Systematic errors and time dependence in rainfall annual maxima statistics in Lombardy

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Introduction: rainfall annual maxima frequency characterization

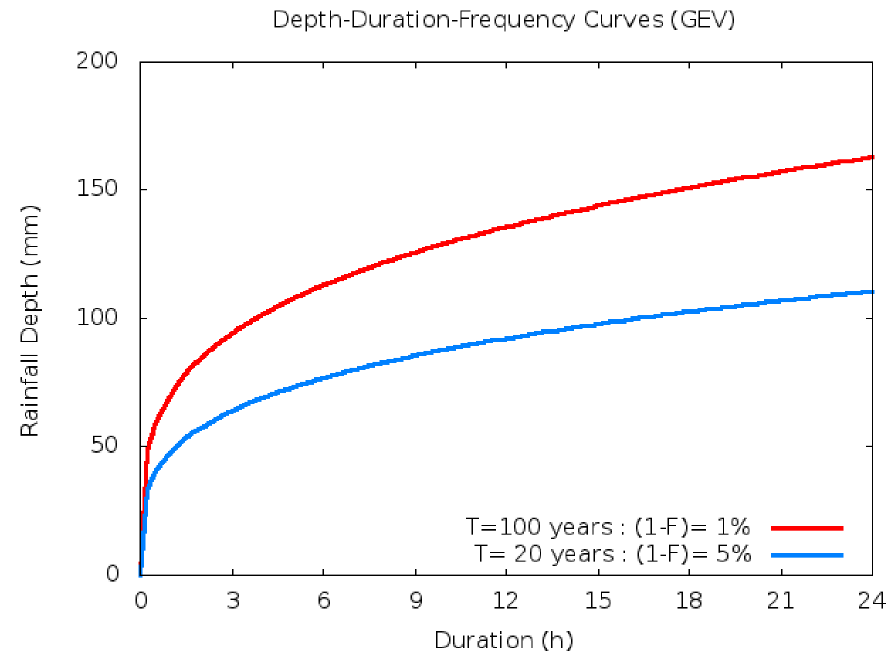
Depth-Duration-Frequency (DDF) curves

- probability map for rainfall annual maxima in a given site
- family of curves $h_T(D)$: **rainfall depth *h*** (mm) vs. **event duration *D*** (h)

Family parameter: **return period**

$$T=(1-F)^{-1}$$

1-F: probability that, in a year, for an event of duration *D*, rainfall depth **exceeds** the threshold *h*.



DDF curves are used in:

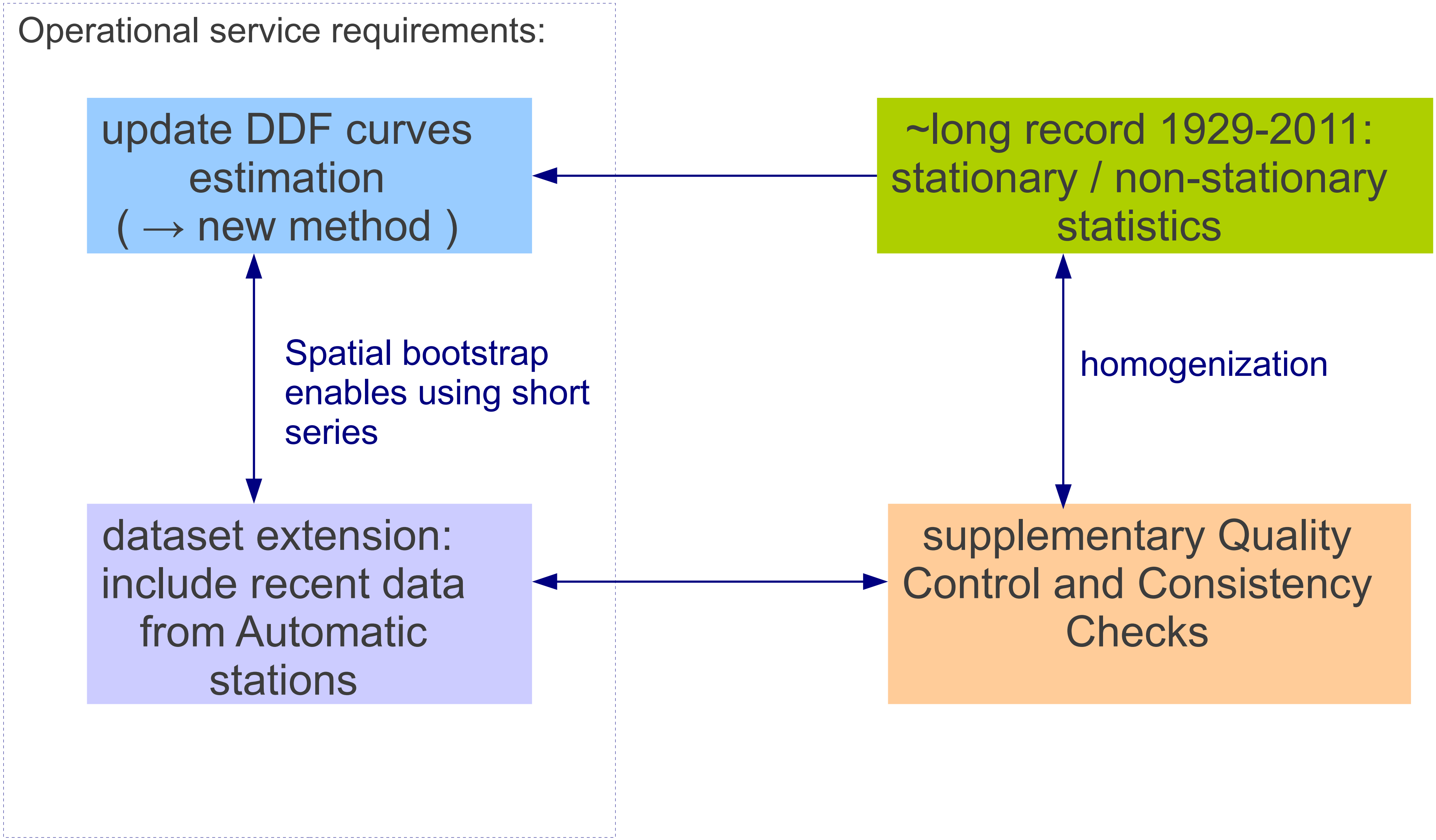
- **Hydrology**: floods associated to intense rainfall events
- **Civil Engineering:** design of structures and plants: sewers, drains, canals, dams, residences, industrial plants, communication and transport lines
- **Civil protection:** define alert threshold in a statistically founded way
- **Climatology**: evaluate drought frequency

New estimate DDF curves 2013:

1) Method: multiple-station spatial bootstrap

2) Extended dataset

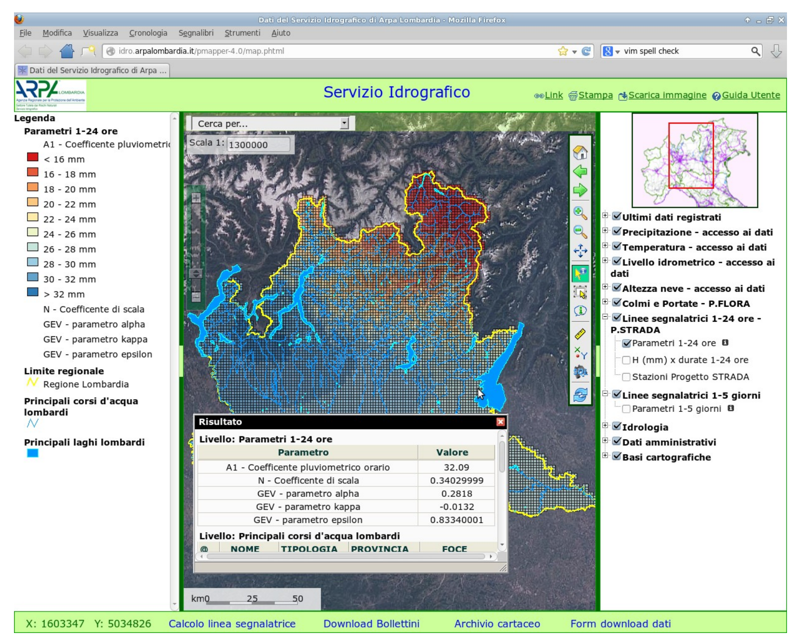
Presentation plan



New estimation DDF curves 2013

Method: MULTIPLE-STATION SPATIAL BOOTSTRAP

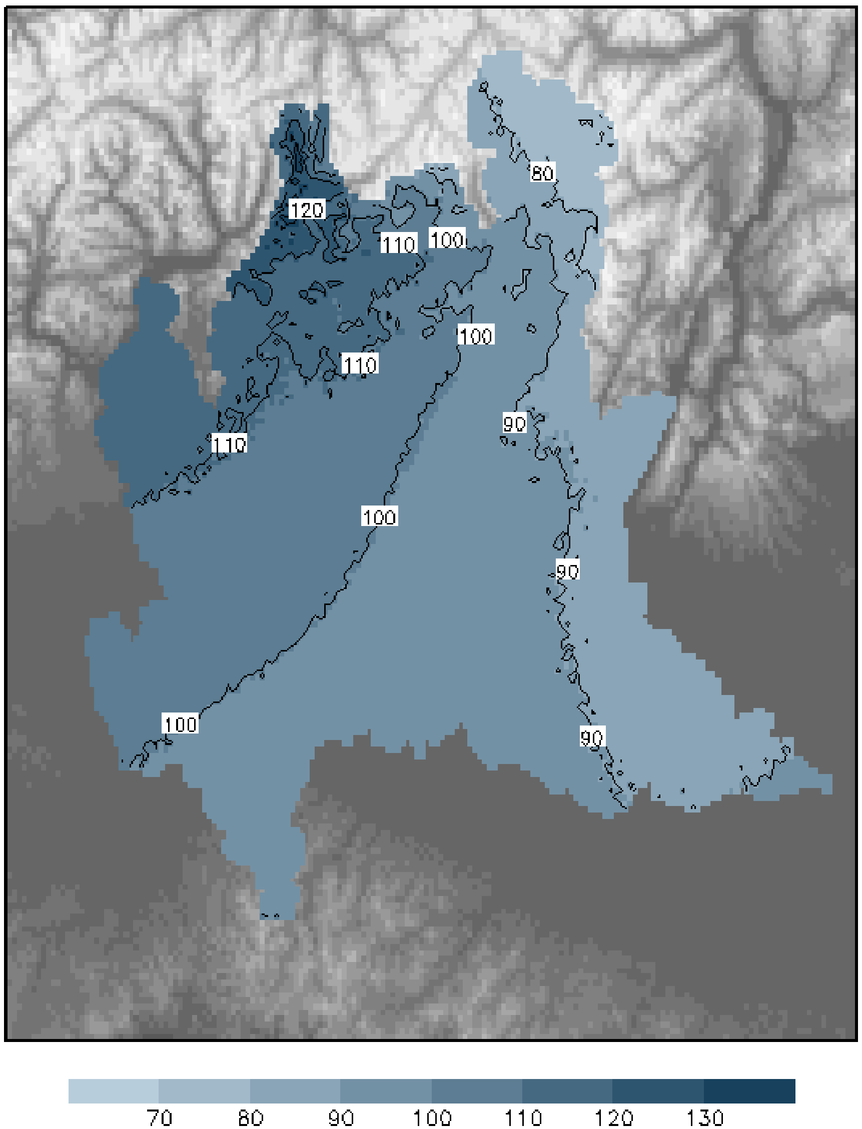
- Local regionalization AND spatial variation
- Based on local resampling followed by GEV parameter estimation
- Use of short time series is enabled
- Straightforward, appropriate outlier treatment
- Direct estimation at any target point
- PROCEDURE REPEATED 1000 TIMES: evaluation of uncertainty associated to each estimated parameter
- Evaluation of uncertainty on DDF curves too → important for applications
- Article: Uboldi, Sulis, Lussana, Cislaghi and Russo, 2013, submitted.
- Operational service, accessible on Web-GIS: *http://idro.arpalombardia.it*



