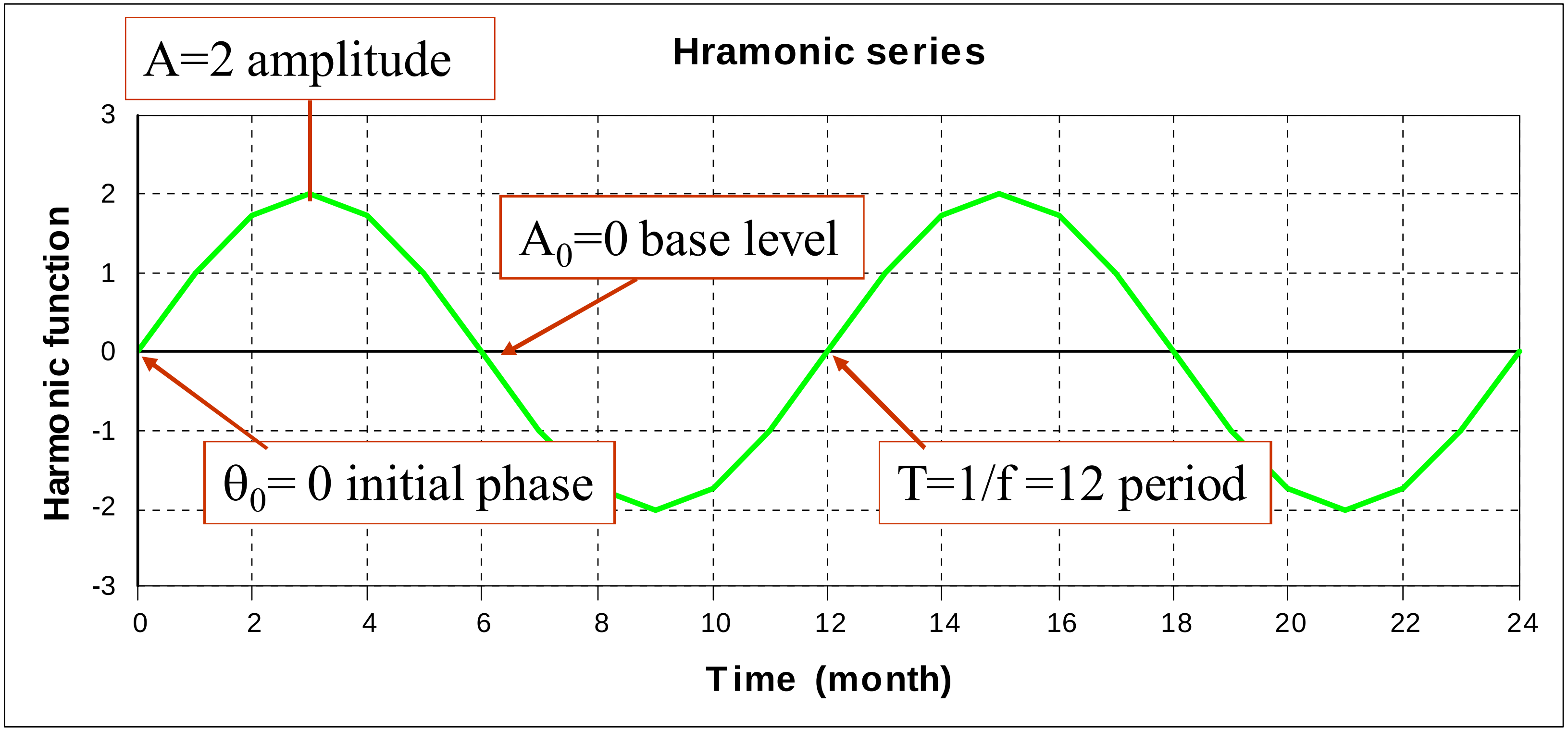
$$t = \frac{|-0.05|}{\sqrt{12*1.0/\sqrt{120*121*119}}} = 18.97 \qquad t_{0.025}(118) = 1.96$$



