To know what we cannot know: Global mapping of minimal detectable precipitation trends

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Talk outline

- ☐ The problem
- ☐ Objectives
- ☐ Methodology
- ☐ Minimal trend detection
- ☐ Global mapping
- ☐ Controls of the minimal detectable trend
- ☐ Hydrological implications
- ☐ Summary

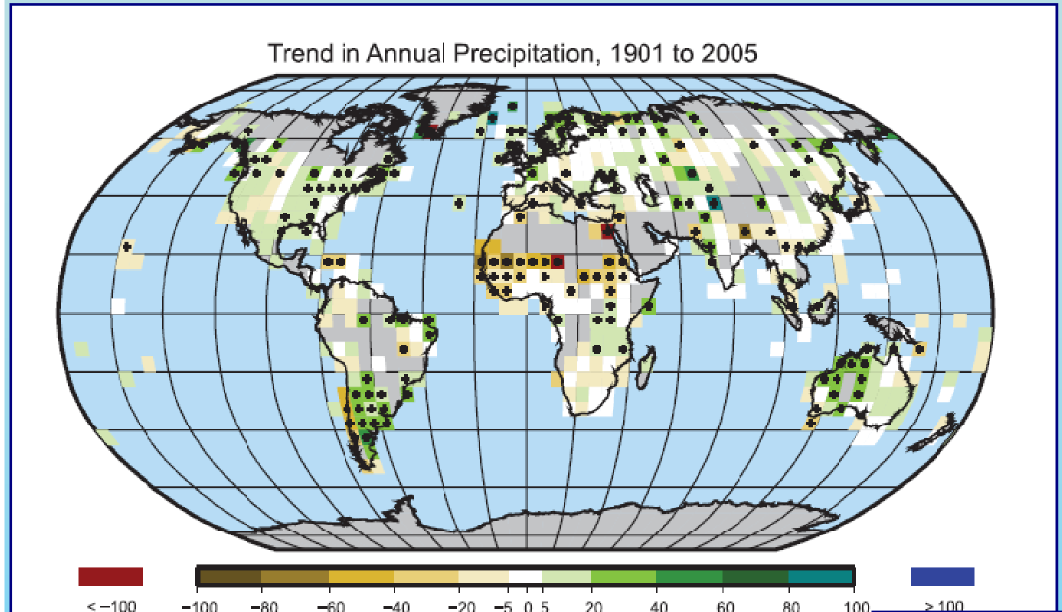
The problem

Precipitation trends **are of special interest in water resources management and planning**

But

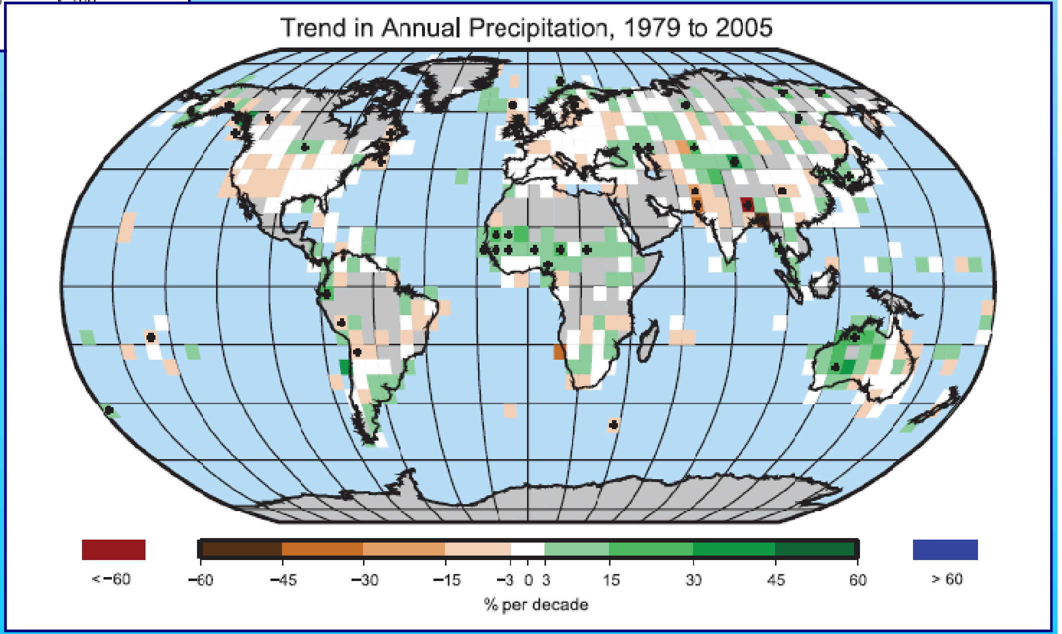
The natural high variability of precipitation data masks the possibility to detect existing trends

The problem



Trend in Annual Precipitation, 1901 to 2005

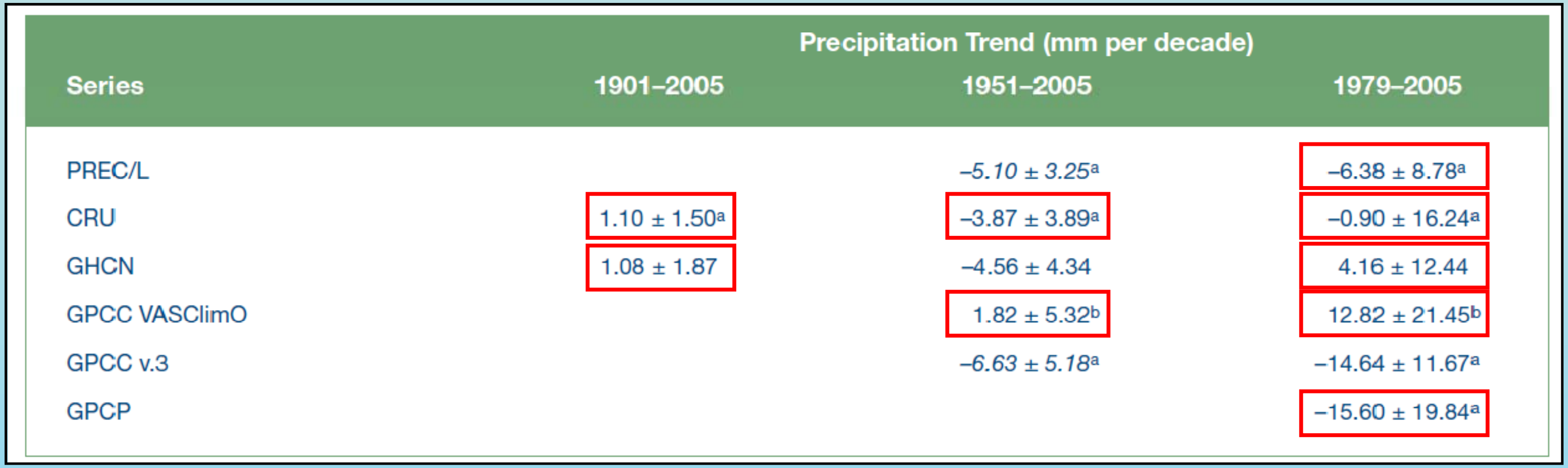
Trends are <u>insignificant</u> in most land areas



Trend in Annual Precipitation, 1979 to 2005

Trenberth et al., 2007 (Ch. 3 in the 4th Assessment Report of the IPCC)

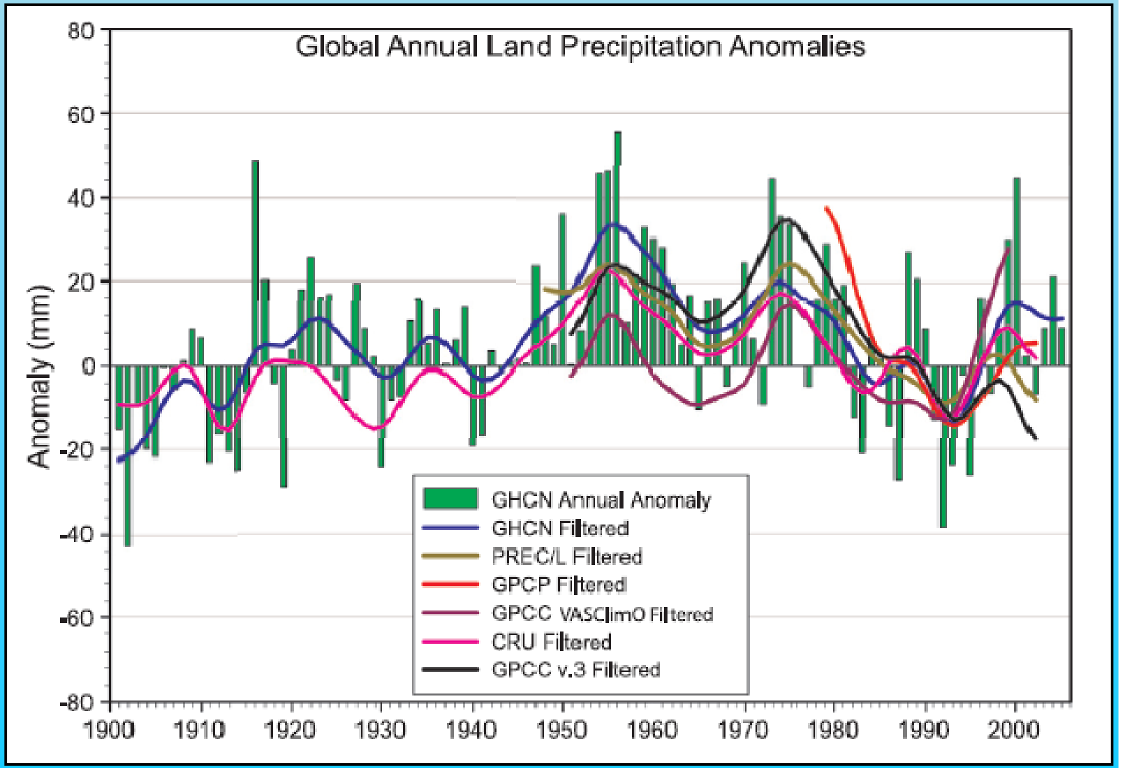
The problem



Series	Precipitation Trend (mm per decade) 1901–2005	1951–2005	1979–2005
PREC/L		*−5.10 ± 3.25*[a]	−6.38 ± 8.78[a]
CRU	1.10 ± 1.50[a]	−3.87 ± 3.89[a]	−0.90 ± 16.24[a]
GHCN	1.08 ± 1.87	−4.56 ± 4.34	4.16 ± 12.44
GPCC VASClimO		1.82 ± 5.32[b]	12.82 ± 21.45[b]
GPCC v.3		*−6.63 ± 5.18*[a]	−14.64 ± 11.67[a]
GPCP			−15.60 ± 19.84[a]

☐ **Insignificant trends**

Trends in land averaged data are also often <u>insignificant</u>

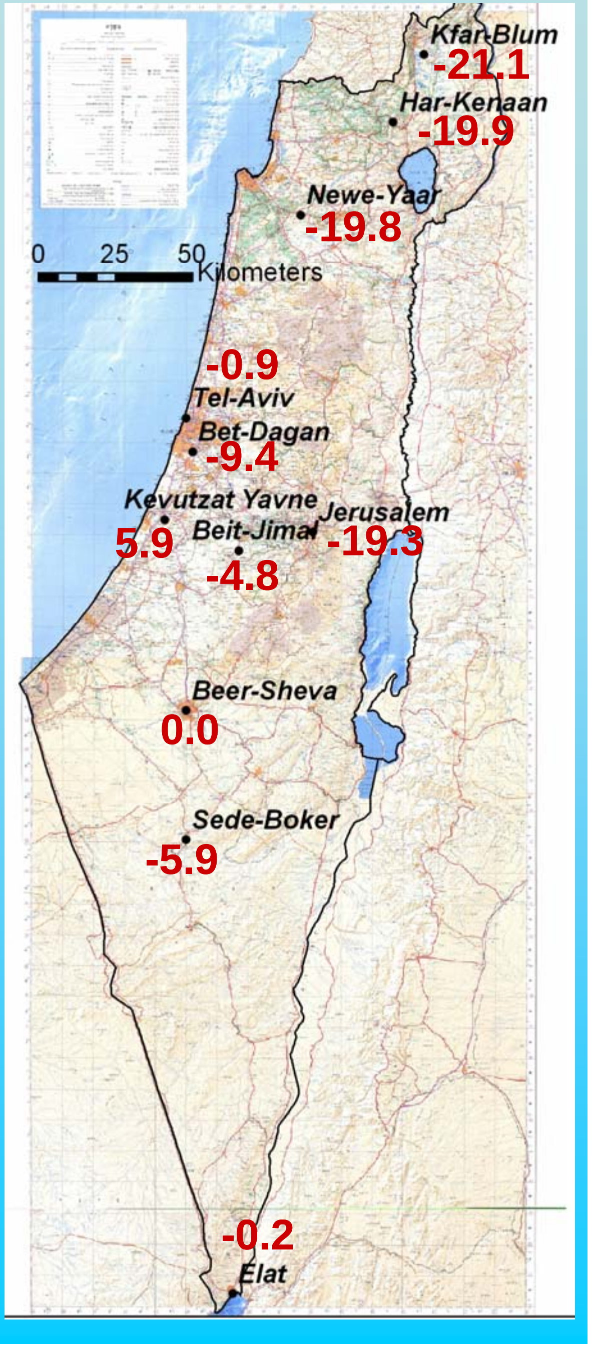


Trenberth et al., 2007 (Ch. 3 in the 4th Assessment Report of the IPCC)