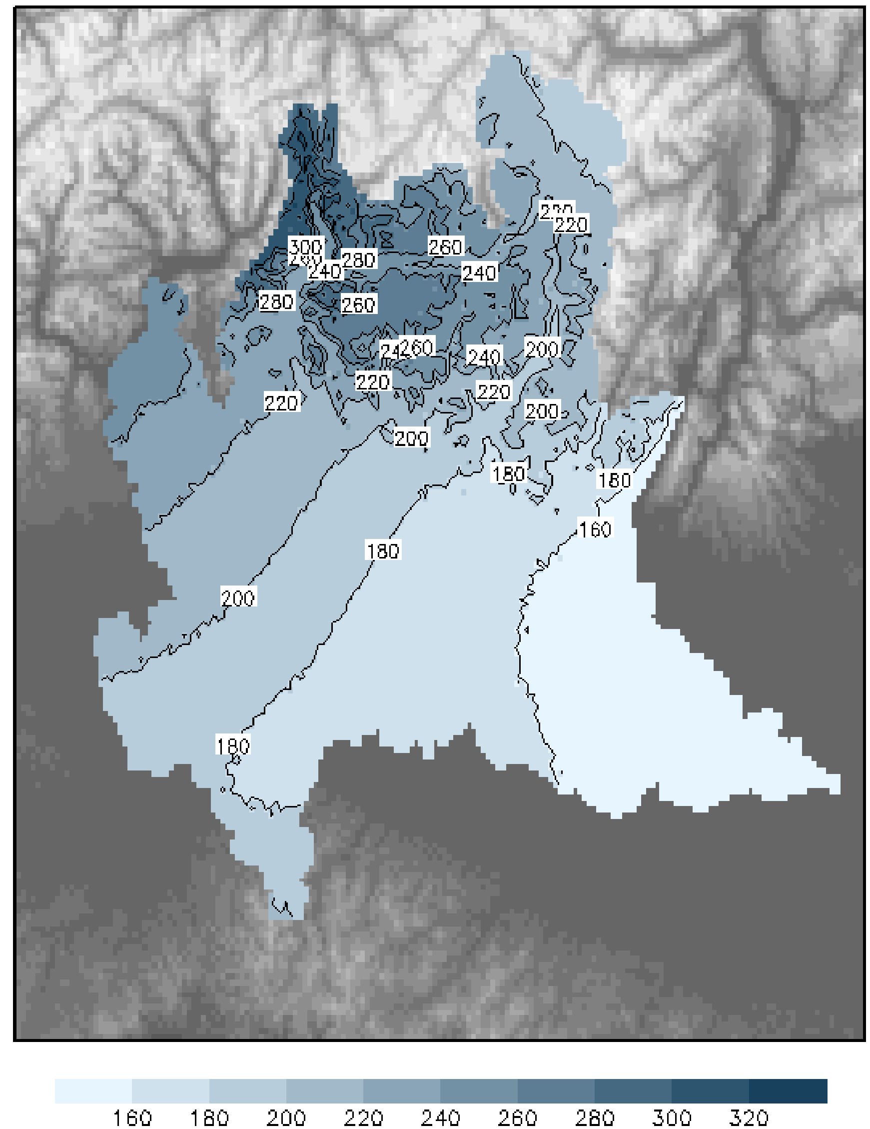
New estimation DDF curves 2013

Example maps of rainfall depth for event duration *D*, exceeded with return period *T*

h_T (mm) $D=3$h $T=200$y



h_T (mm) $D=24$h $T=200$y



New estimation DDF curves 2013

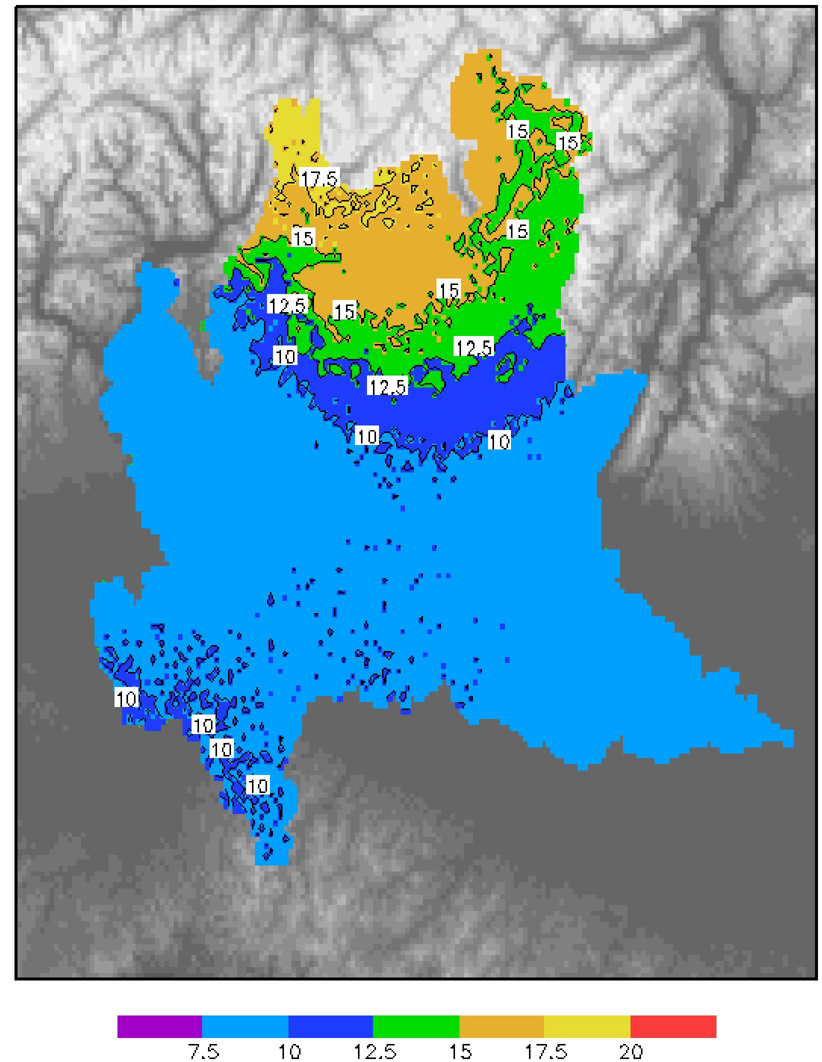
Partial Relative Uncertainty

on $\boldsymbol{h}_{T,D}(\pi)$ due to uncertainty on the generic parameter π:

$$\rho_\pi \equiv \frac{h_{T,D}(\pi+\sigma_\pi)-h_{T,D}(\pi)}{2\,\sigma_\pi}$$

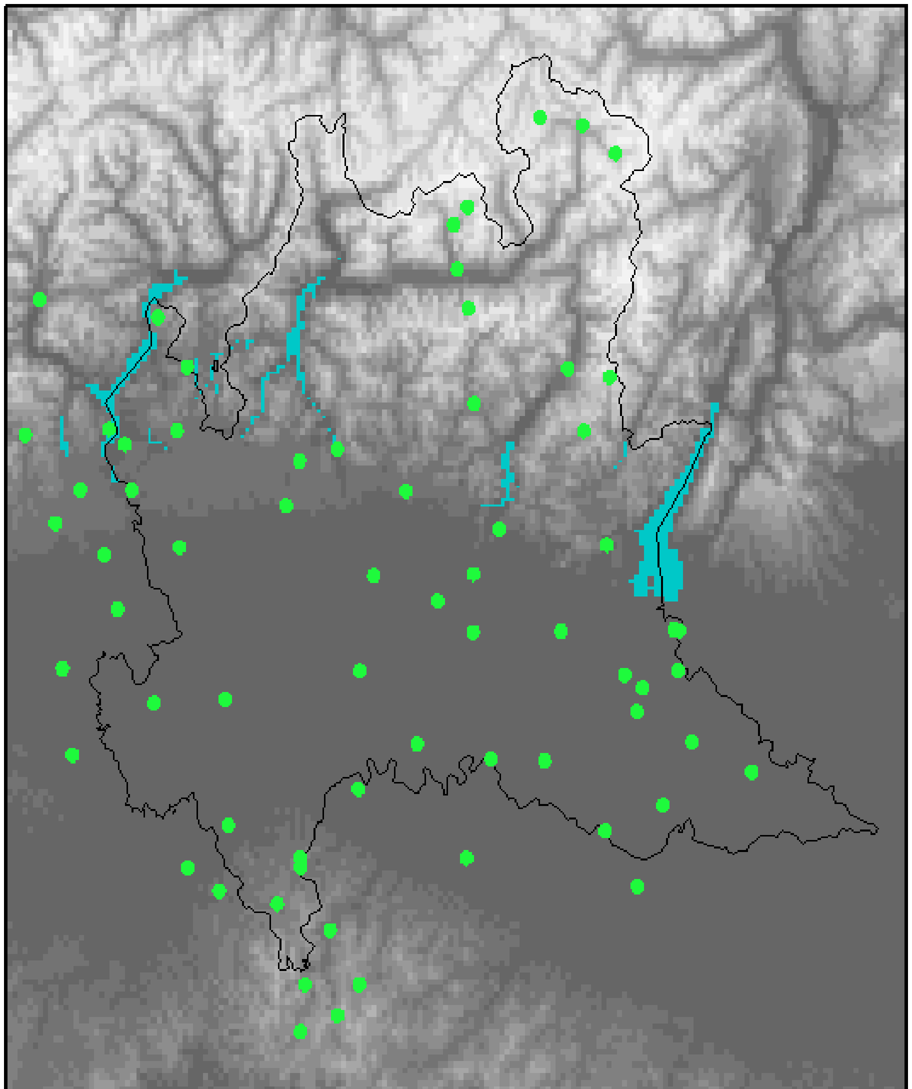
σ : standard deviation (evaluated by means of the bootstrap technique) of parameter π (estimated by the mean)

Partial relative uncertainty on $\boldsymbol{h}_{T,D}$ (%)
due to uncertainty on GEV "shape" ξ
for T= 200y



This is the largest component for long return periods (it depends on T, not on D)

Dataset extension



OLD dataset:

- 1929-2003
- Annals and stations from SIMN (Servizio Idrografico e Mareografico Italiano, 1917-1998)
- 69 historical stations: mostly **M**echanic with analog instrumentation, partly substituted with **A**utomatic stations since the '90s
- Stations **selected by series length**: 24 years at least
- Total: 2753 annual records

Dataset extension

1990s: progressive installation of **new Automatic stations** by different institutions, with different goals and criteria.

In the same period: **old Mechanic stations progressively dismantled**, only occasionally substituted with a new Automatic station in the same site.
Last data from **M** station: 2005.