# Detection of a periodic trend

Characteristics of a harmonic function

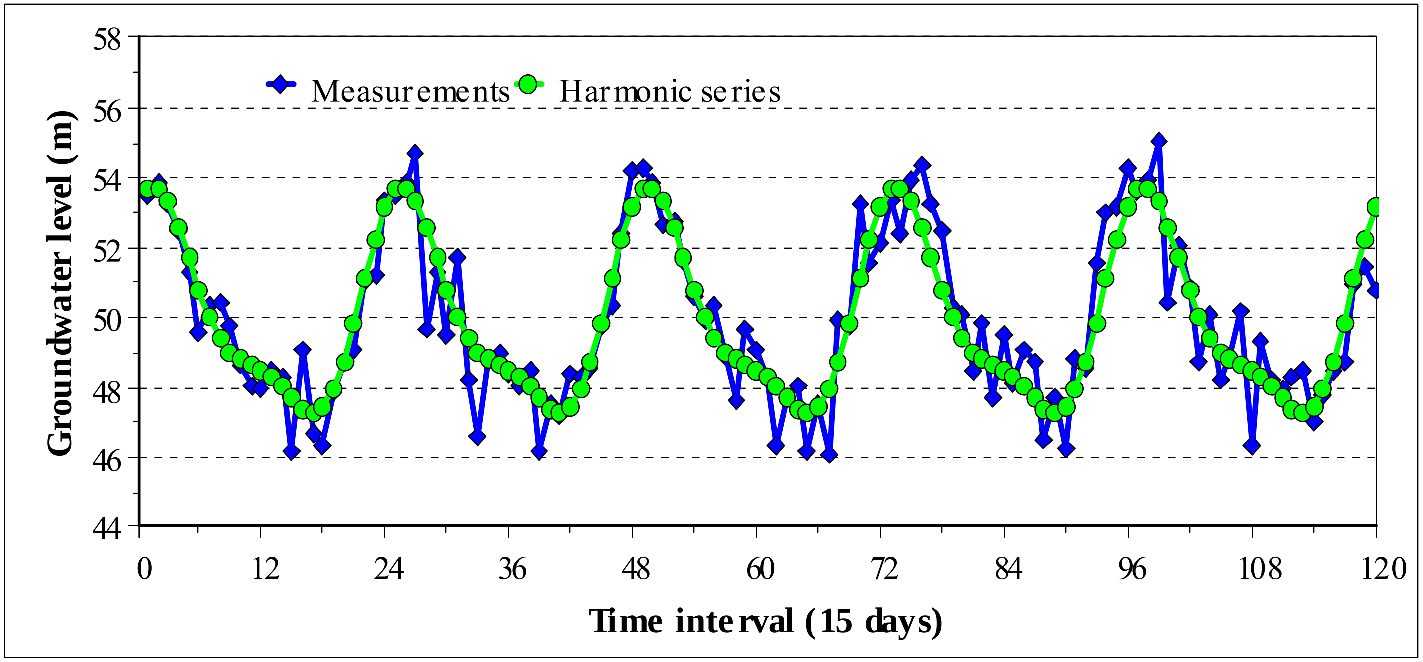
$$h_t = A_0 + A\,\sin(2\pi f\, t + \theta_0)$$



# Detection of a periodic trend

Fit of harmonic series with 2 harmonics

$$h_t = 49.97 + 2.23\cos\left(\frac{2\pi t}{24}\right) + 1.68\sin\left(\frac{2\pi t}{24}\right) + 0.86\cos\left(\frac{2\pi t}{12}\right) + 0.53\sin\left(\frac{2\pi t}{12}\right)$$



# Shifts in the Mean

1. Student's t-test
2. Bayesian analysis
3. Mann–Whitney U-test
4. Wilcoxon rank sum
5. Pettitt test
6. Mann-Kendall test
7. Lepage test
8. Standard normal homogeneity test
9. Regression-based approach
10. CUSUM test
11. Oerlemans method
12. Signal-to-noise ratio
13. Intervention analysis
14. Markov chain Monte Carlo
15. Lanzante method