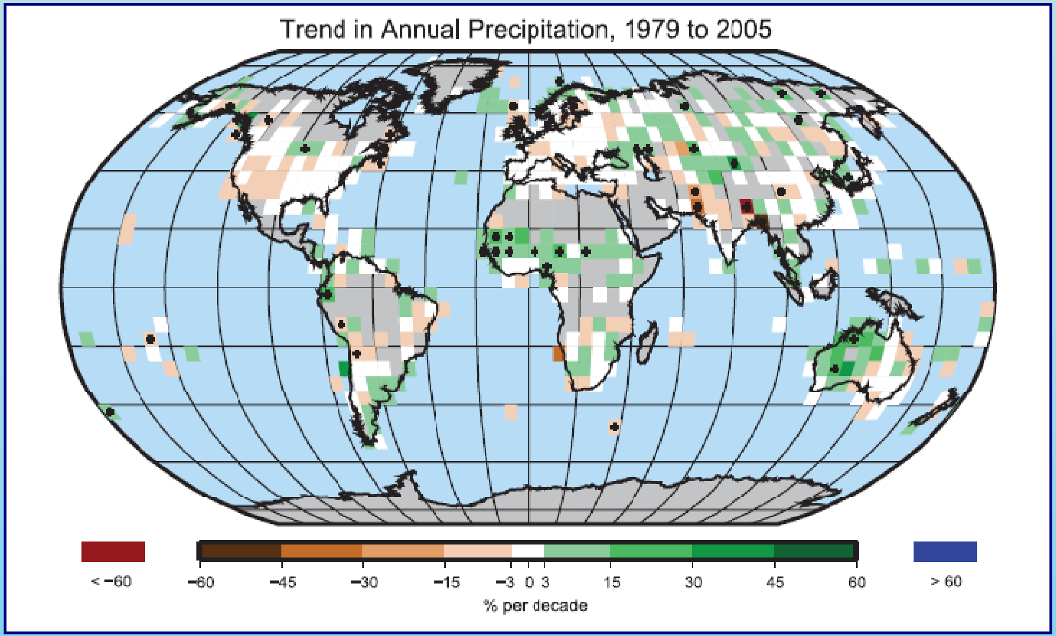
The problem

Israeli stations: Trends in mm per decade for 1964-2003

Trends are <u>insignificant</u> in <u>all</u> examined stations



The problem



<u>**How to deal with insignificant trends?**</u>

Option 1: assume there are no trends

Option 2: understand that trends maybe exist but have a low chance to be detected (i.e., probability of type II error is large)

Taking approach 2 we can at least estimate what is the "<u>**minimal detectable trend**</u>" for specific conditions

Objective

The main objective is to quantify and to map over the globe lower limits of detectable annual precipitation linear trends

Objective

The minimal detectable trend:

The minimal trend (absolute value) that the probability to identify it as significant (5% level) is higher than a pre-selected threshold (in this study: 20 and 50%).

In statistical terms: the minimal trend for which the power of the test (the complementary of the probability of type II error) is higher than a pre-selected threshold.

Methodology

Assumptions:

- Record length: 50 years

$$t_1 \cdots t_{50}$$

- Annual precipitation data

$$P_1 \cdots P_{50}$$

- Linear trends

$$P_i = \alpha + \beta t_i + \varepsilon_i$$

- Assumptions on residuals: depends on trend detection method

- 5% significance level

Methodology

Linear trend detection

Simple linear regression method:

Residuals are assumed to be independent, normally distributed with equal variance. Regression parameters are estimated from data using least square method, and their significance is examined with a t-test.

Mann-Kendall method:

A good non-parametric, rank-based alternative for simple linear regression when the normality assumption cannot be met and an outlier effect should be reduced. Modifications exist to account for serial correlation of residuals.

Methodology

Mann-Kendall method:

$$\hat{\beta} = \underset{i<j}{median}\left(\frac{P_j - P_i}{t_j - t_i}\right)$$

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(P_j - P_i)$$

$$Var(S) = \frac{1}{18}\left(n(n-1)(2n+5)\right)$$

$$z = \frac{S - sign(S)}{\sqrt{Var(S)}} \sim N(0,1) \quad \text{for n>8}$$

* Accounting for serial correlation

* Accounting for ties

Minimal trend detection

Realizations of annual precipitation 50-year data series were generated for a given positive trend (β) and precipitation characteristics: mean ($\overline{P}$) and coefficient of variance ($CV(P)$)

$$t_i = 1951:2000$$

$$P_i = \alpha + \beta t_i + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2)$$ independent

$$\alpha = \overline{P} - \beta \cdot \overline{t}$$

Minimal trend detection

Residual variance is related to precipitation moments assuming zero covariance between the residuals and the time:

$$\sigma^2 = Var(\varepsilon) =$$

$$= Var(P) - \beta^2 \cdot Var(t) =$$

$$= \left(CV(P) \cdot \overline{P}\right)^2 - \beta^2 \cdot Var(t)$$

Minimal trend detection

Example:

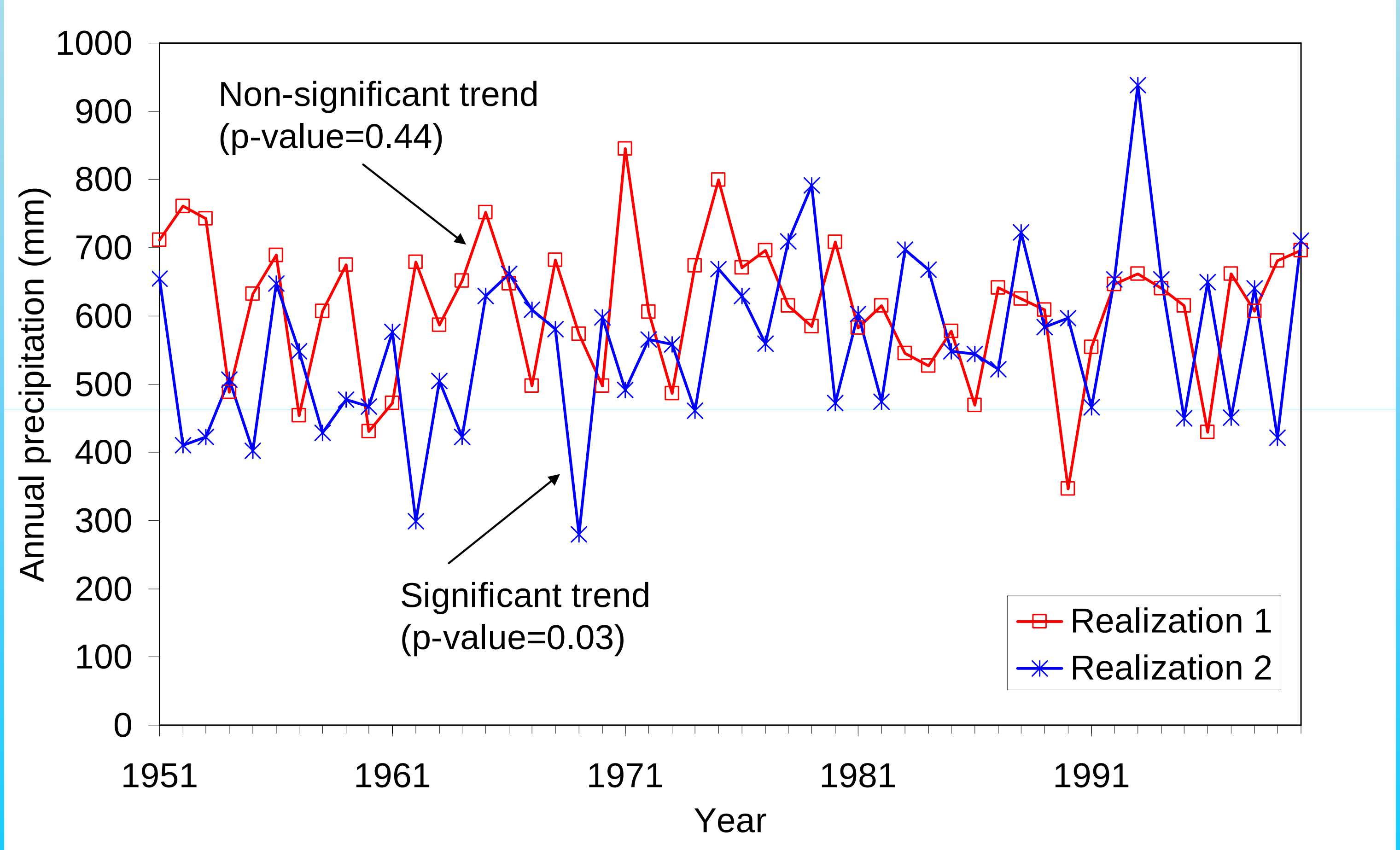
$$\overline{P} = 600mm$$

$$Std(P) = 120mm$$

$$CV(P) = 0.20$$

$$\beta = 10mm/decade$$

=> 8% in 50 years



Minimal trend detection

Example:

$$\overline{P} = 600mm$$

$$Std(P) = 120mm$$

$$CV(P) = 0.20$$

$$\beta = 10mm/decade$$

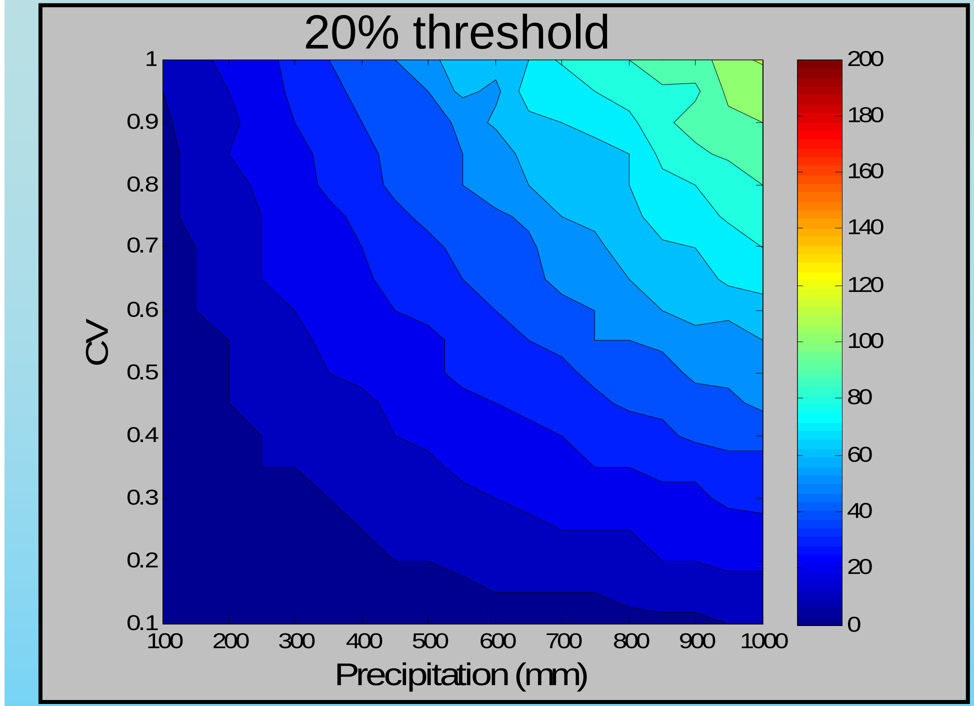
=> 8% in 50 years

Monte-Carlo simulations: 1000 realizations
12% found significant, 88% found insignificant at 5% level
(i.e., estimated probability of type II error is: 88%)