Since **~2003**, subnetwork integration → → → ARPA Lombardia mesoscale network

Quality control

- Since ~2003: subjective human operator checks (portions of the network only)
- **2008**: work started for a proper ***data quality assurance system***, first operational version 2009 *(Ranci and Lussana, 2009; Lussana et al., 2010)*.

~2008 : Hourly accumulated rainfall observations → Hydrographic Service archive

DATASET EXTENSION: integration of the "OLD dataset" with annual maxima recostructed from all hourly precipitation observations present in the Hydrographic Service archive

- Supplementary quality control and consistency check
- Analysis of spatial and temporal data distribution

Stationarity analysis

Evaluate whether **rainfall annual maxima statistics** can be considered **stationary** or **not**.

Both the spatial distribution of observing sites and their instrumentation changed in time: these are non-stationary features of the observational network that:

A) Make difficult to evaluate changes in time of climatology, related either to natural variability, or to local effect of global warming.

B) In fact, constitute a variation in time of the observational input of the extreme-value distribution parameter estimation, then of frequency and return period of events exceeding assigned rainfall depth thresholds.

A+B → ***Periodical update of statistics is required***

Stationarity analysis

The identification of non-climatic sources for temporal variation is a prerequisite to the analysis of local climatic non-stationarities

Possible reasons of temporal variation of rainfall annual maxima statistics:

NON-climatic:

- Variation in time of the observational network: number of stations and uniformity of their spatial distribution
- Variation in time of station type: **M**echanic or **A**utomatic.
- Heterogeneity of the observational network, built by merging different sub-networks, originally installed at different times, with different aims and criteria, at different locations (urban, rural, mountain...), with different instrumentation (400 cm^2 or 1000 cm^2 raingauges). *LACK OF METADATA*
- Variation in time of station elevation above sea level

Climatic:

- Long period oscillations and/or trends, either due to natural variability or anthropogenic global warming, need to be evaluated anyway

Stationarity analysis: homogeneous areas

Spatial aggregation of time series

Stationarity issues, climatic or not, regard an area, not a single point

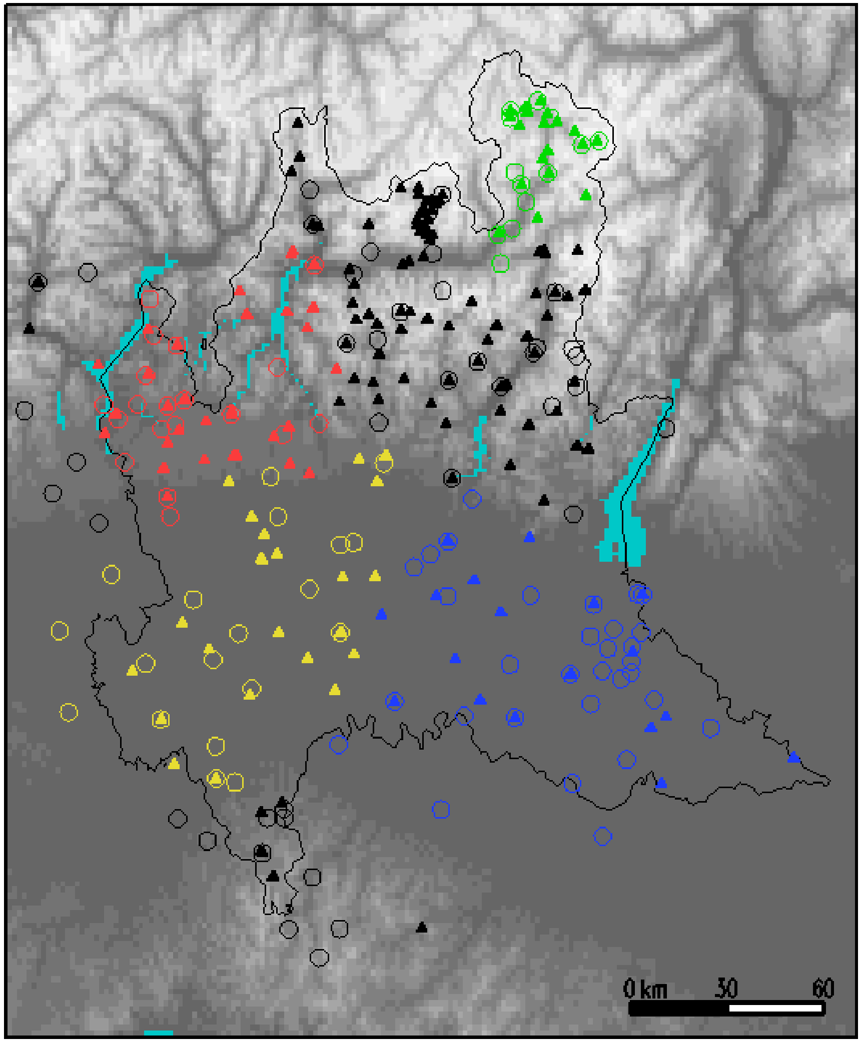
Climatic and topographic complexity of Lombardy

Spatial aggregation is effective to compensate inhomogeneities present in time series, localized systematic errors, network density changes *(guidelines WMO: Klein Tank et al, 2009)*

Homogeneous areas:

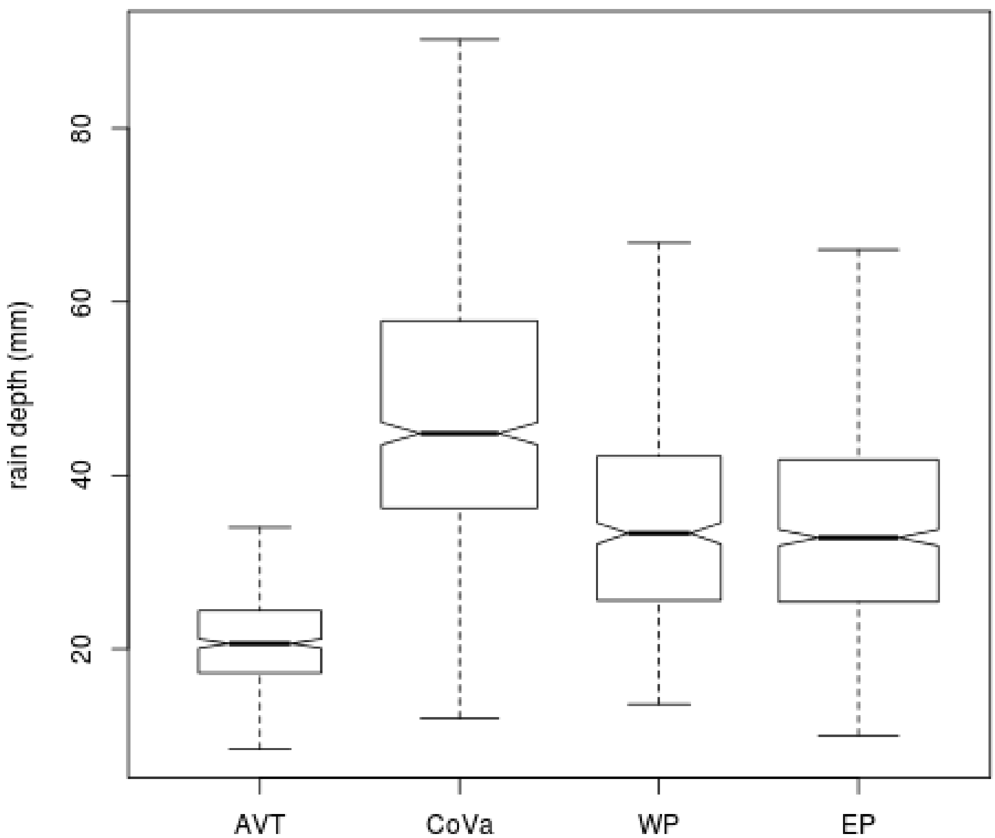
1) Alta Valtellina : **AVT**
2) Como-Varese : **CoVa**
3) Western Plain: **WP**
4) Eastern Plain: **EP**