# Shifts in the Variance

1. Downton-Katz test

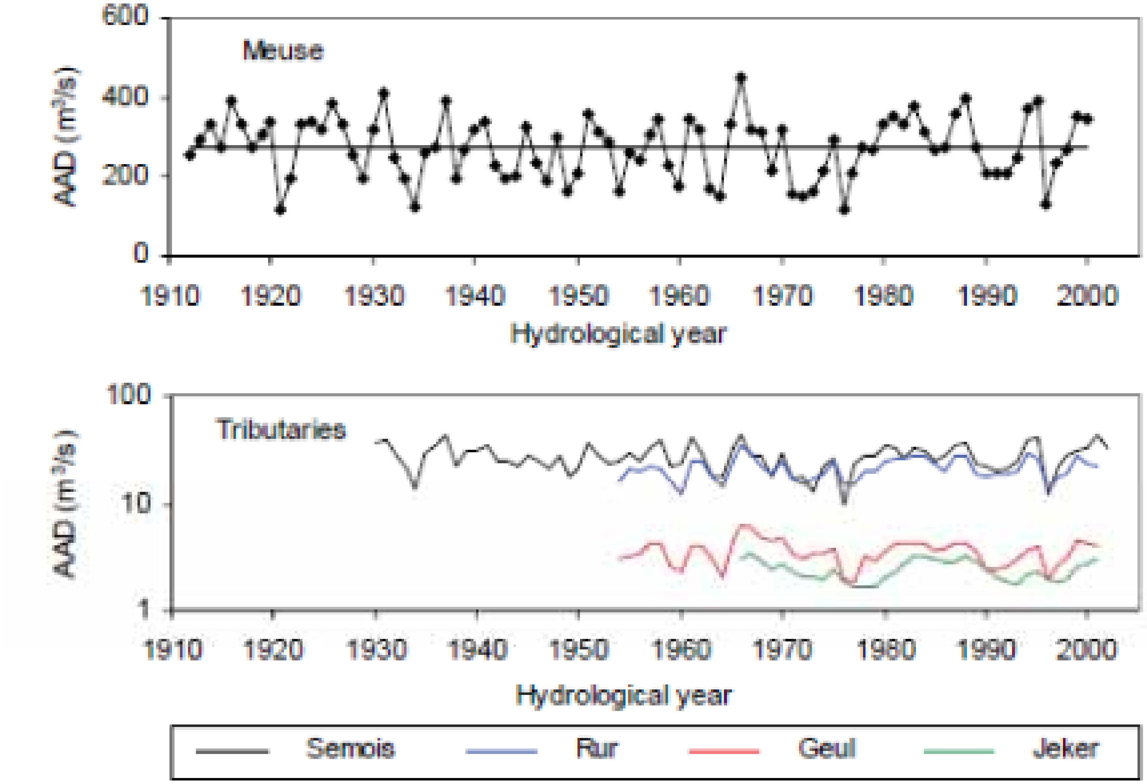
# Shifts in the Spectrum

1. Nikiforov method

# Shifts in the System

1. Principal component analysis
2. Average standard deviates
3. Fisher information
4. Vector autoregressive method

# Example: Min Tu – Assessment of the effects of climate variability and land use change on the hydrology of the Meuse river basin (2006)