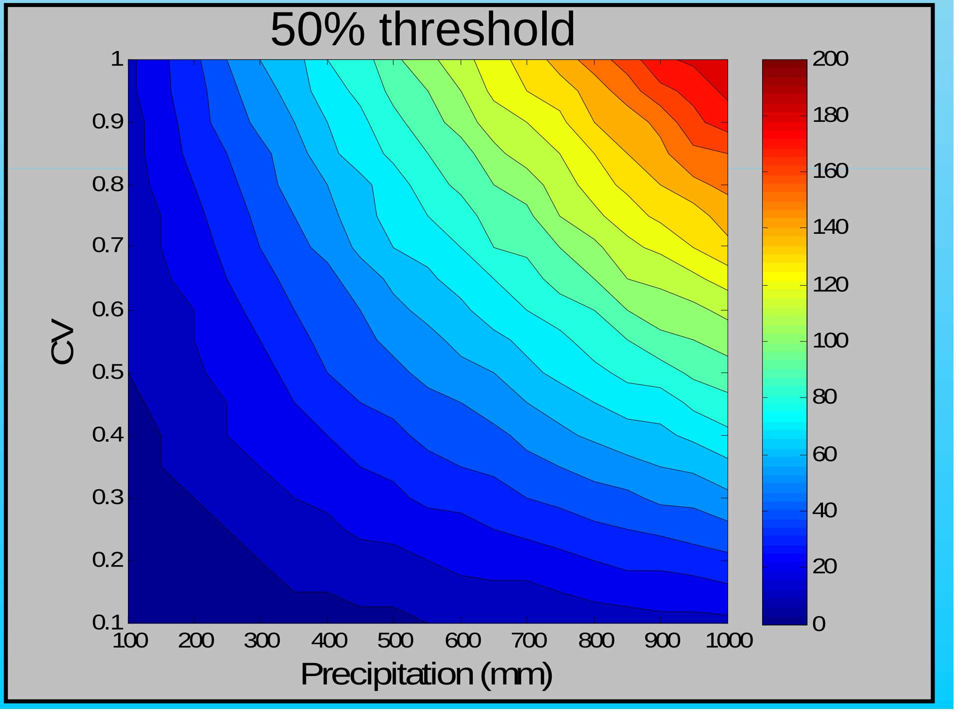
Probability of this trend to be detected is estimated 12% which is lower from the pre-defined thresholds of 20 and 50%.
The computations is done for different trend magnitudes until the thresholds are exceeded.
For mean precipitation of 600 mm and CV of 0.2 the minimal detectable trends are:

12.5 mm/decade with 20% probability threshold
20.0 mm/decade with 50% probability threshold

Minimal trend detection



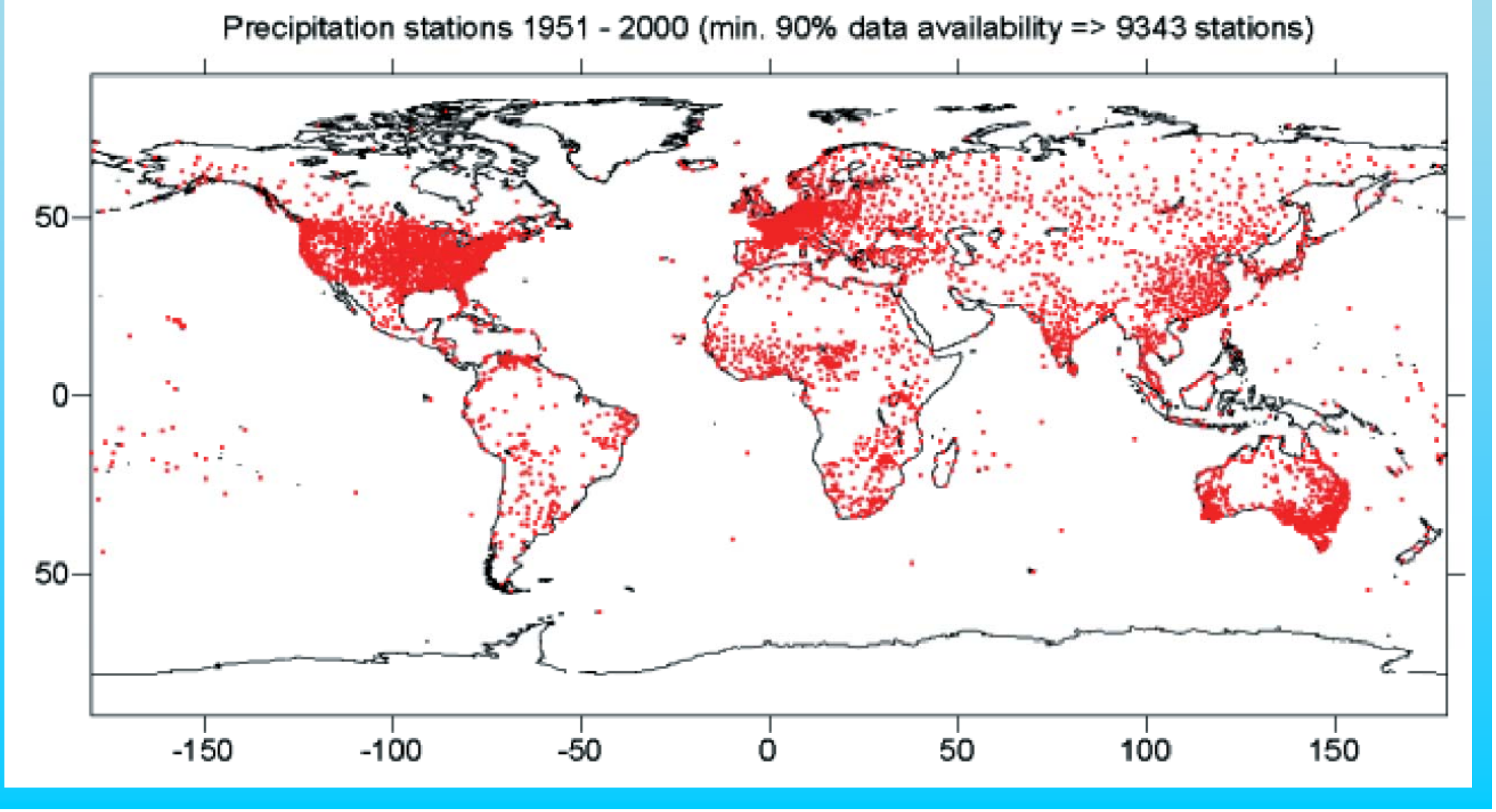
Response surfaces of the minimal detectable trend (in mm/decade) as a function of the precipitation mean and CV



Global mapping

The GPCC VASClimO data set was used to compute mean annual precipitation and CV globally over land areas for years 1951-1999 at 0.5º x 0.5º resolution

Beck et al., 2004

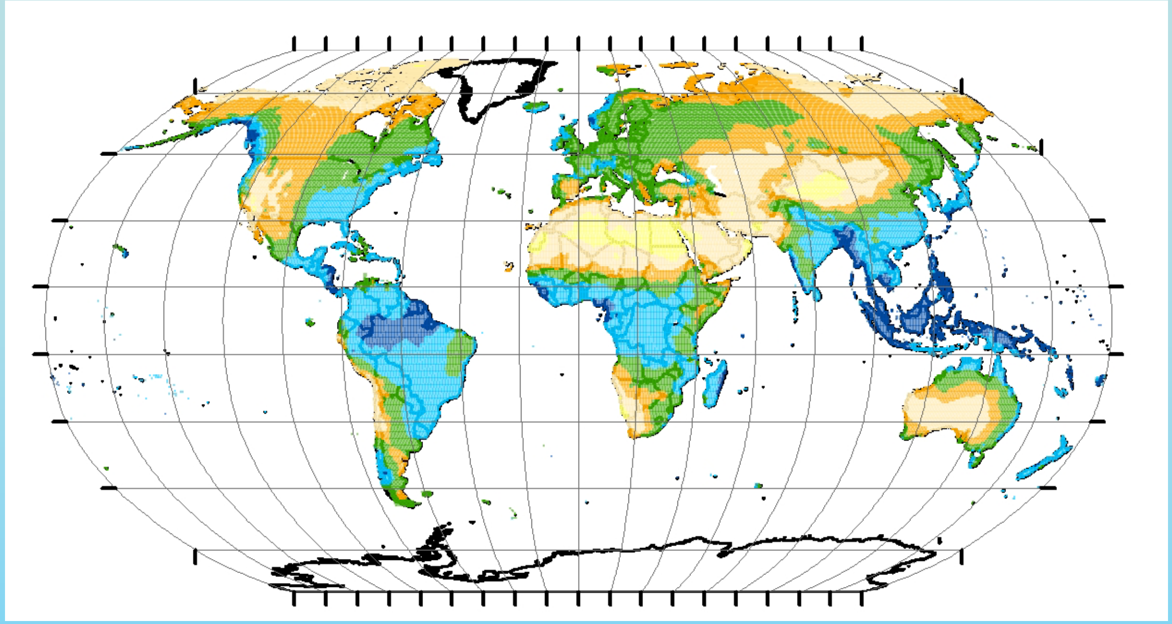


Global mapping

Mean annual precipitation

Precipitation (mm)

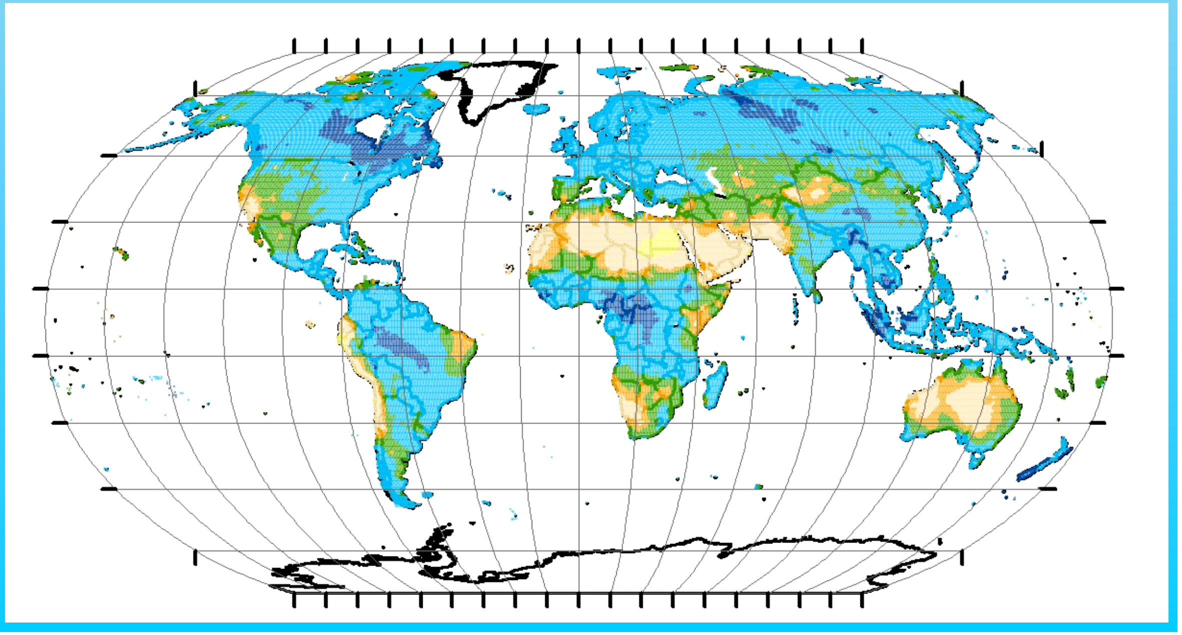
- ● < 100
- ● 100 - 300
- ● 300 - 500
- ● 500 - 1000
- ● 1000 - 2000
- ● > 2000