only 4 areas ← data availability

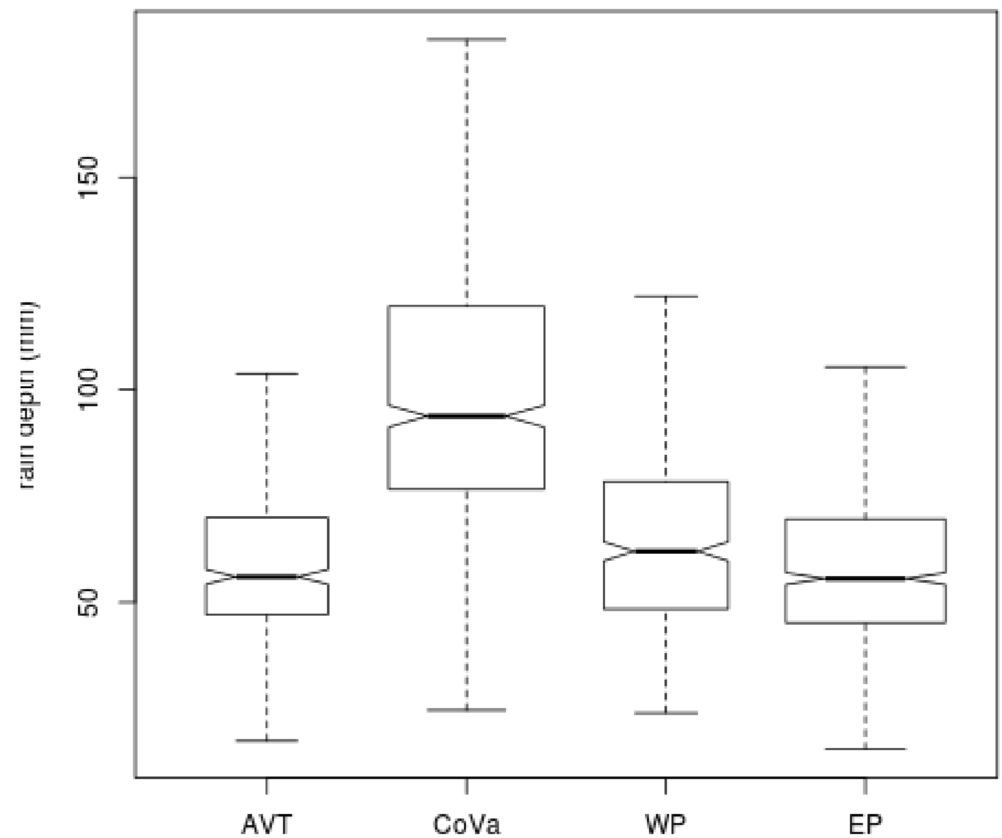


Stationarity analysis: areas comparison

D=03h



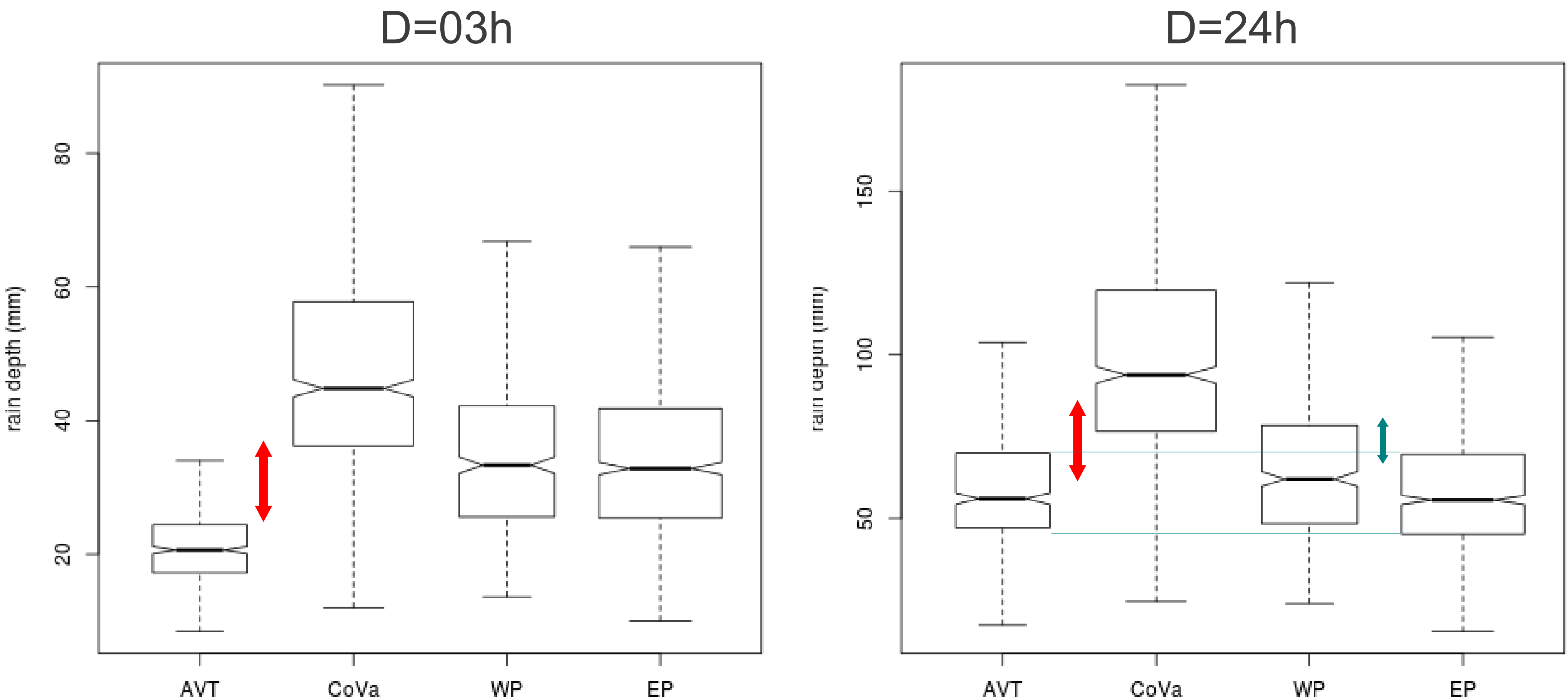
D=24h



Annual maxima distributions in the 4 areas for durations *D*=3h e *D*=24h, respectively significant for convective and stratiform events.

Outliers do not appear in this figure to enhance quartile differences.
"notches" are used to evidentiate median differences

Stationarity analysis: areas comparison



Annual maxima distributions in the 4 areas for durations *D*=3h e *D*=24h, respectively significant for convective and stratiform events.

Area AVT (Alpine, extreme North-East) is apparently less rainy than CoVa (Alpine West).

The two Plain areas, WP e EP, are very similar to each other for short events, but **for long events EP has lower quartiles than WP, and similar to AVT**.

Outliers do not appear in this figure to enhance quartile differences.

"notches" are used to evidentiate median differences

Quality control

Basic checks: climatologic plausibility, consistency (monotony) between durations

M stations: manned, systematic maintenance; digitalization required

A station: **un**manned, **did not undergo systematic maintenance for the whole activity period**. Data available directly in digital form.

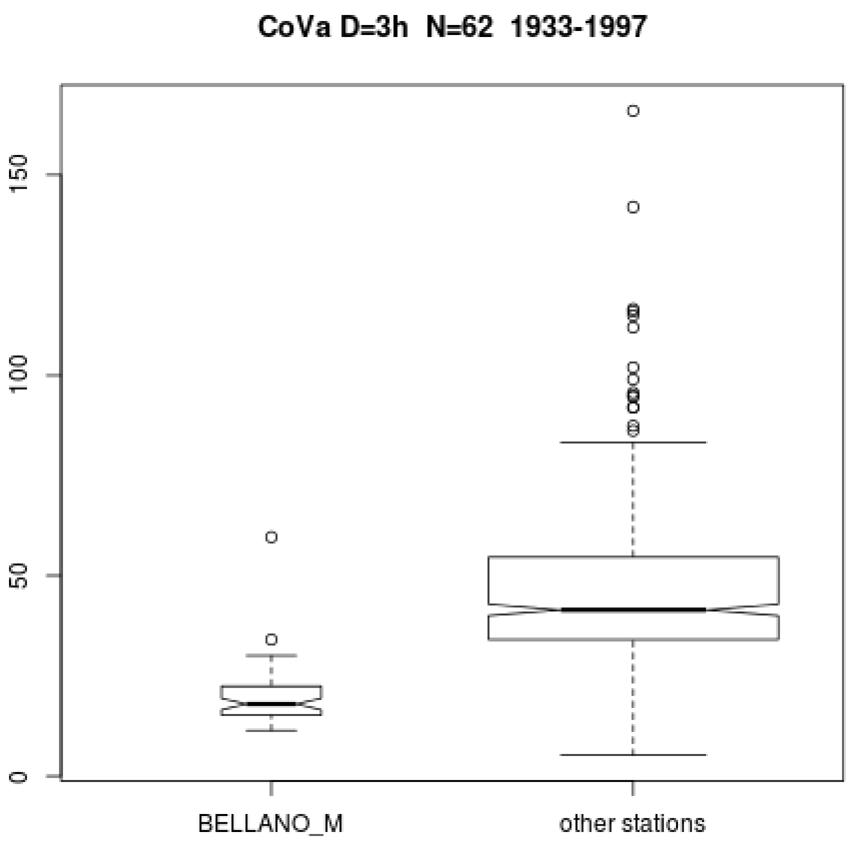
Requirement for each annual maximum: at least 90% of data in the year

CROSS-VALIDATION approach: **each time series** is seen as a sample distribution which is compared with the annual maxima distribution, in the same years, of **all other time series** in the same homogeneous area:
➨ **DISCARD the whole series** if the InterQuartile Ranges do not intersect.

- CROSS-VALIDATION for **individual time series**
- CROSS-VALIDATION for **subnetworks**

Quality control: CROSS-VALIDATION: BELLANO (M)

Quality control: CROSS-VALIDATION: BELLANO (M)



Quality control: CROSS-VALIDATION for subnetworks

For each subnetwork, the whole set of time series for the correspondent stations is seen as a single sample distribution which is compared with the annual maxima distribution, in the same years, of **all other time series** in the same homogeneous area:

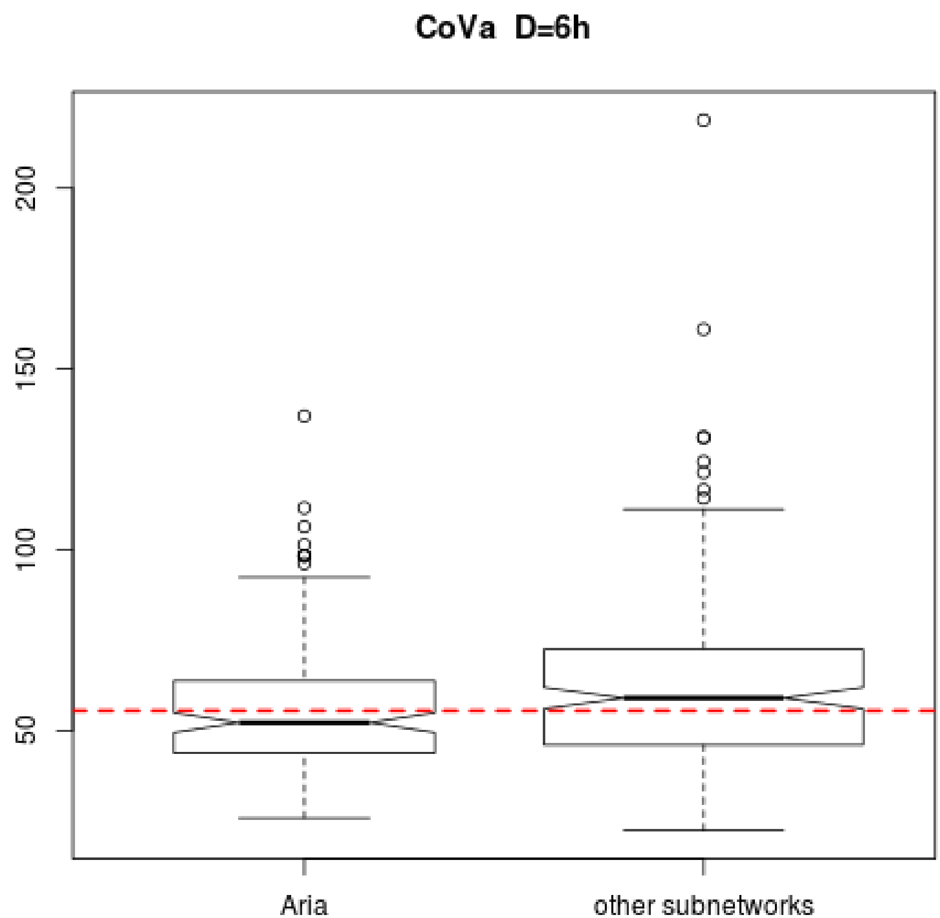
DISCARD the whole subnetwork if the median difference is significant

Outcome: The subnetwork "Aria" (Automatic Stations) data has been discarded systematic errors likely due to:
- difference in the instrumentation:
- difference in the location: mainly urban sites with the presence of obstacles

The *lack of metadata* -in particular, for automatic stations- does not give us confidence in identifying the reasons for the different behaviour. Then, our restrictive choice has been to discard the whole "Aria" subnetwork.