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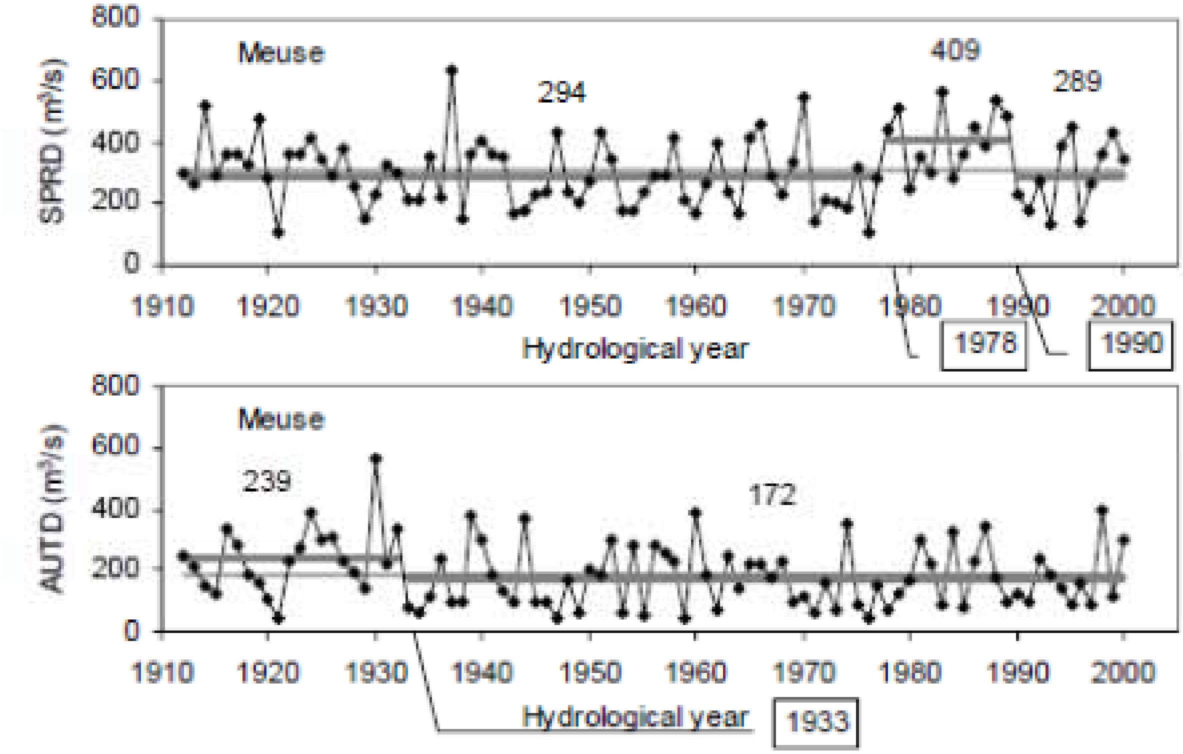

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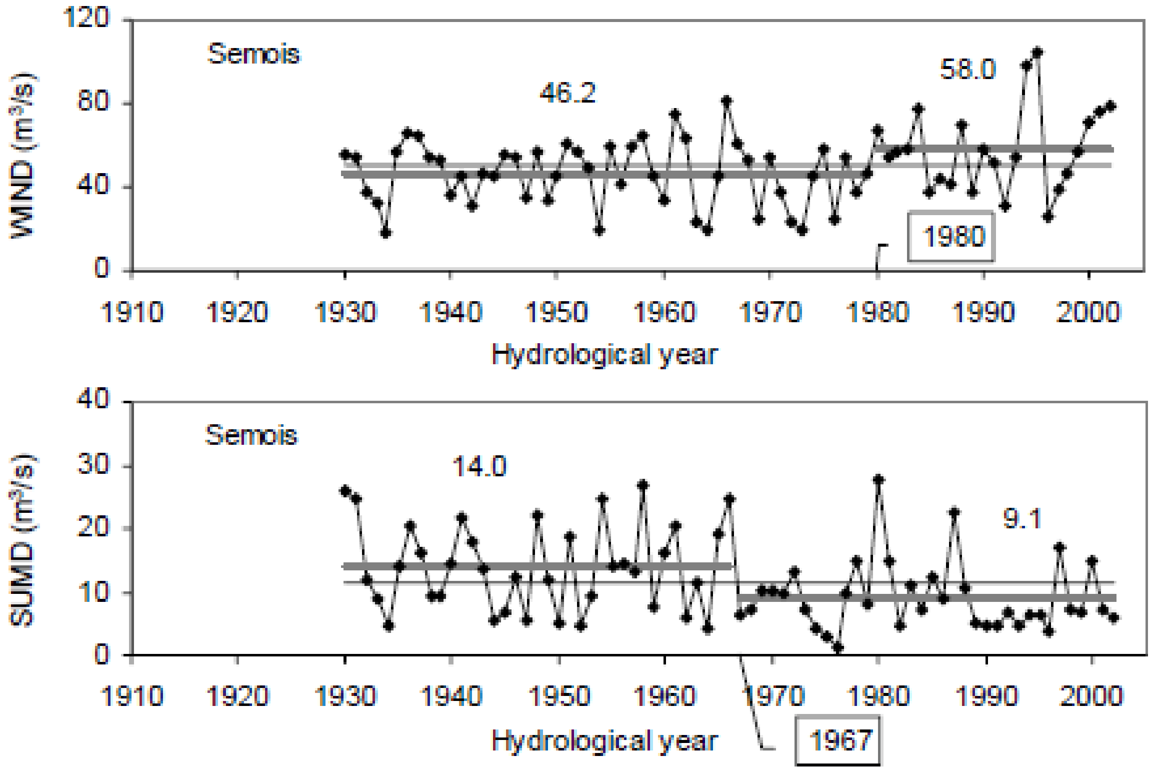