CV

CV

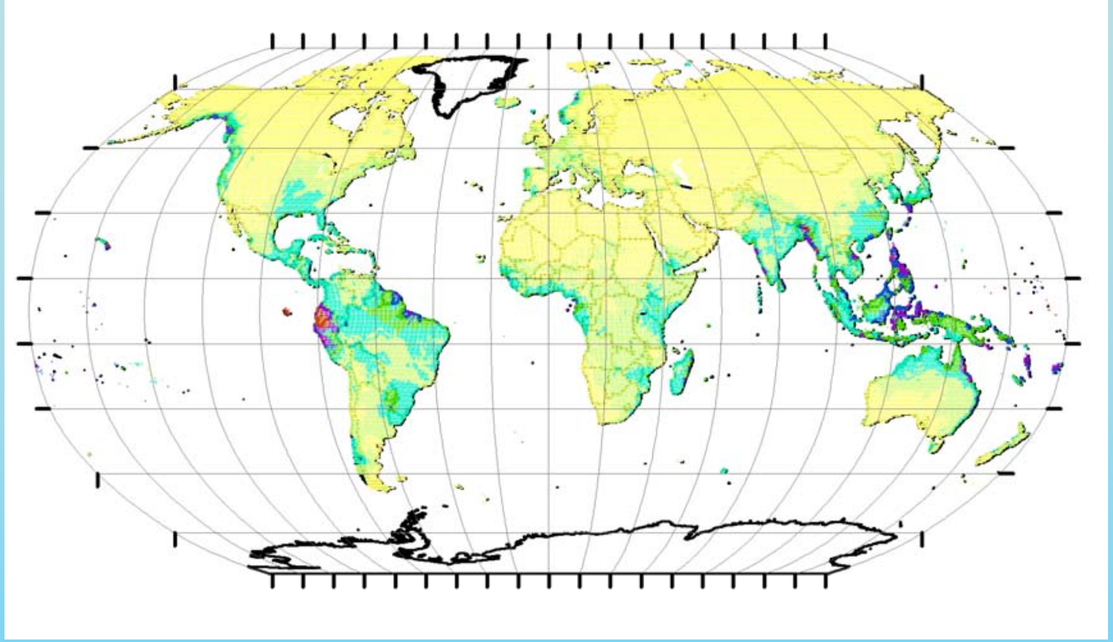
- ● < 0.1
- ● 0.1 - 0.2
- ● 0.2 - 0.3
- ● 0.3 - 0.4
- ● 0.4 - 1.0
- ● > 1.0



Based on GPCC VASClimO data set

Global mapping

20% probability threshold

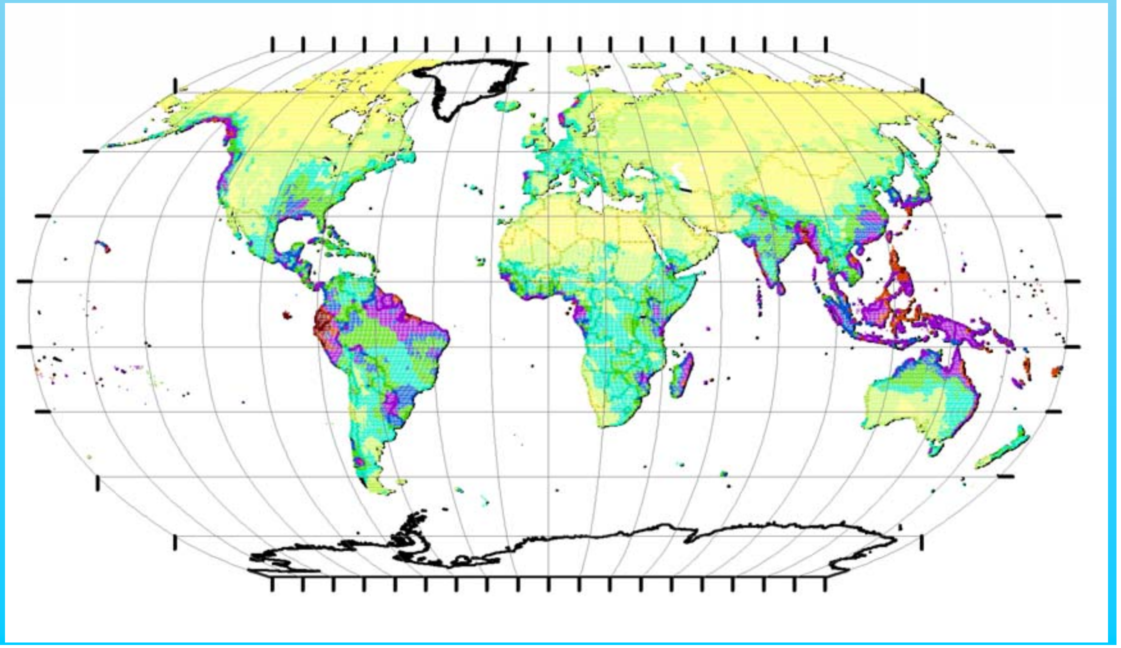


Absolute minimal detectable trend

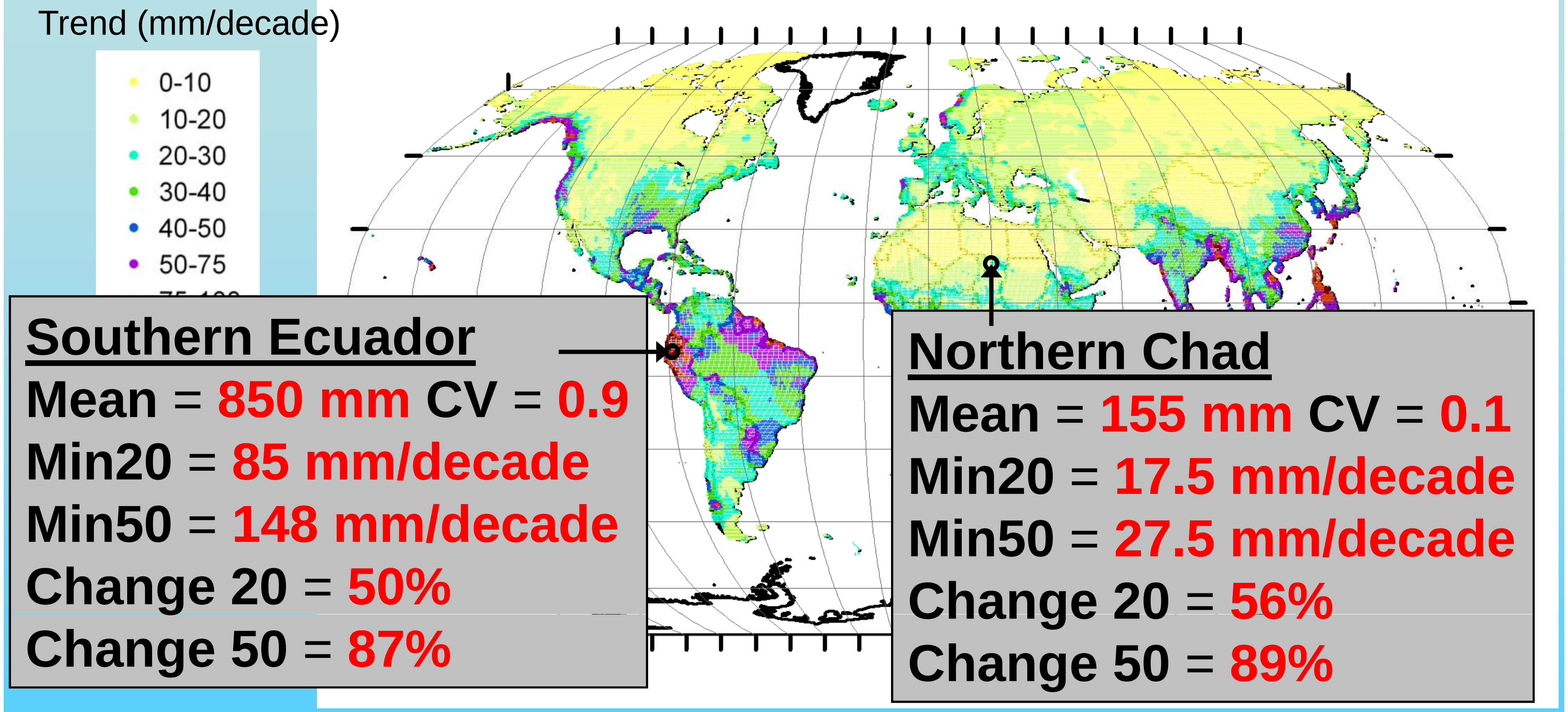
Trend (mm/decade)

- ● 0-10
- ● 10-20
- ● 20-30
- ● 30-40
- ● 40-50
- ● 50-75
- ● 75-100
- ● >100

50% probability threshold



Global mapping



Southern Ecuador
Mean = **850 mm** **CV** = **0.9**
Min20 = **85 mm/decade**
Min50 = **148 mm/decade**
Change 20 = **50%**
Change 50 = **87%**

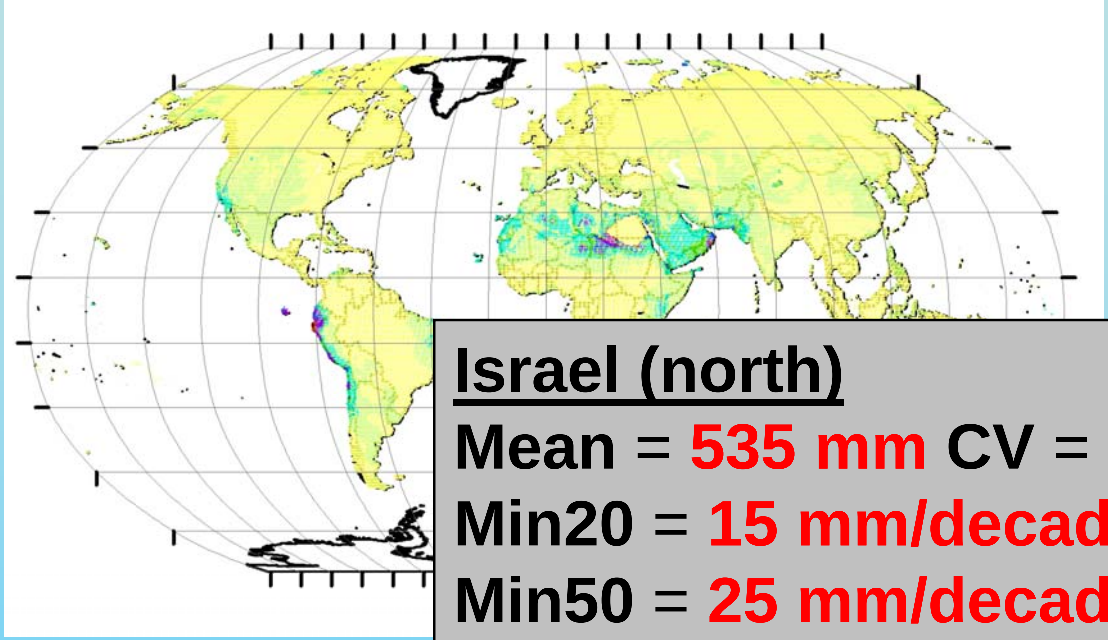
Northern Chad
Mean = **155 mm** **CV** = **0.1**
Min20 = **17.5 mm/decade**
Min50 = **27.5 mm/decade**
Change 20 = **56%**
Change 50 = **89%**

The highest undetectable trends are mainly in the tropics due to high precipitation mean and variability.

In arid and semi-arid regions the minimal detectable trends are considerably lower but are very substantial when translated into percent change in annual precipitation.

Global mapping

20% probability threshold



Absolute relative minimal detectable trend

ange from the mean
er 50 years

Israel (north)