Quality control: CROSS-VALIDATION for subnetworks

Automatic stations: "Aria" network discarded



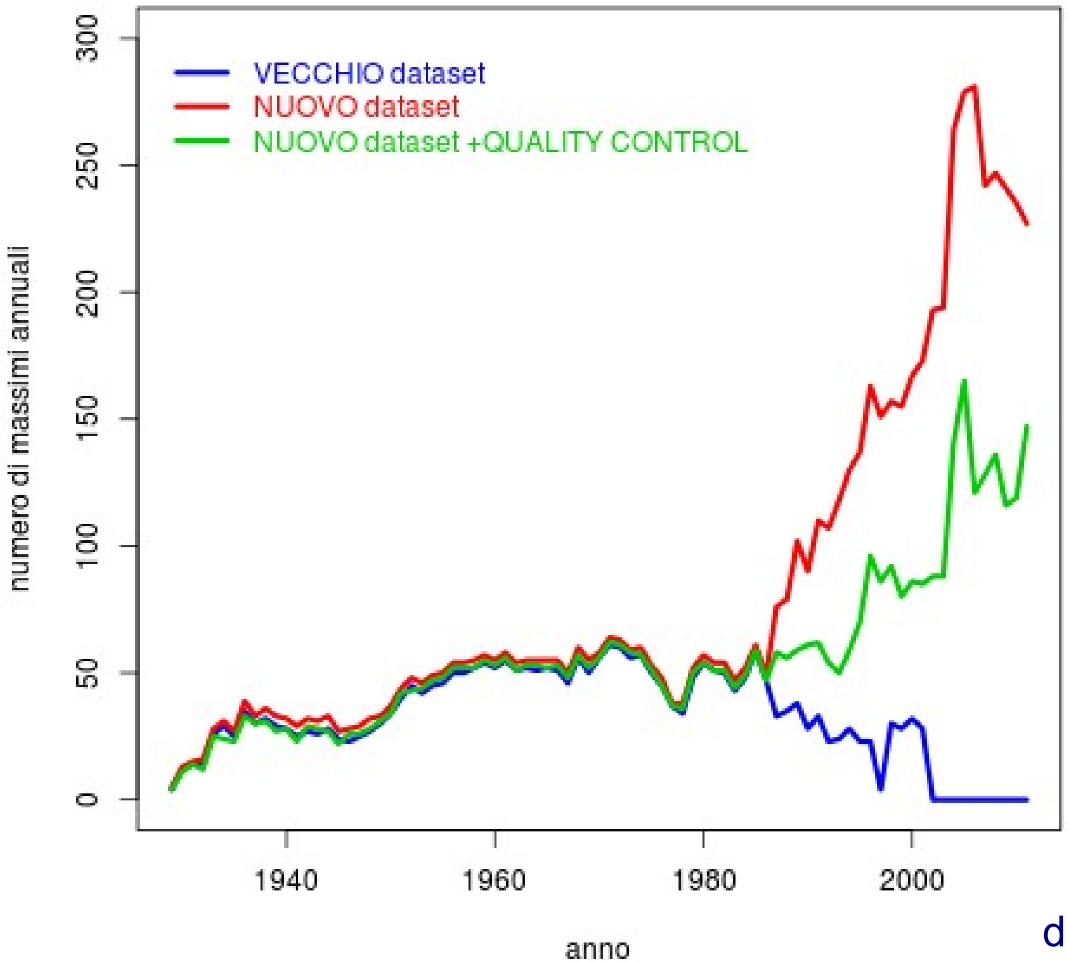
Significant difference between the medians is evaluated by means of the notches.

The notch value is based on the assumption of asymptotically normal distribution for the mdian and its definition takes into account the IQR value and the sample dimension N:
notch= ±*1.58* IQR/ *sqrt(N)*
(McGill et al., 1978)

← Como-Varese area (the most rainy)

Dataset extension

Quality control



NEW extended dataset:

- 1929-2011
- **Quality Control**
- 312 stations (125 **M**echanic, 187 **A**utomatic)
- Presence of "short series"
- Total: 4510 annual records

Quality Control: annual maxima discarded mostly because:

- Less than 90% of data in the year
- Exclusion of the oldest automatic sub-network "Aria"

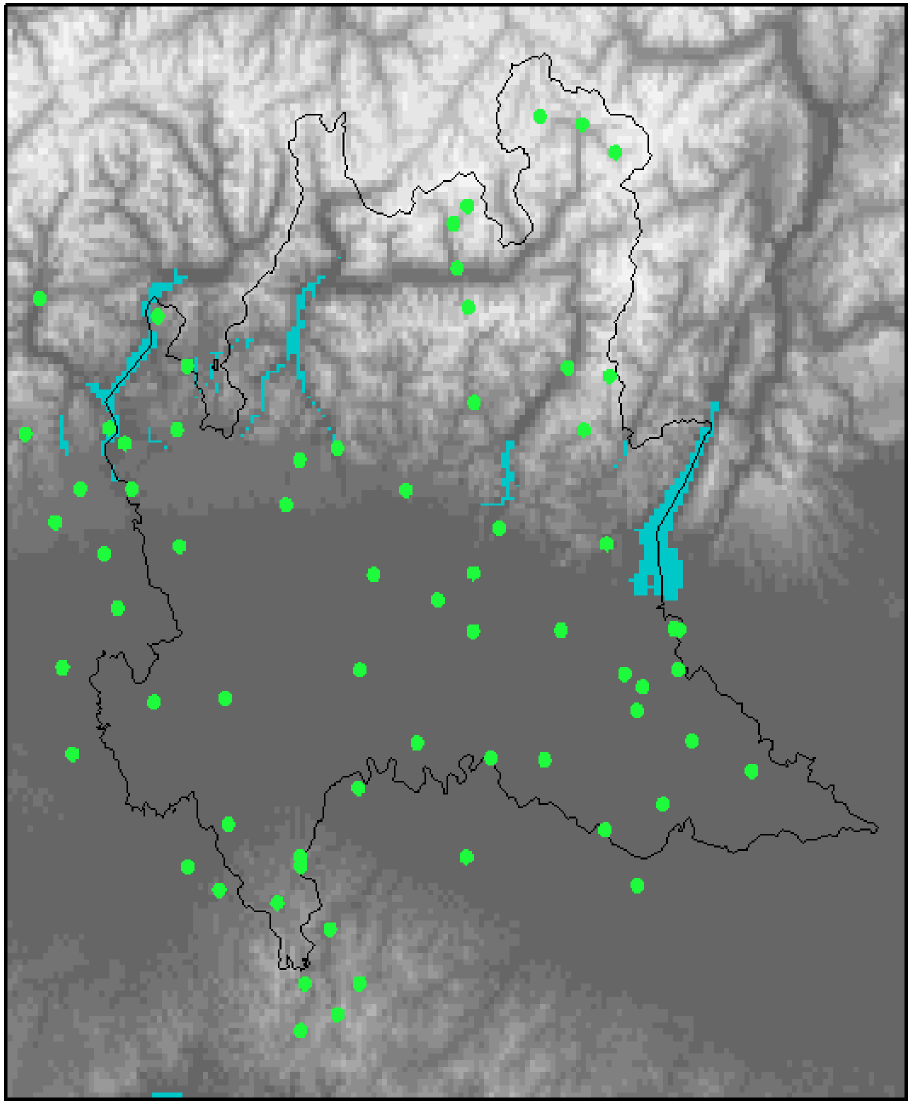
dataset	stations	Annual records
OLD	69	2753
EXTENDED	370	6853
EXTENDED + QUALITY CONTROL	312	4510

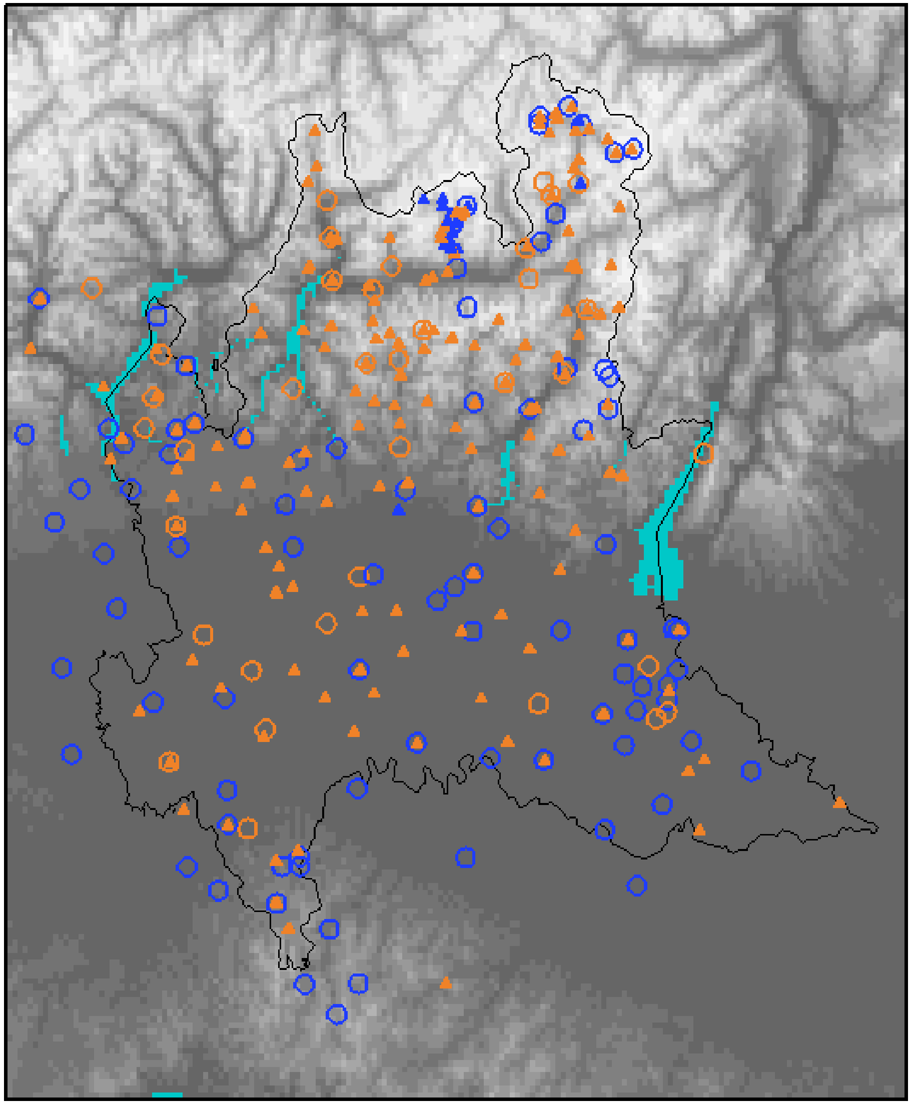
Dataset extension

Circle: **M**echanic; Triangle: **A**utomatic

Blue: at least 10 annual records;

Orange: less than 10 records





Stationarity analysis: areas comparison

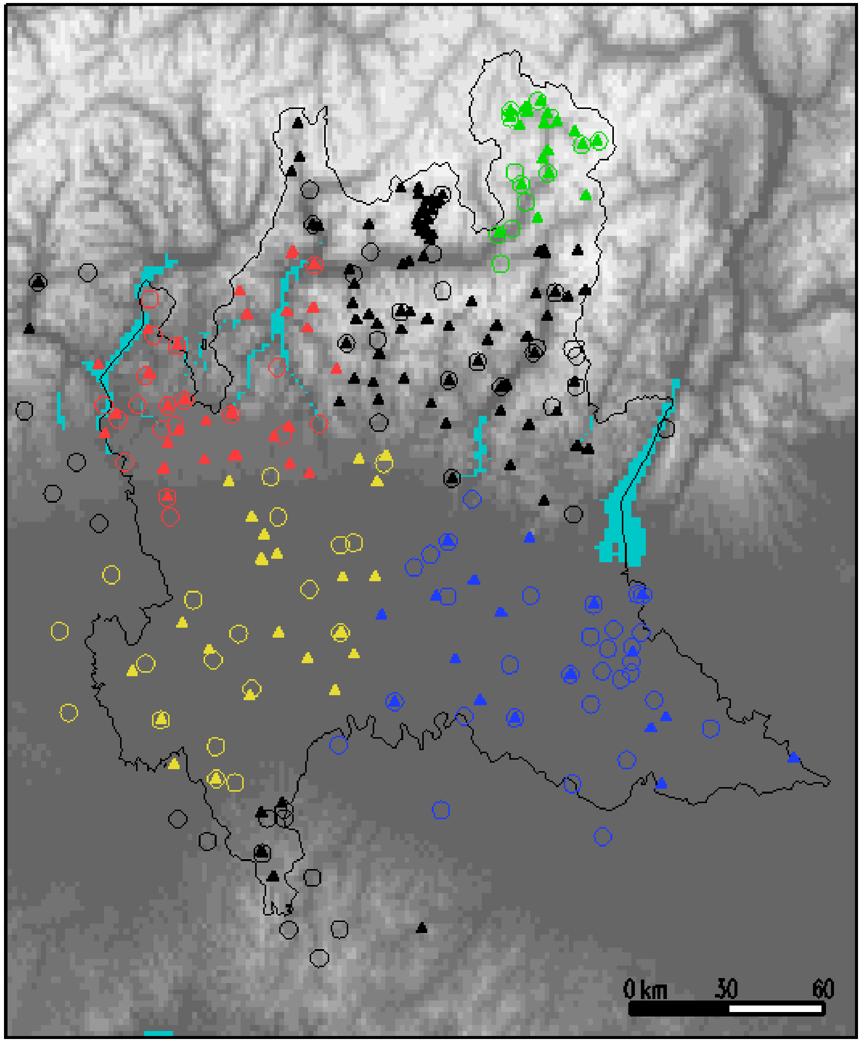
Two consecutive steps:

1) **Study the rainfall annual maxima sample distribution for each area**.