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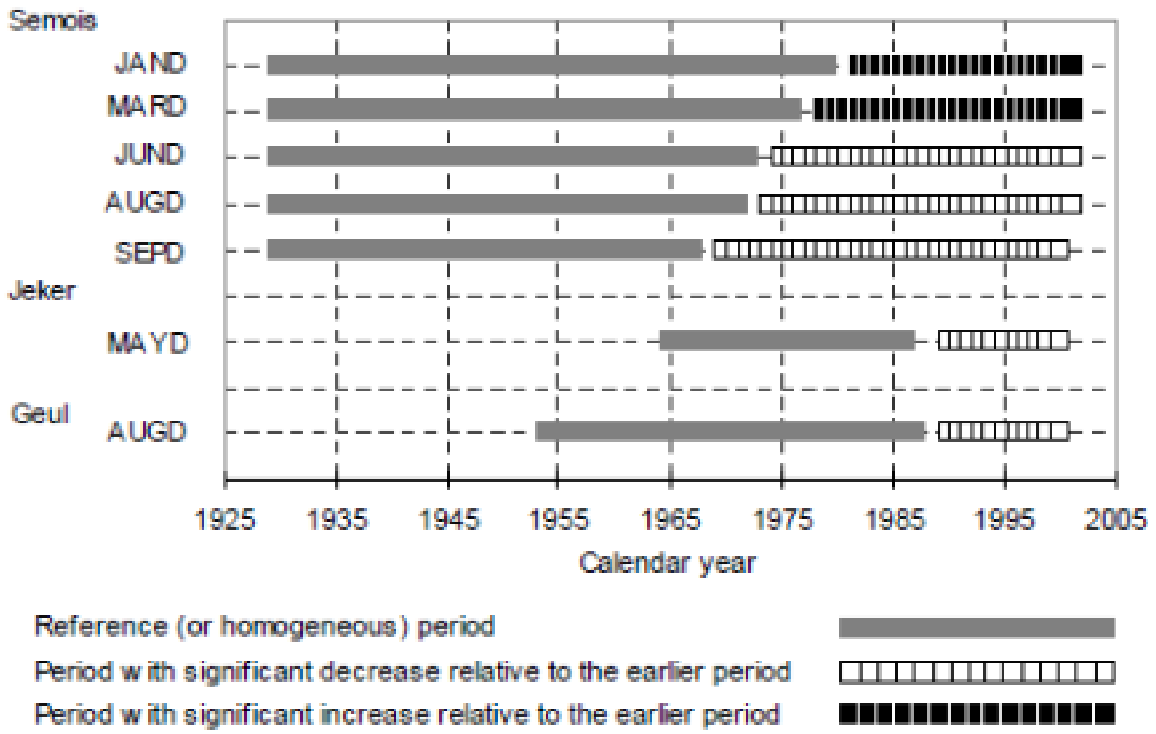

# Example: Min Tu – Assessment of the effects of climate variability and land use change on the hydrology of the Meuse river basin (2006)

- Climate-induced increase in the magnitude/frequency of winter floods in the Meuse river since the early 1980s;
- Marginal or statistically undetectable effects of the historical land use changes on the discharge regime of the Meuse river during the 20th century.

# Change detection in monitoring time series

## Summary

- What is a time series?
- What are we monitoring?
- What is a change?
    - Step, linear, periodicity, etc
- How can we detect the time series changes?
    - Visual, double mass, statistical, ....

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