Mean = 535 mm CV = 0.25

Min20 = 15 mm/decade

Min50 = 25 mm/decade

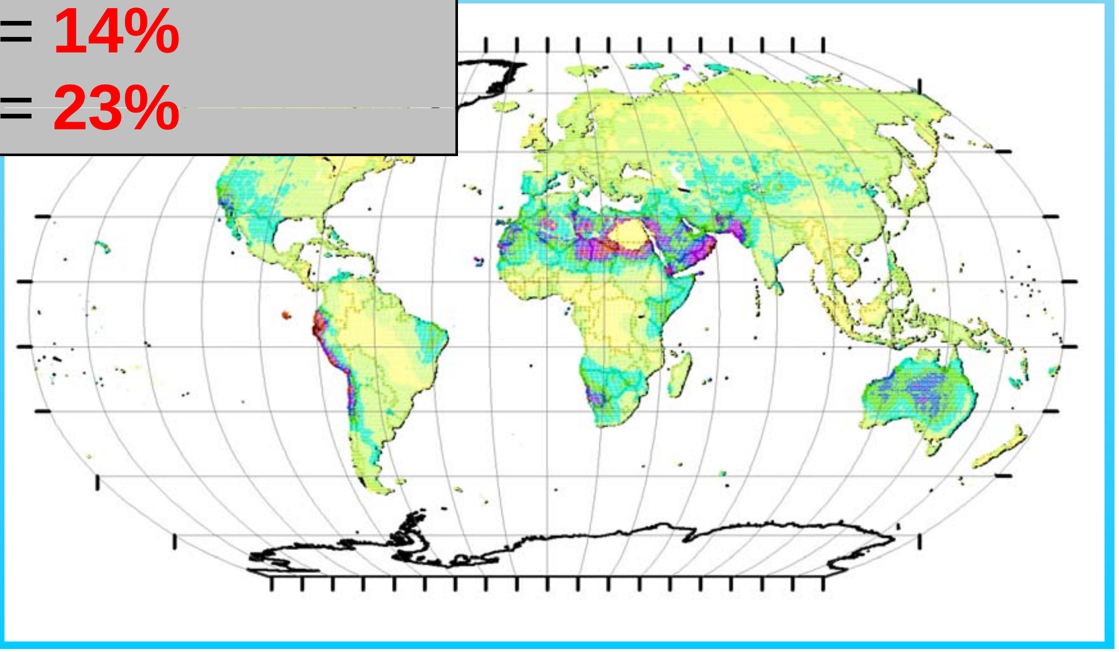
Change 20 = 14%

Change 50 = 23%

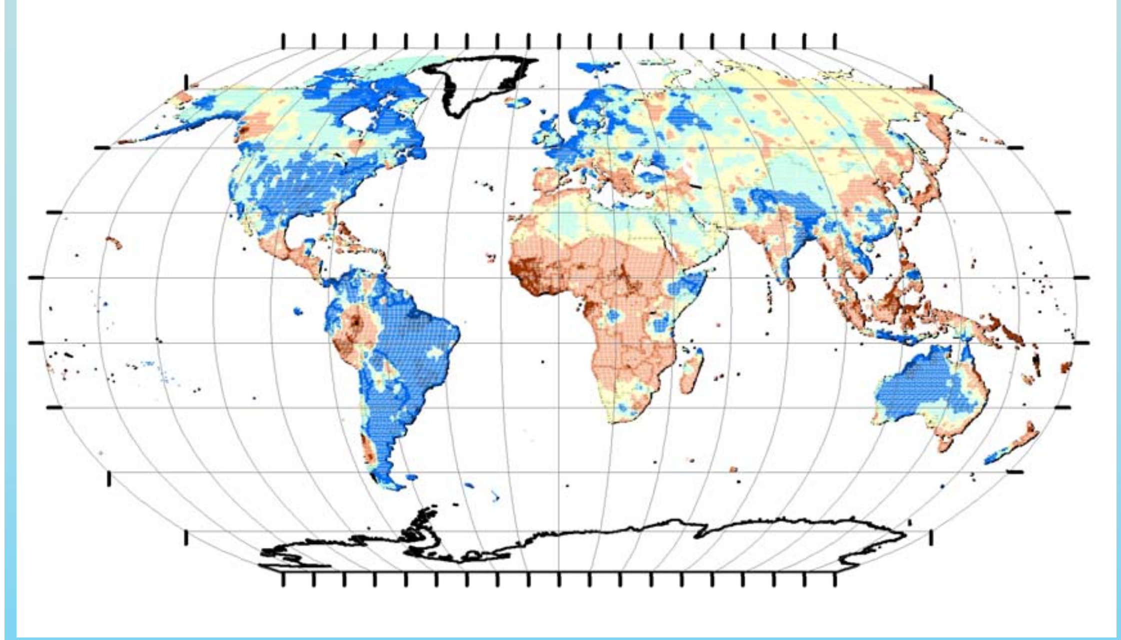
Precipitation
(% in half ce

- ● 0-10
- ● 10-20
- ● 20-30
- ● 30-40
- ● 40-50
- ● 50-75
- ● 75-100
- ● >100

50% probability threshold

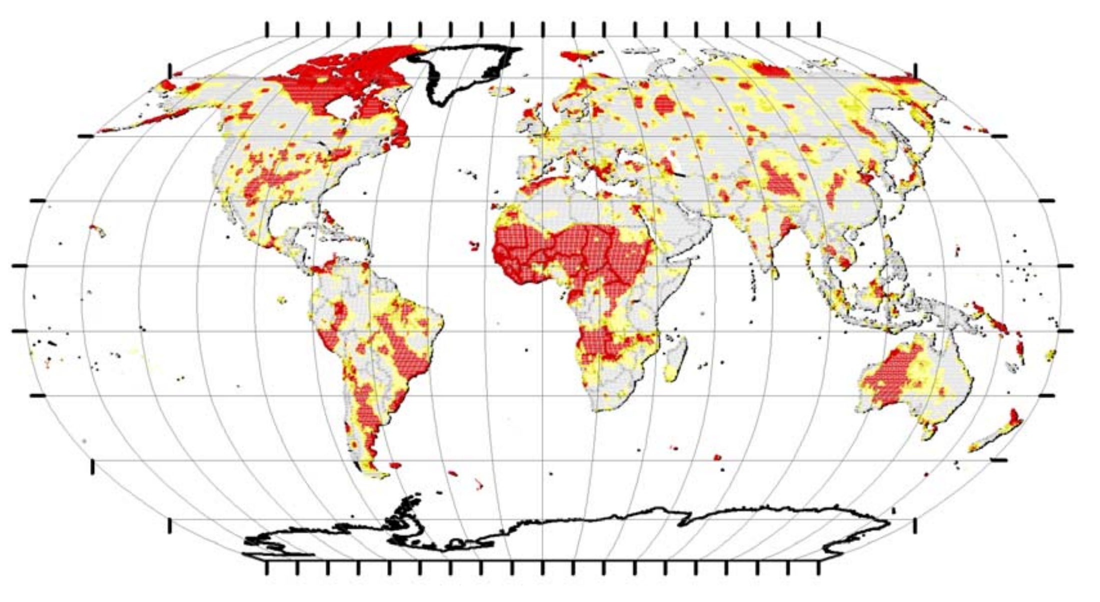


Global mapping



Observed trend (mm/decade)

- ● < -50
- ● -50 - -10
- ● -10 - 0
- ● 0 - +10
- ● +10 - +50
- ● > +50



P-value

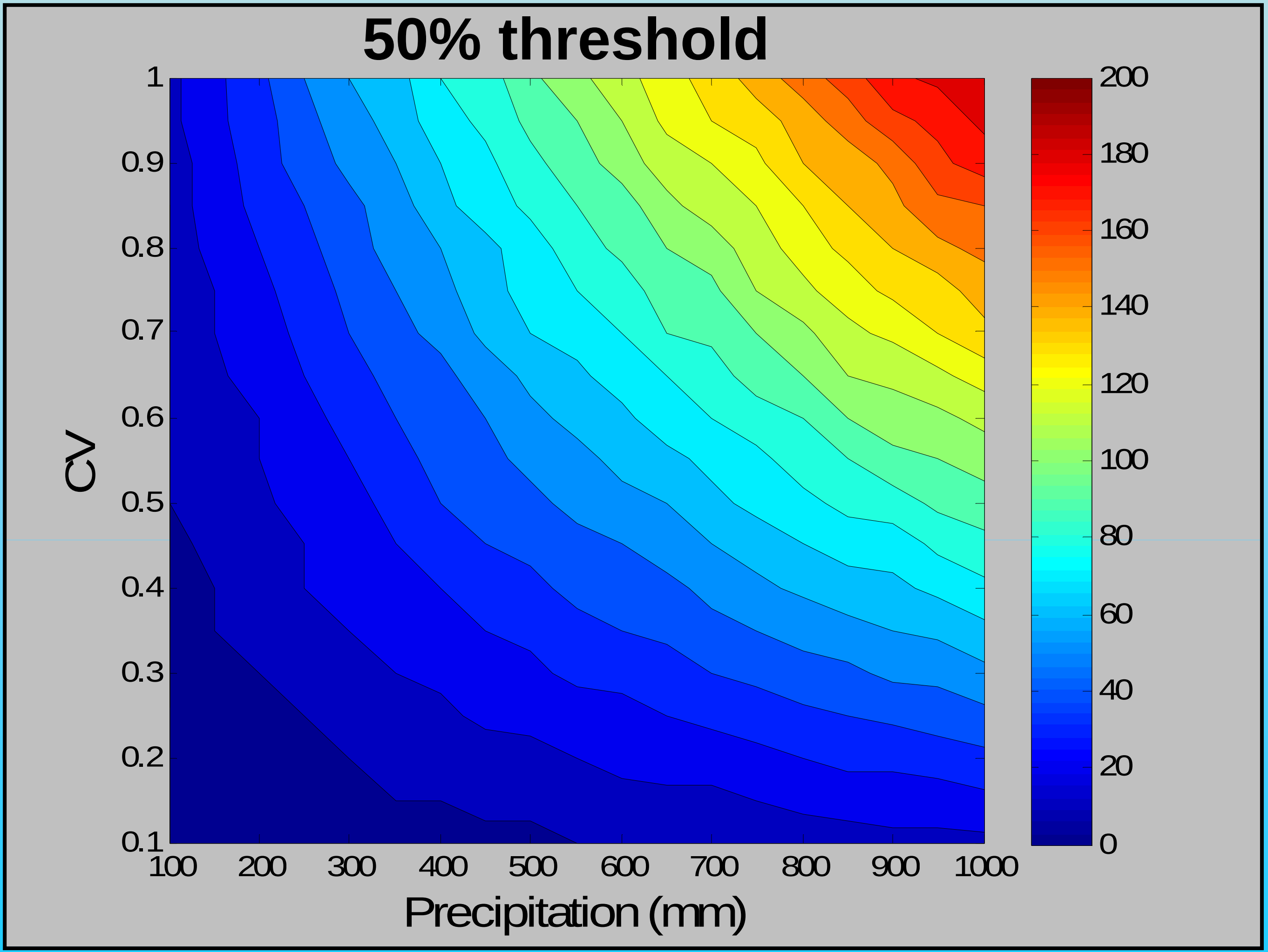
- ● 0.00 - 0.05
- ● 0.05 - 0.10
- ● 0.10 - 0.30
- ● > 0.30

Controls of the minimal detectable trend

- Mean and CV of annual precipitation
- Record length
- Temporal smoothing/Serial correlation
- Spatial averaging/Spatial correlation

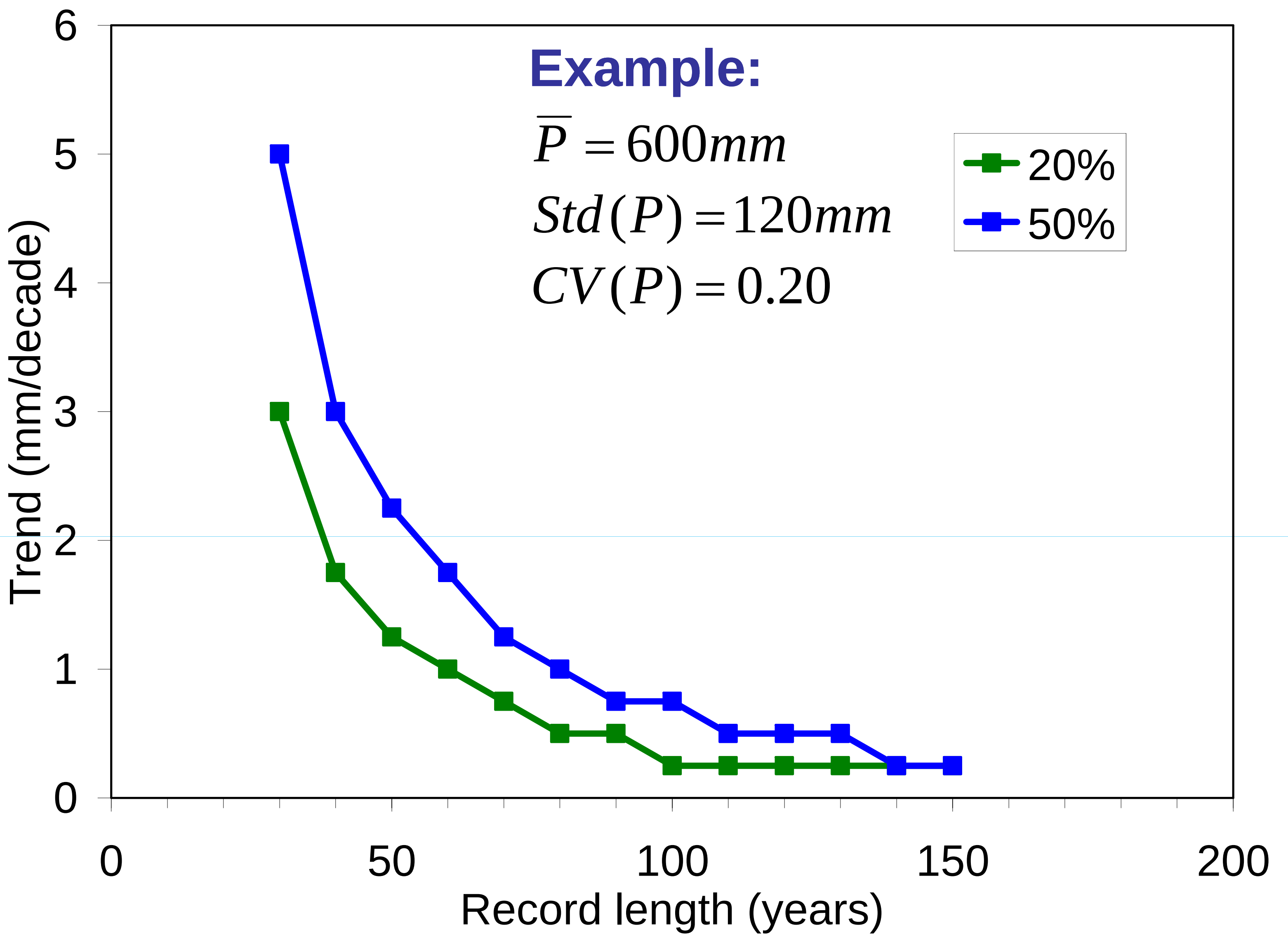
Controls of the minimal detectable trend