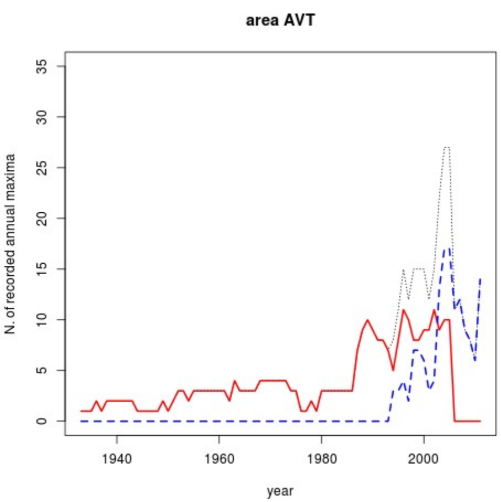
We are dealing with a dataset of extreme values, then our choice has been to consider the more stable quartiles (median, .25 and .75 quantiles) instead of tails or outliers.

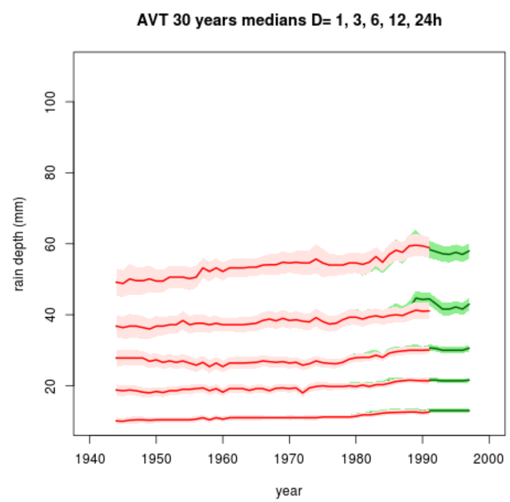
The *goal* is to identify systematic errors (Quality Control) and to evaluate relevant quartiles variations in time.

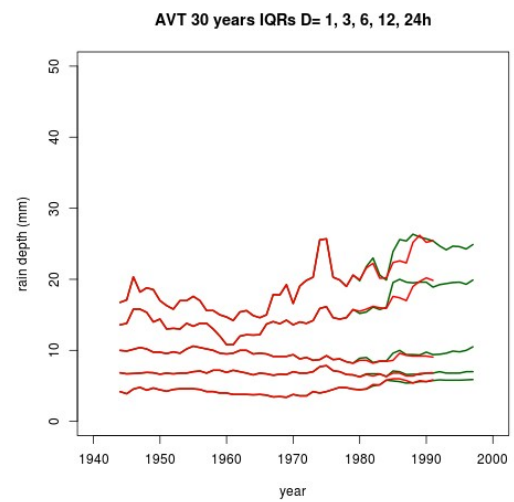
2) **Estimate GEV distribution parameters in each area,** by making use of the Quality-Controlled dataset, assuming stationarity within every reference period.



Stationarity analysis: area AVT Alta Valtellina



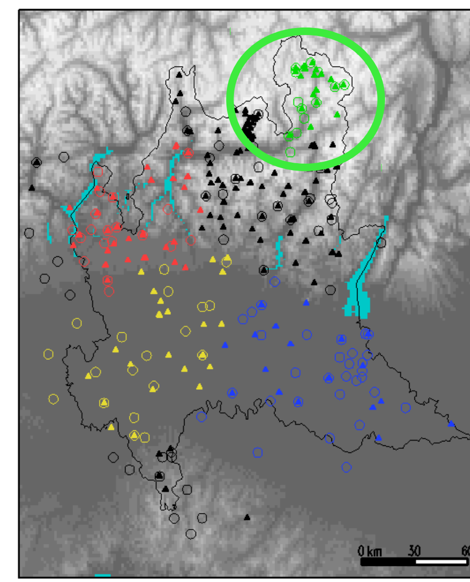




Number of annual records:
M A M+A

sample median

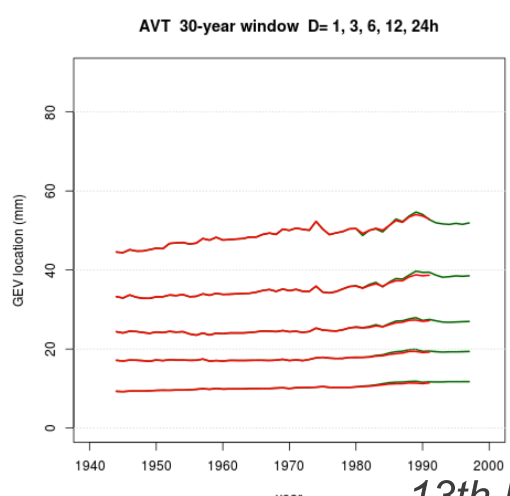
sample IQR

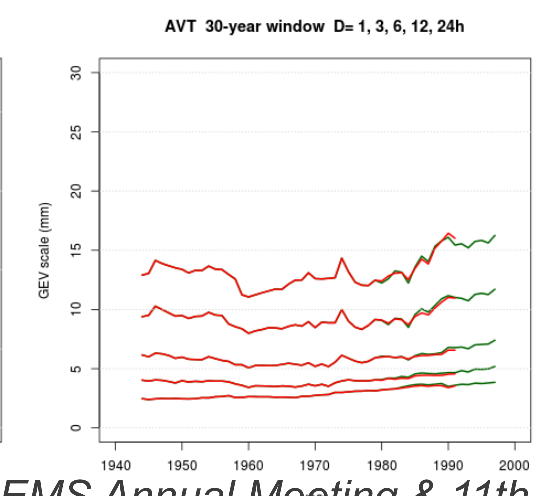


30-year running window: **M** **M+A**

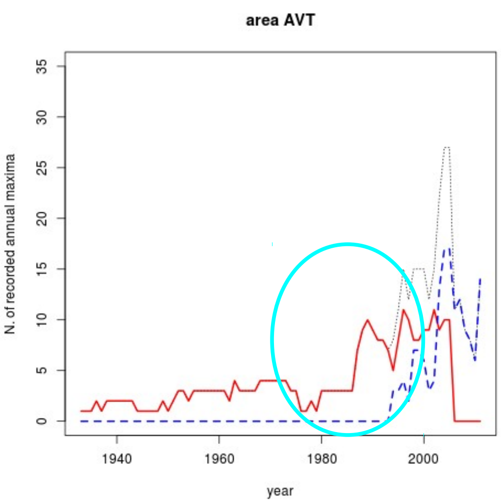
GEV location μ

GEV scale α

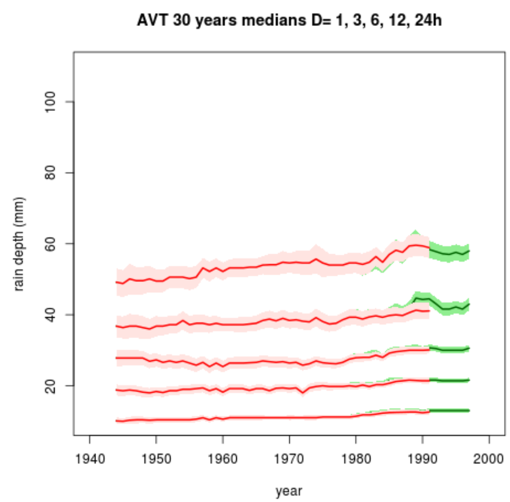




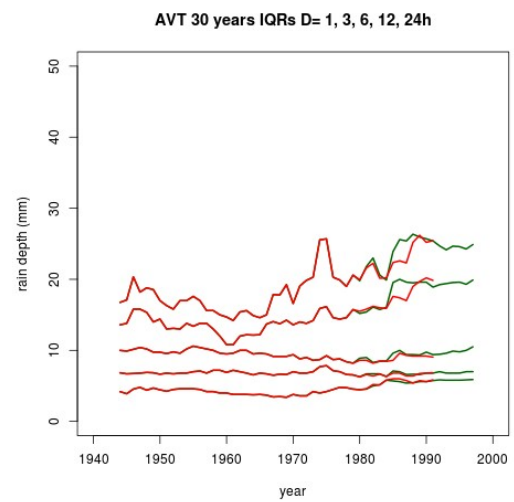
Stationarity analysis: area AVT Alta Valtellina