Mean and CV of annual precipitation



Controls of the minimal detectable trend

Record length



Example:

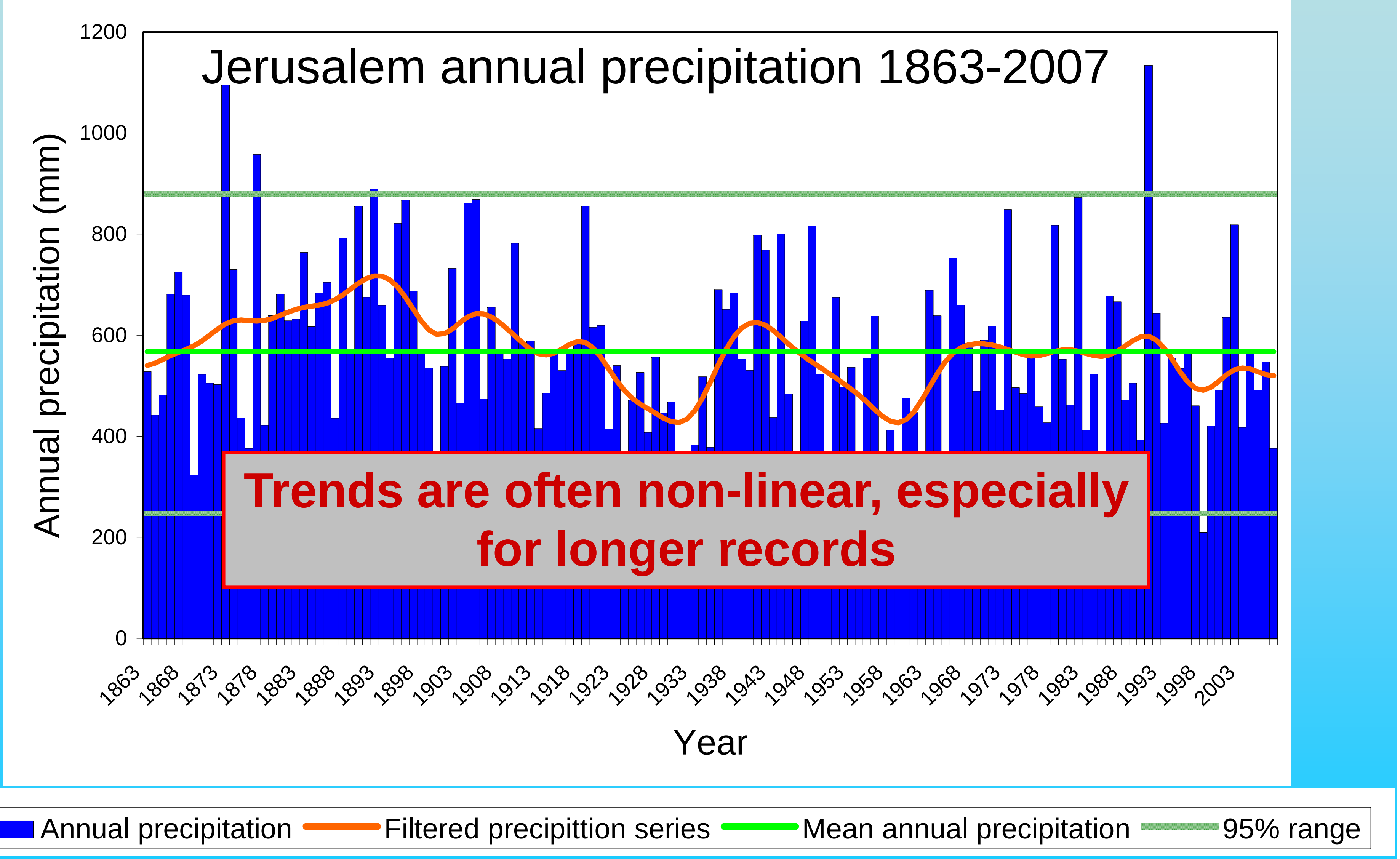
$$\overline{P} = 600mm$$

$$Std(P) = 120mm$$

$$CV(P) = 0.20$$

Controls of the minimal detectable trend

Record length



Trends are often non-linear, especially for longer records

Controls of the minimal detectable trend

Temporal smoothing/Serial correlation (under study):

Smoothing reduces variance but also increases the serial correlation.

In general, if a time series is positively correlated then the trend identification test will find a significant trend more often than it will for an independent series (Kulkarni and von Storch, 1995).

Controls of the minimal detectable trend

Temporal smoothing/Serial correlation (under study):

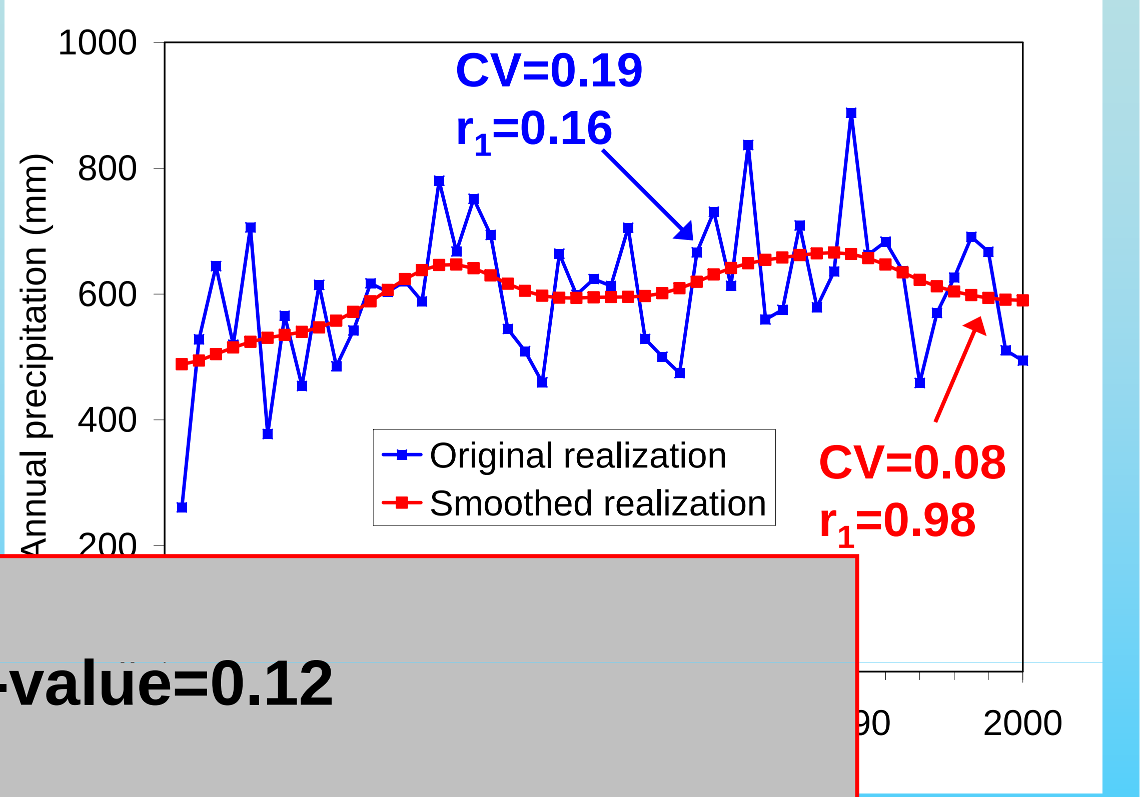
Example:

$$\overline{P} = 600mm$$

$$Std(P) = 120mm$$

$$CV(P) = 0.20$$

$$\beta = 0$$



Original data:
Slope=15.9 mm/decade **p-value=0.12**

Smoothed data without accounting for serial correlation:
Slope=23.4 mm/decade **p-value<0.001**

Smoothed data with accounting for serial correlation:
Slope=23.4 mm/decade **p-value<0.09**

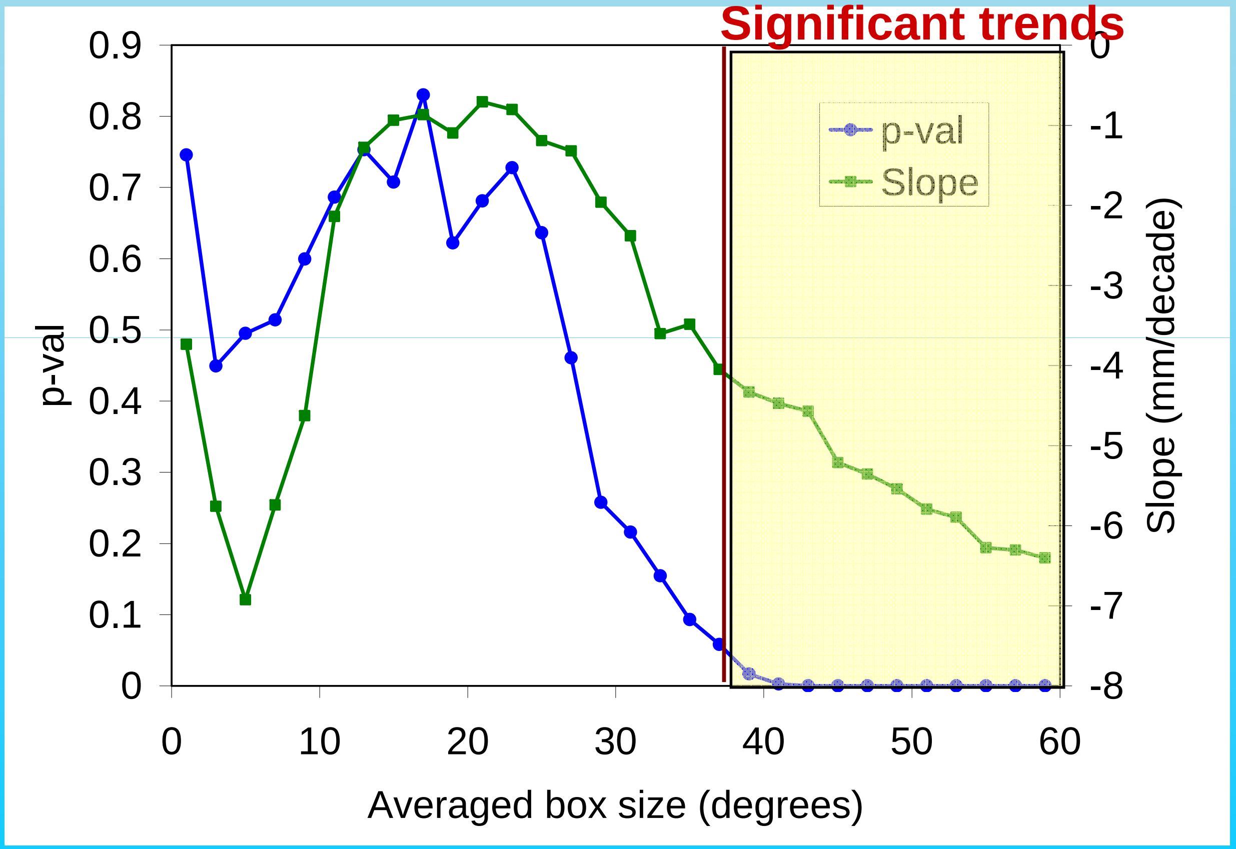
Controls of the minimal detectable trend

Spatial averaging/Spatial correlation (under study):

Spatial averaging reduces variance and can improve trend detectability. However, averaging over large area (> 35^o) is required to get significant trends and in this area may include different trend signs.

Example:

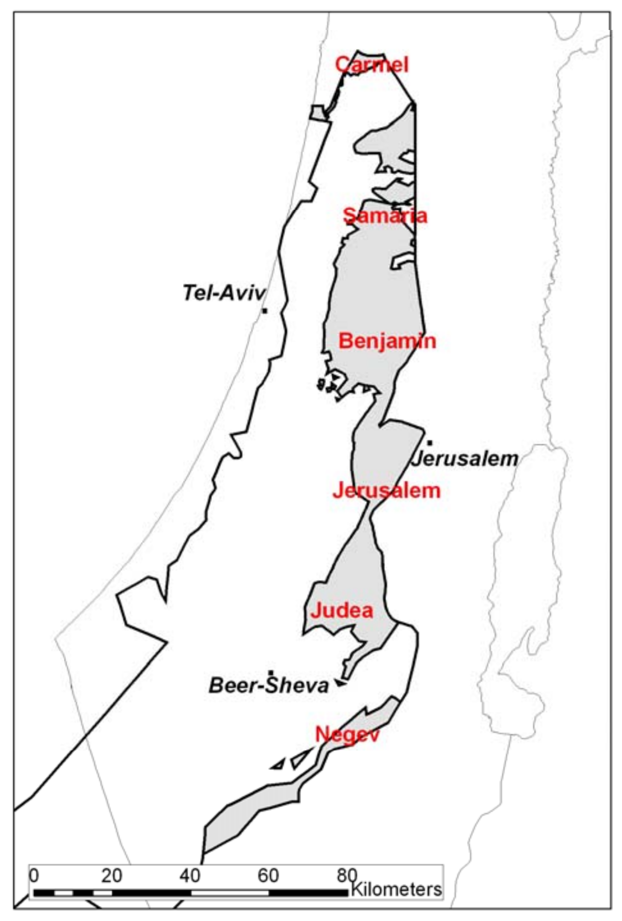
Averaging around Israel pixel



Hydrological implications

Israel (north)
Mean = 535 mm CV = 0.25
Min20 = 15 mm/decade
Min50 = 25 mm/decade
Change 20 = 14%
Change 50 = 23%

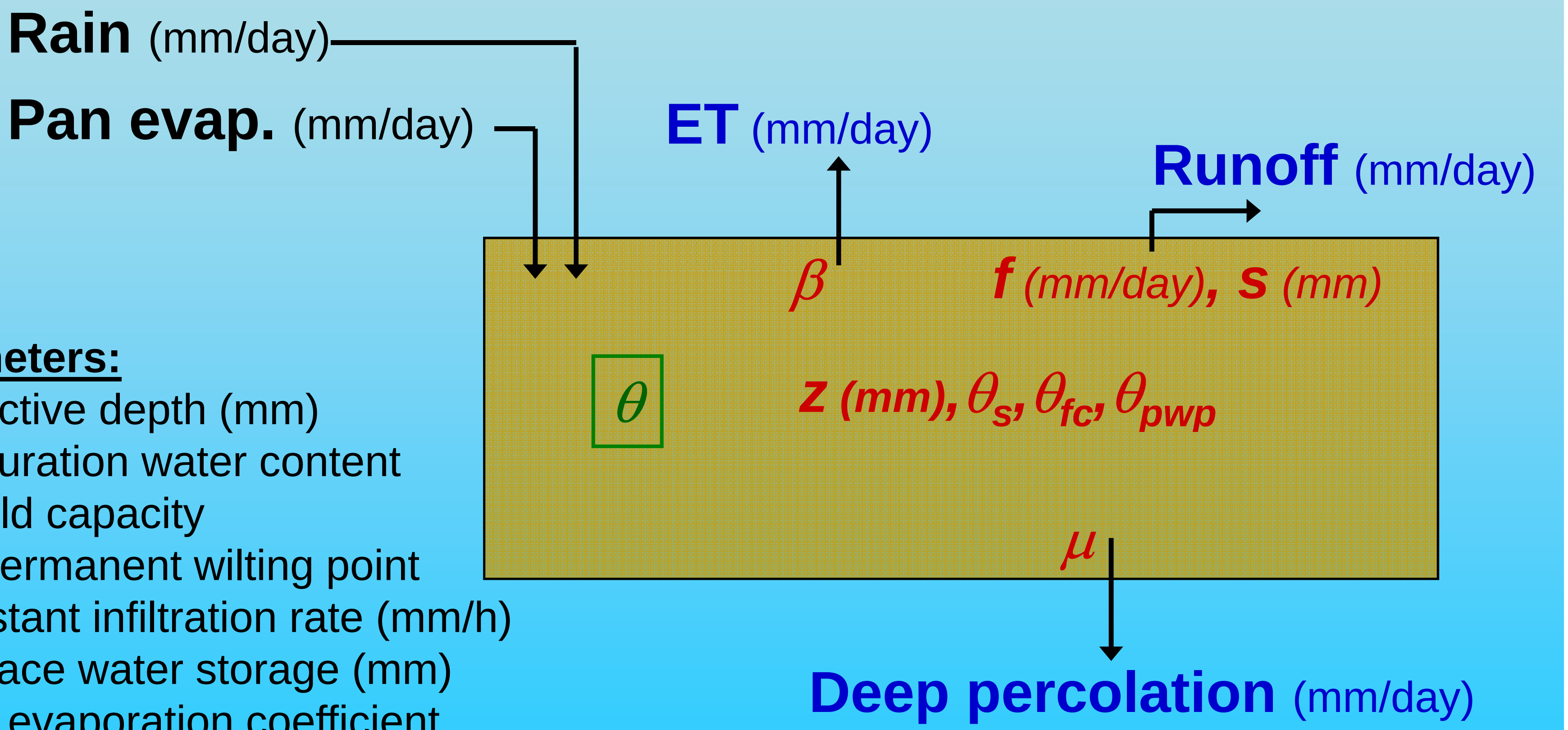
Recharge to the Yarqon-Taninim regional Aquifer



Runoff volume in the Taninim catchment (51 km^2)

Hydrological implications

Continuous hydrological model representing the main processes of the water budget: rain, infiltration, runoff, evapotranspiration, and deep percolation.



Rain (mm/day)

Pan evap. (mm/day)

ET (mm/day)

Runoff (mm/day)

β **f** *(mm/day)*, **s** *(mm)*

θ

z (mm), θ_s, θ_{fc}, θ_{pwp}

μ

Deep percolation (mm/day)

Parameters:

Z: Effective depth (mm)

θ_s: Saturation water content

θ_{fc}: Field capacity

θ_{pwp}: Permanent wilting point

f: Constant infiltration rate (mm/h)

s: Surface water storage (mm)

β: Pan evaporation coefficient

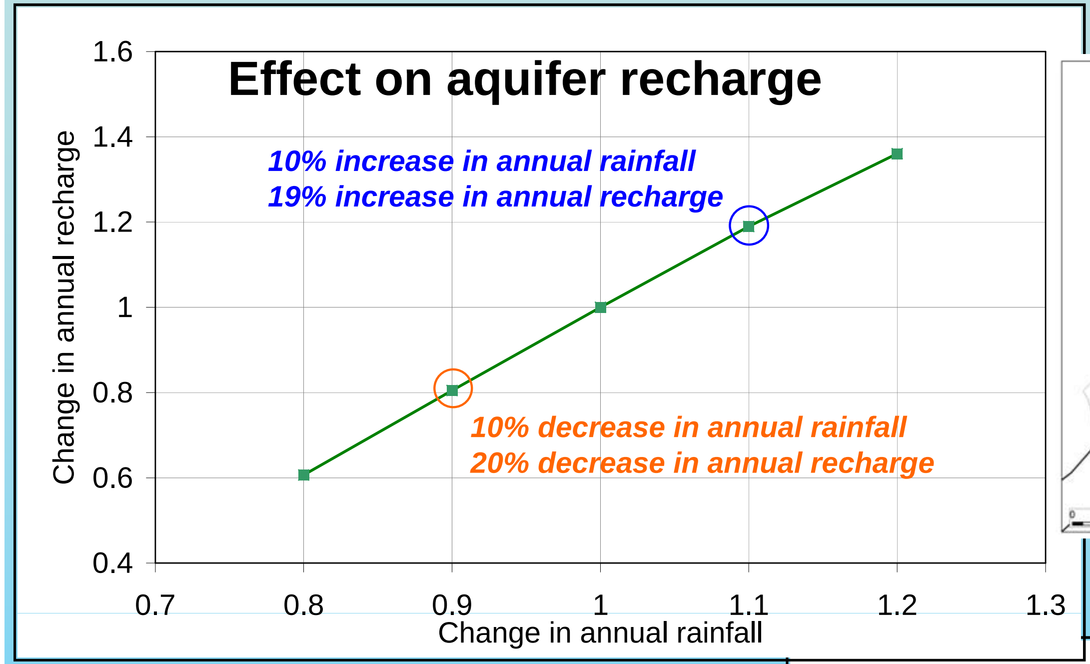
μ: Deep percolation coefficient

State variable:

θ: Current water content

Based on: Sheffer et al., 2009 with modifications

Hydrological implications



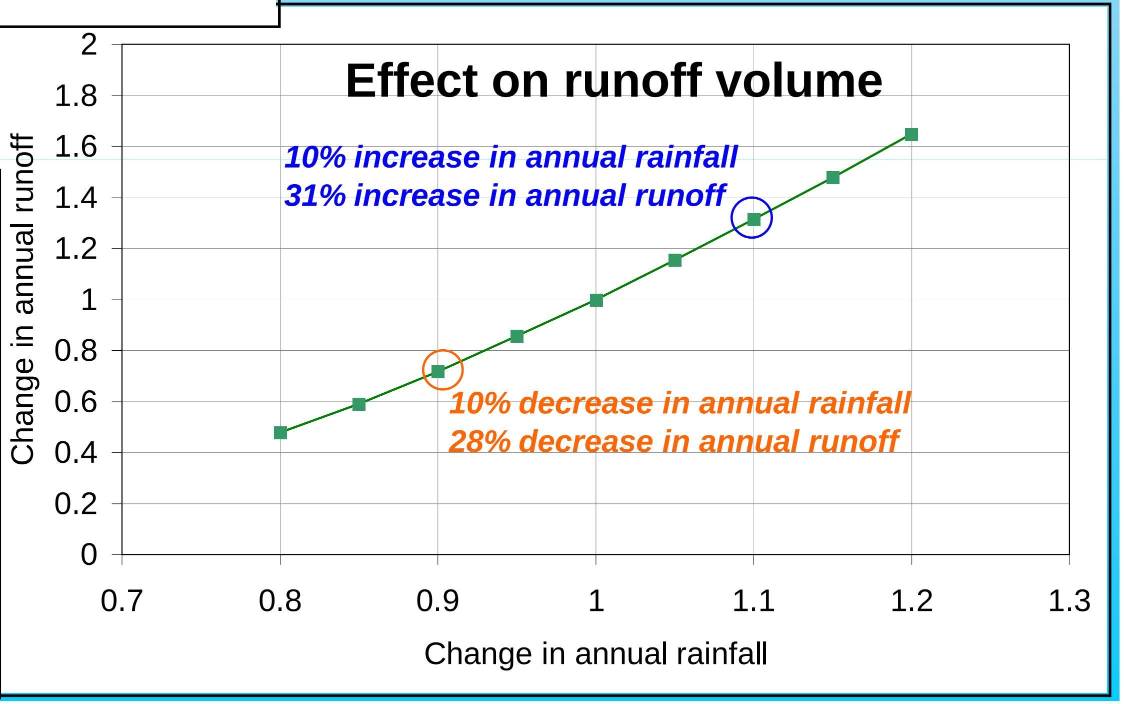
Effect on aquifer recharge

10% increase in annual rainfall
19% increase in annual recharge

10% decrease in annual rainfall
20% decrease in annual recharge

Yarqon-Taninim aquifer

Taninim catchment



Effect on runoff volume

10% increase in annual rainfall
31% increase in annual runoff

10% decrease in annual rainfall
28% decrease in annual runoff

Summary

- Trends in precipitation data are often masked by their high variance.
- Monte-Carlo simulations together with the Mann-Kendall method were applied to detect the probability of existing trends to be found significant.
- The minimal detectable trends were derived using probability thresholds of 20% and 50%.
- Minimal trends were mapped globally both in mm/decade and in percent from mean annuals. The GPCC VASClimO data set was used for the mapping.
- The highest minimal detectable trends were found in the tropics and other wet regions, but in terms of percent from mean semi-arid and arid areas are emphasized.
- The main controls of the minimal detectable trends are: mean precipitation, CV, record length, temporal and spatial smoothing.
- It is demonstrated that the hydrological systems (aquifer recharge and catchment runoff volume) magnifies trends in precipitation means.

Conclusions

- **In many cases the chance to detect a significant trend in precipitation data series is low even if the trend exists.**
- **Only trends above some threshold are detectable.**
- **The undetectable (in terms of statistical significance) trends are in practice not negligible and can have a crucial impact on water resources availability.**
- **The knowledge of these limits is important input especially for risk assessment that is related to adaption decision making.**

Thanks for your attention!