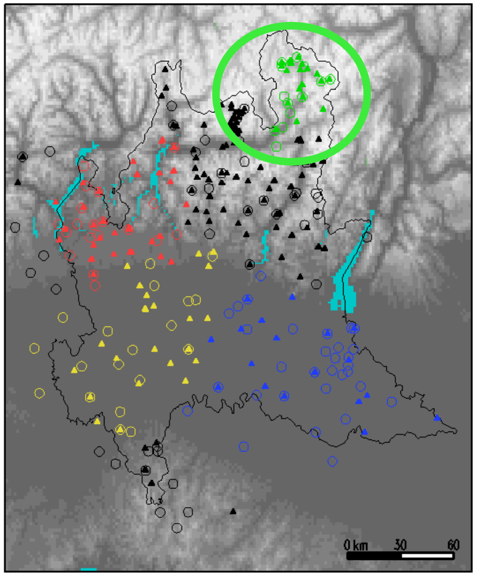
Number of annual records:
M A M+A



sample median

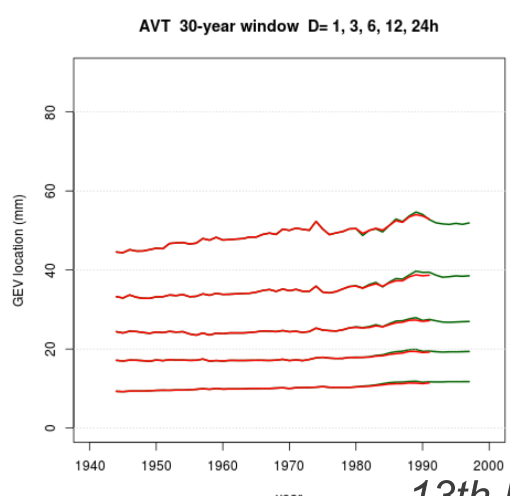


sample IQR

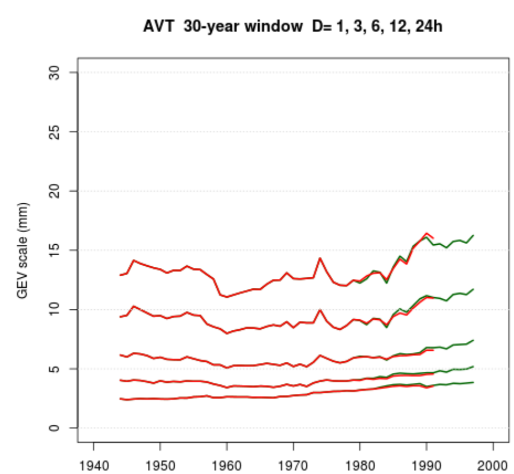


30-year running window: **M** **M+A**

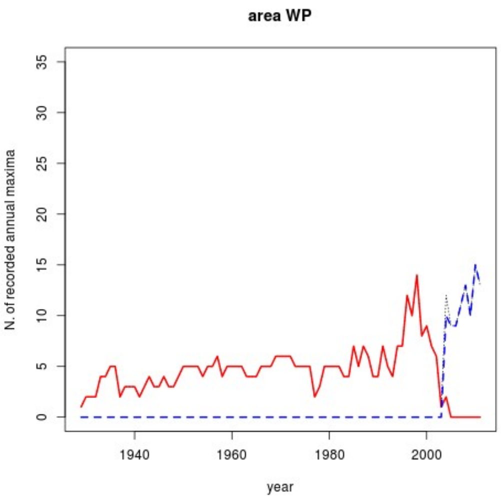
GEV location μ



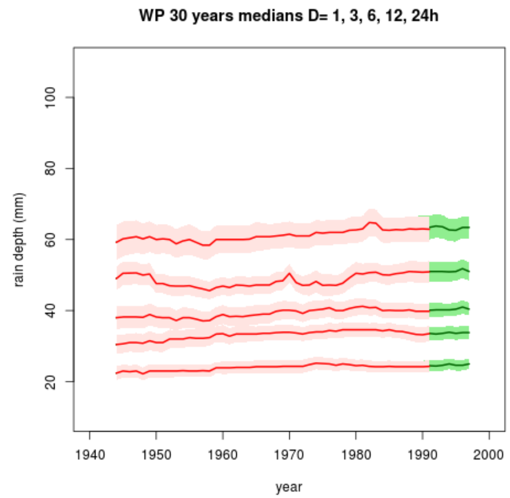
GEV scale α



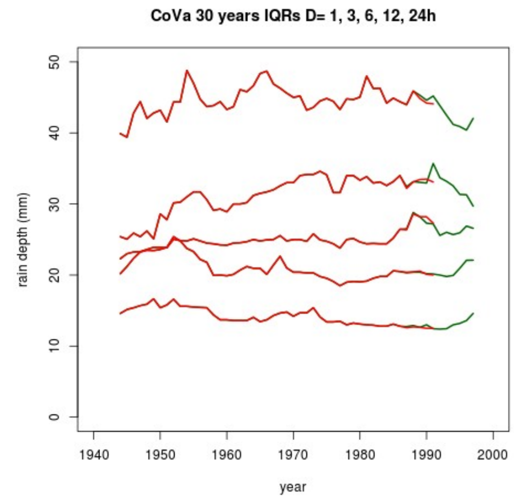
Stationarity analysis: area WP West Plain



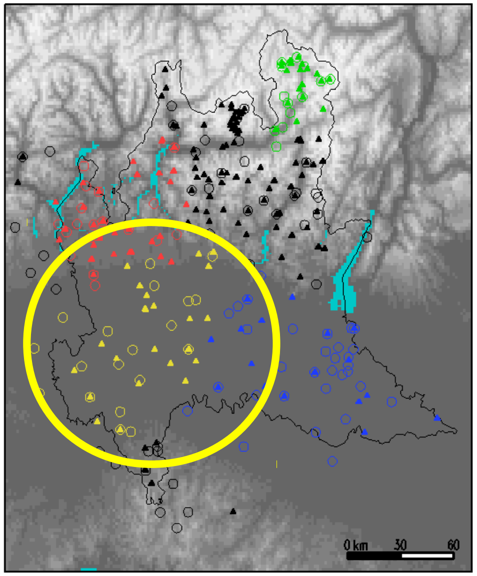
Number of annual records:
M A M+A



sample median



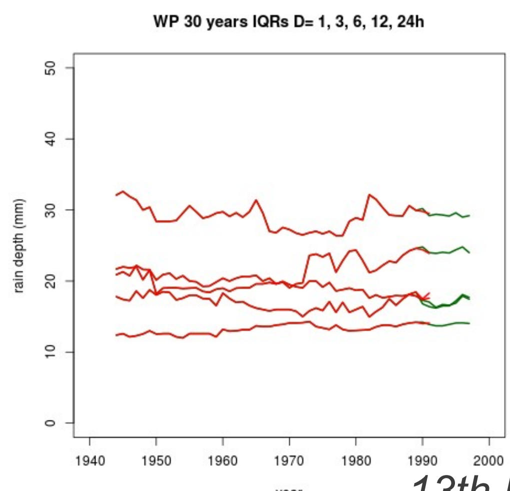
sample IQR

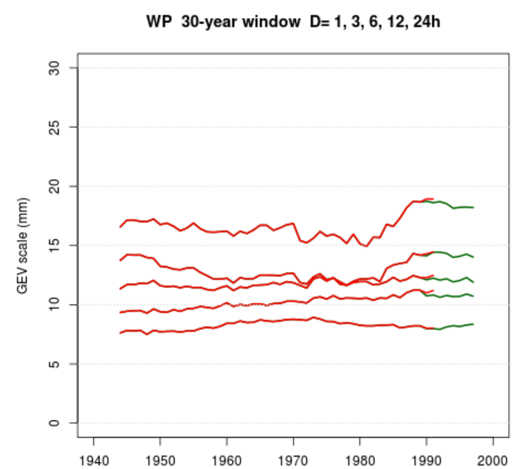


30-year running window: **M** **M+A**

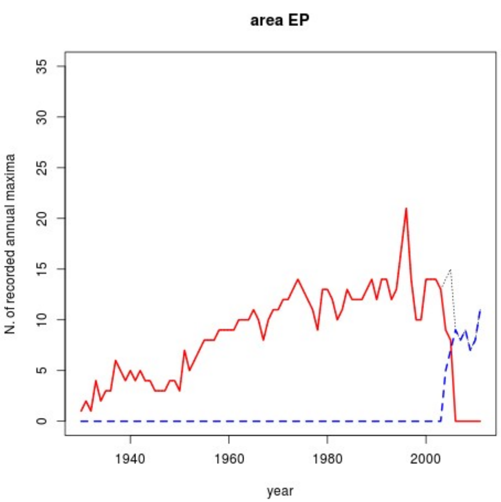
GEV location μ

GEV scale α

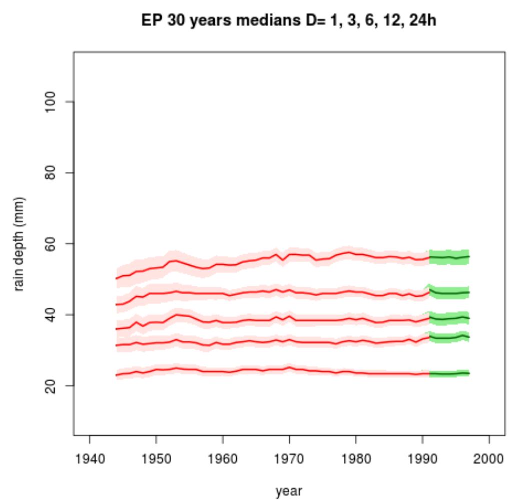




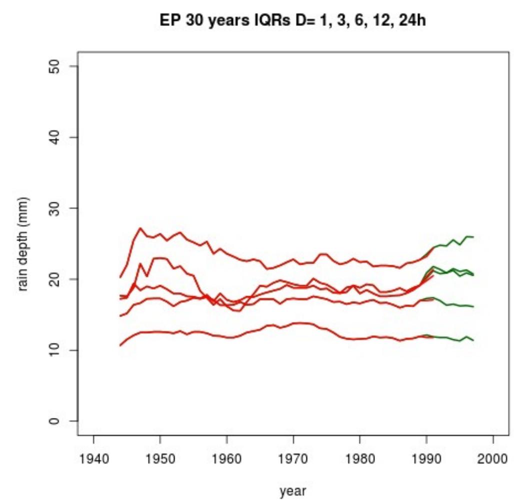
Stationarity analysis: area EP East Plain



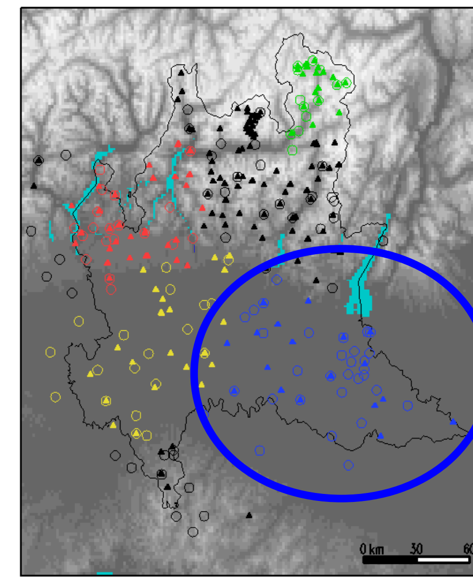
Number of annual records:
M A M+A



sample median

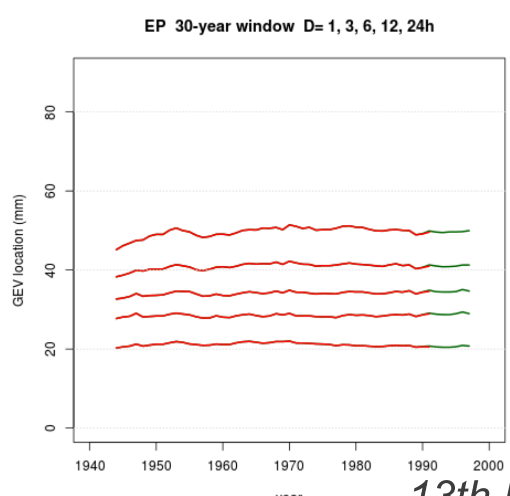


sample IQR

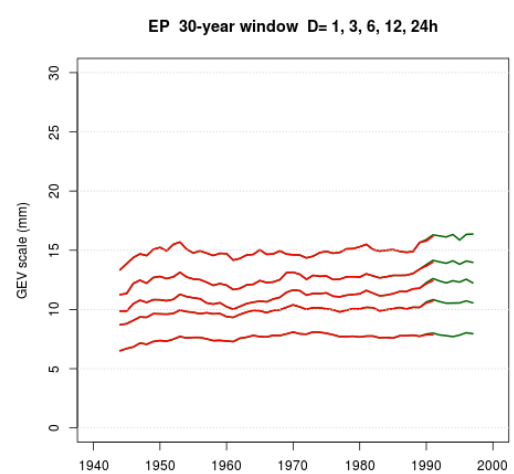


30-year running window: **M** **M+A**

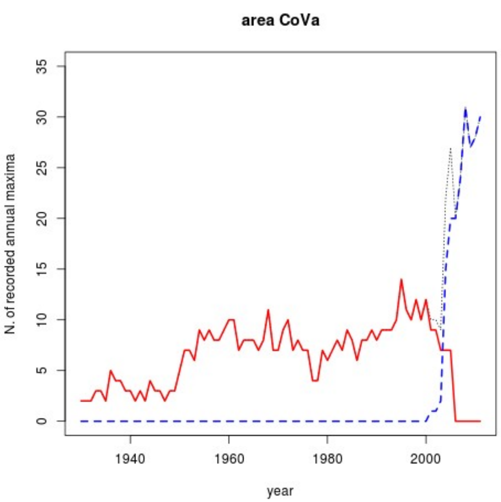
GEV location μ

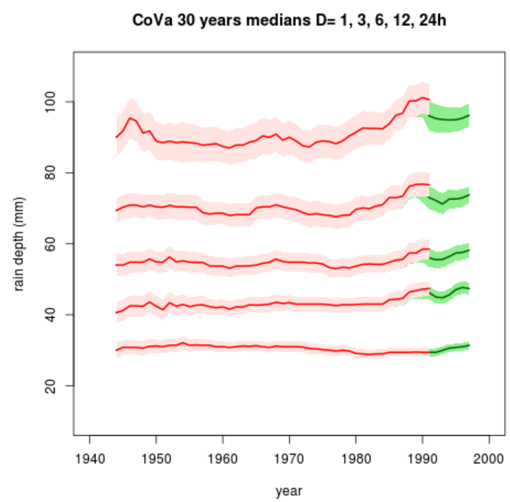


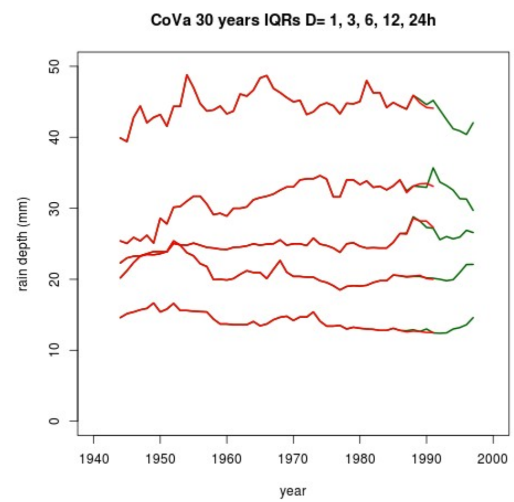
GEV scale α



Stationarity analysis: area CoVa Como-Varese



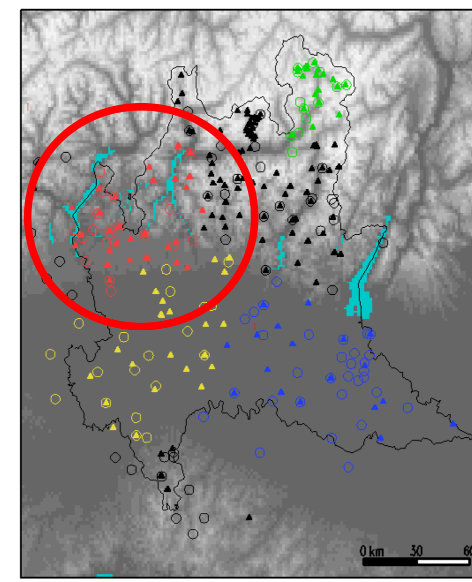




Number of annual records:
M A M+A

sample median

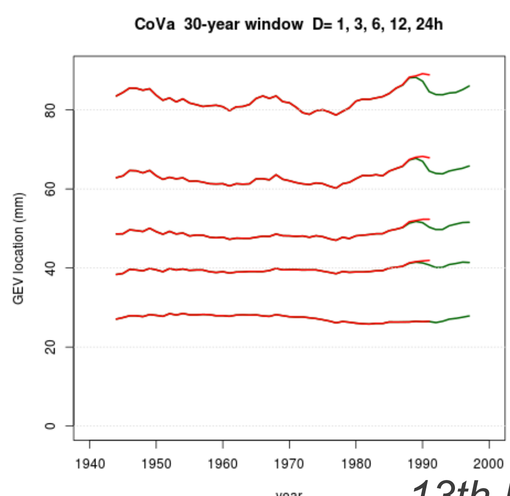
sample IQR

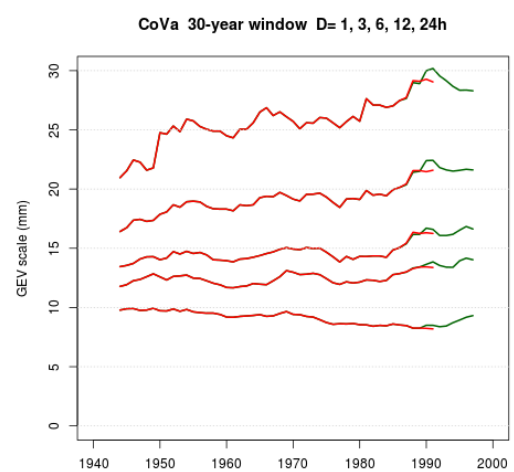


30-year running window: **M** **M+A**

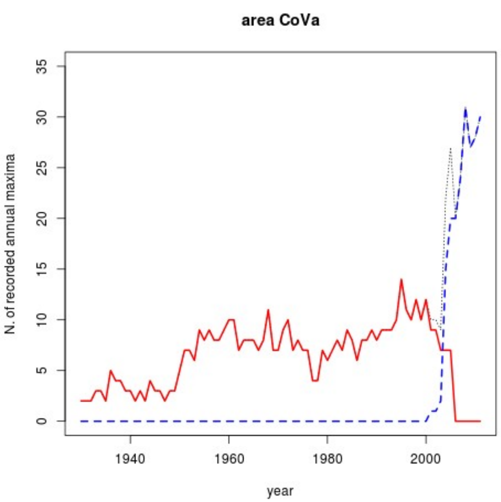
GEV location μ

GEV scale α

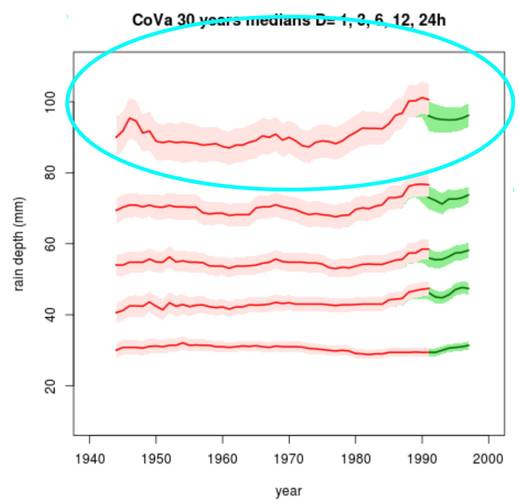




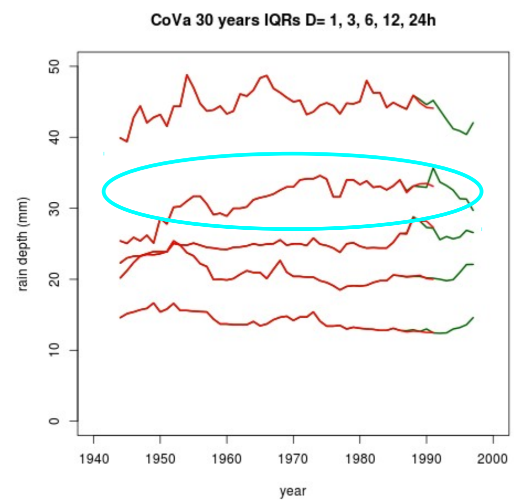
Stationarity analysis: area CoVa Como-Varese



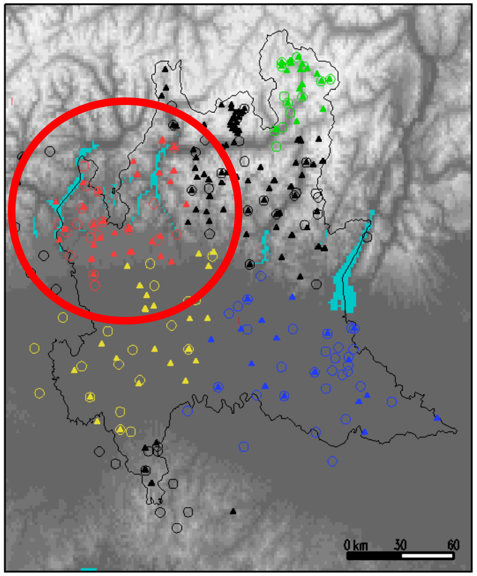
Number of annual records:
M A M+A



sample median

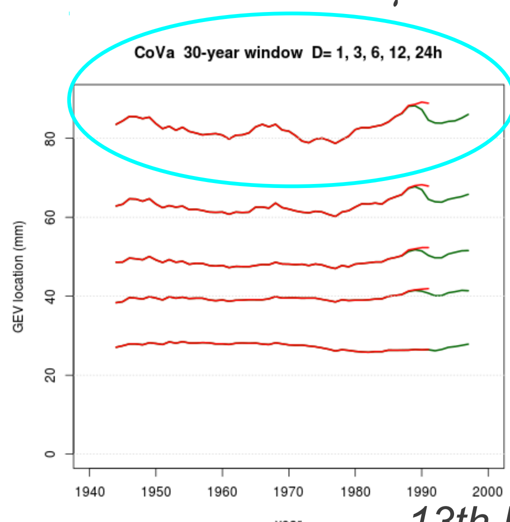


sample IQR

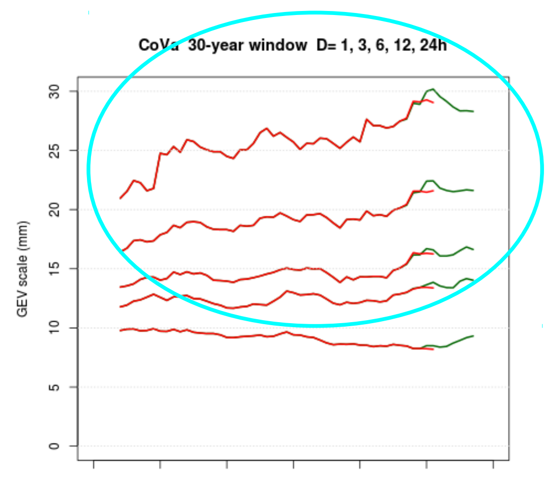


30-year running window: **M** **M+A**

GEV location μ



GEV scale α



CONCLUSIONS

- **New and improved dataset** more reliable data and with a well organized structure
- Weak point 1: Systematic errors in Automatic Station data
- Weak point 2: Lack of metadata.

- **Multiple-station spatial bootstrap method** available (robust and efficient)

- **Non-stationarity in the variability**: GEV scale parameter and IQR (D=6h) of the rainfall annual maxima distribution for the CoVa area
- Possible **non-stationarity** in the **median** and GEV location parameter of the rainfall annual maxima distribution for the **CoVa** area: Como and Varese rainy area. Difficult (but for this application also irrelevant from a practical point of view) to discriminate between a linear trend or a long multidecadal oscillation (~80 year period) in the data.
- AVT (Alta Valtellina) area: the variations in time are likely to be related to the increased station density.

- A periodic (5-10 year) DFF curves update is recommended
- Highly recommended (in particular, for Automatic Stations): 1) **investigation of systematic errors**; 2) detailed **collection of metadata**
- The presence of **non-stationarity** must be properly handled. At least, the present study should be repeated in the future, including 2011-2020 data for example.