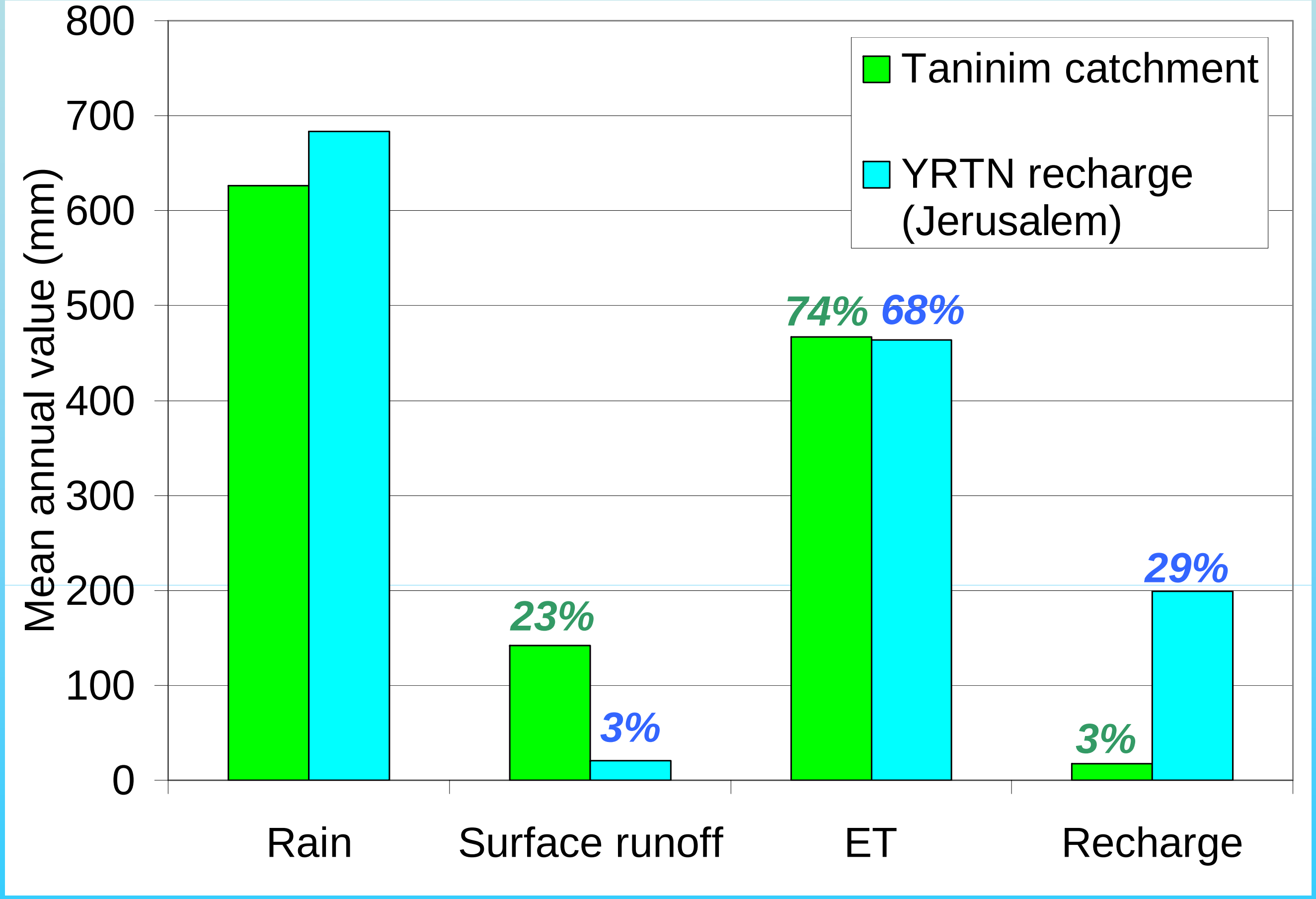
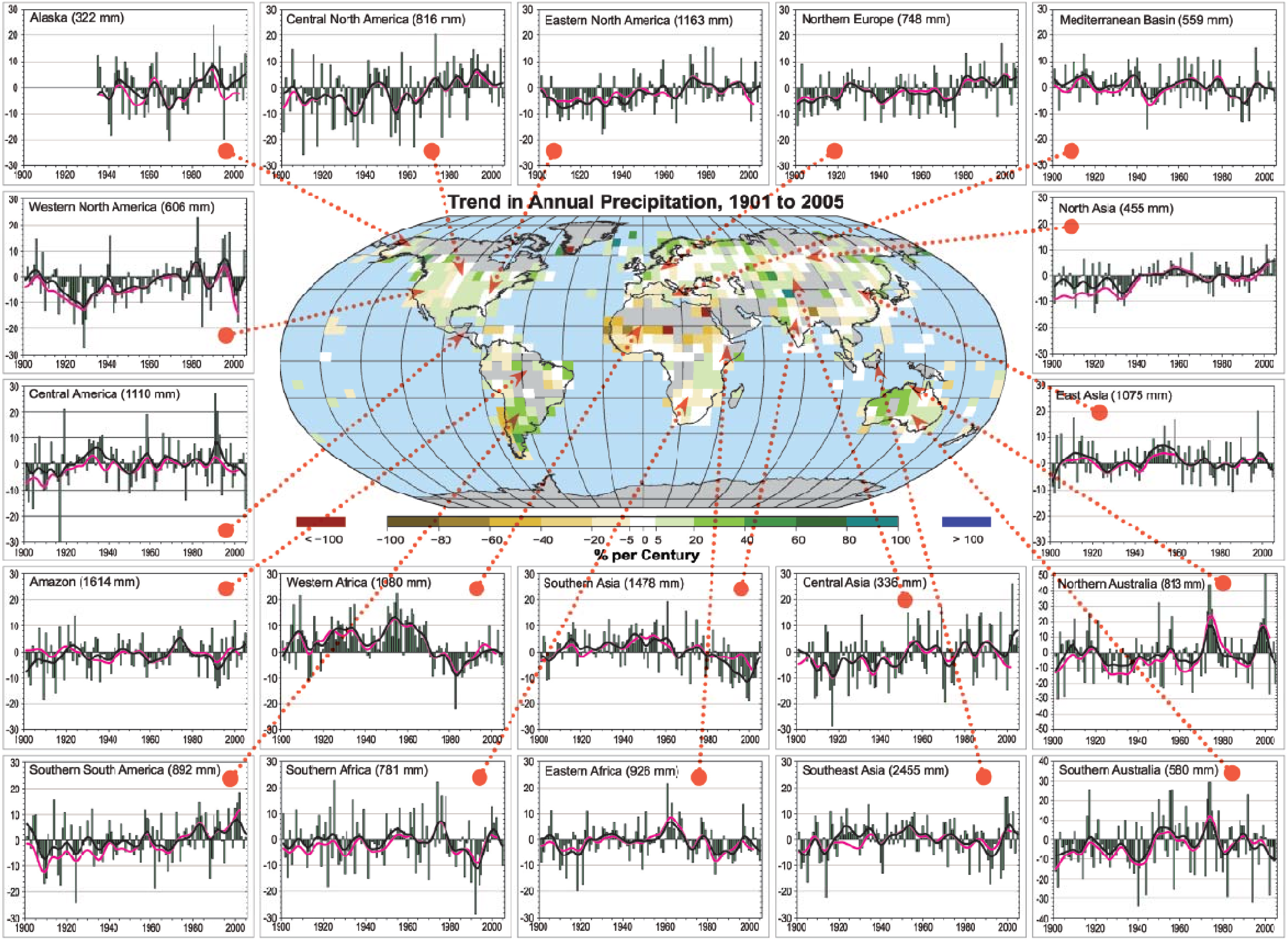
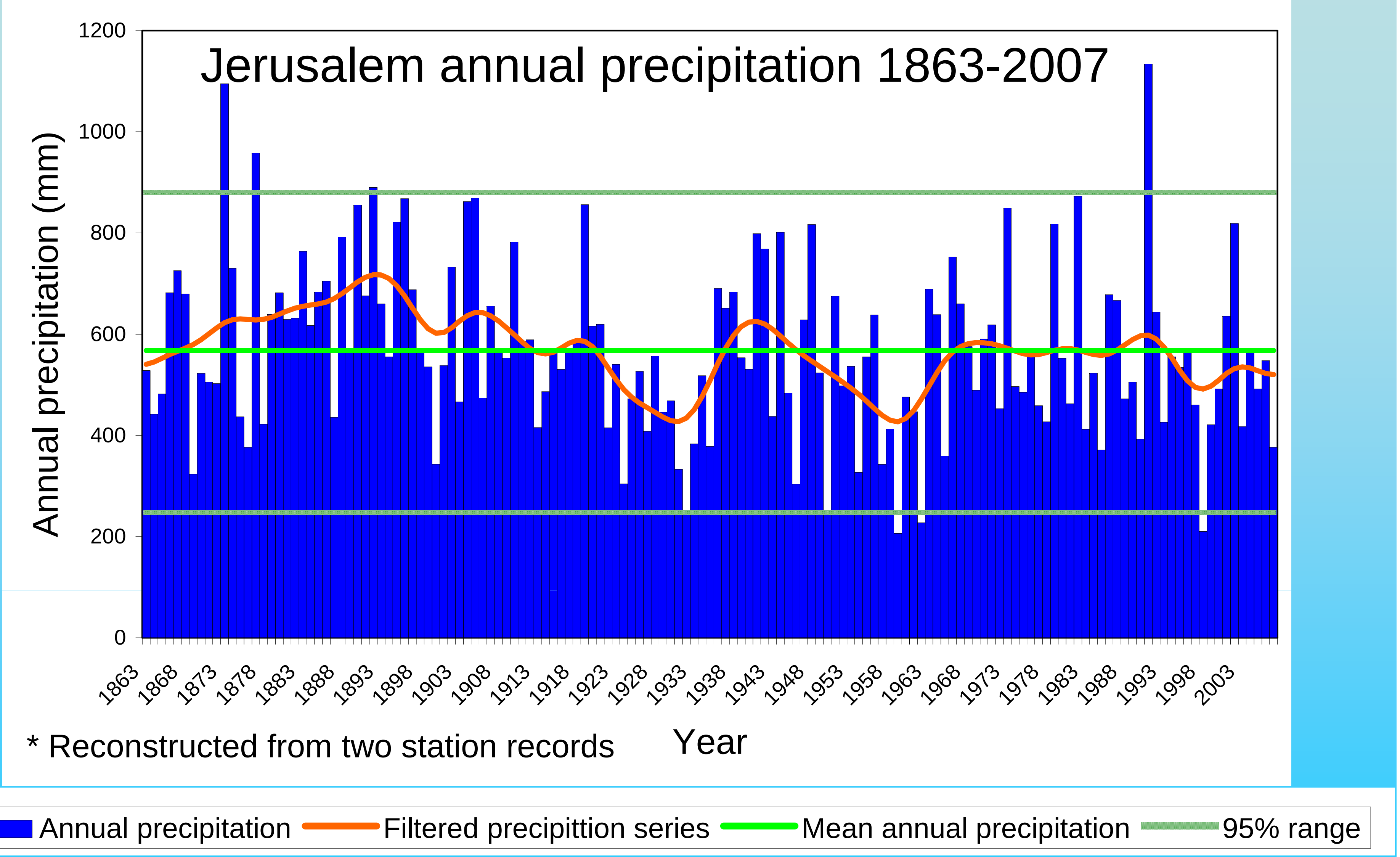

800
700
600
500
400
300
200
100
0
Mean annual value (mm)
Taninim catchment
YRTN recharge (Jerusalem)
74%
68%
23%
3%
3%
29%
Rain
Surface runoff
ET
Recharge

Figure 3.14. *Precipitation for 1900 to 2005. The central map shows the annual mean trends (% per century). Areas in grey have insufficient data to produce reliable trends. The surrounding time series of annual precipitation displayed (% of mean, with the mean given at top for 1961 to 1990) are for the named regions as indicated by the red arrows. The GHCN precipitation from NCDC was used for the annual green bars and black for decadal variations (see Appendix 3.A), and for comparison the CRU decadal variations are in magenta. The range is +30 to –30% except for the two Australian panels. The regions are a subset of those defined in Table 11.1 (Section 11.1) and include: Central North America, Western North America, Alaska, Central America, Eastern North America, Mediterranean, Northern Europe, North Asia, East Asia, Central Asia, Southeast Asia, Southern Asia, Northern Australia, Southern Australia, Eastern Africa, Western Africa, Southern Africa, Southern South America, and the Amazon.*



The problem



* Reconstructed from two station records

1-lag autocorrelation = 0.09 (p-value = 0.29)

Coefficient of variance = 169 / 568 = 0.30

Minimal trend detection