WEATHER RADAR AND FLASH FLOOD (*UNDERSTANDING AND*) FORECASTING

Marco Borga

University of Padova, Padova, Italy
HYDRATE team (www.hydrate.tesaf.unipd.it)

RIMAX OPAQUE

KARLSRUHE

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Talk Overview

- **Flash flood characteristics;**

- **Radar monitoring of flash flood-generating rainfall:**
- Radar/raingauge estimation and hydrologic visibility
- Study of ground rainfall/ radar rainfall as a function of range
- Effects of the VPR, Z-R etc

- **Use of radar-rainfall estimates with hydrological models**

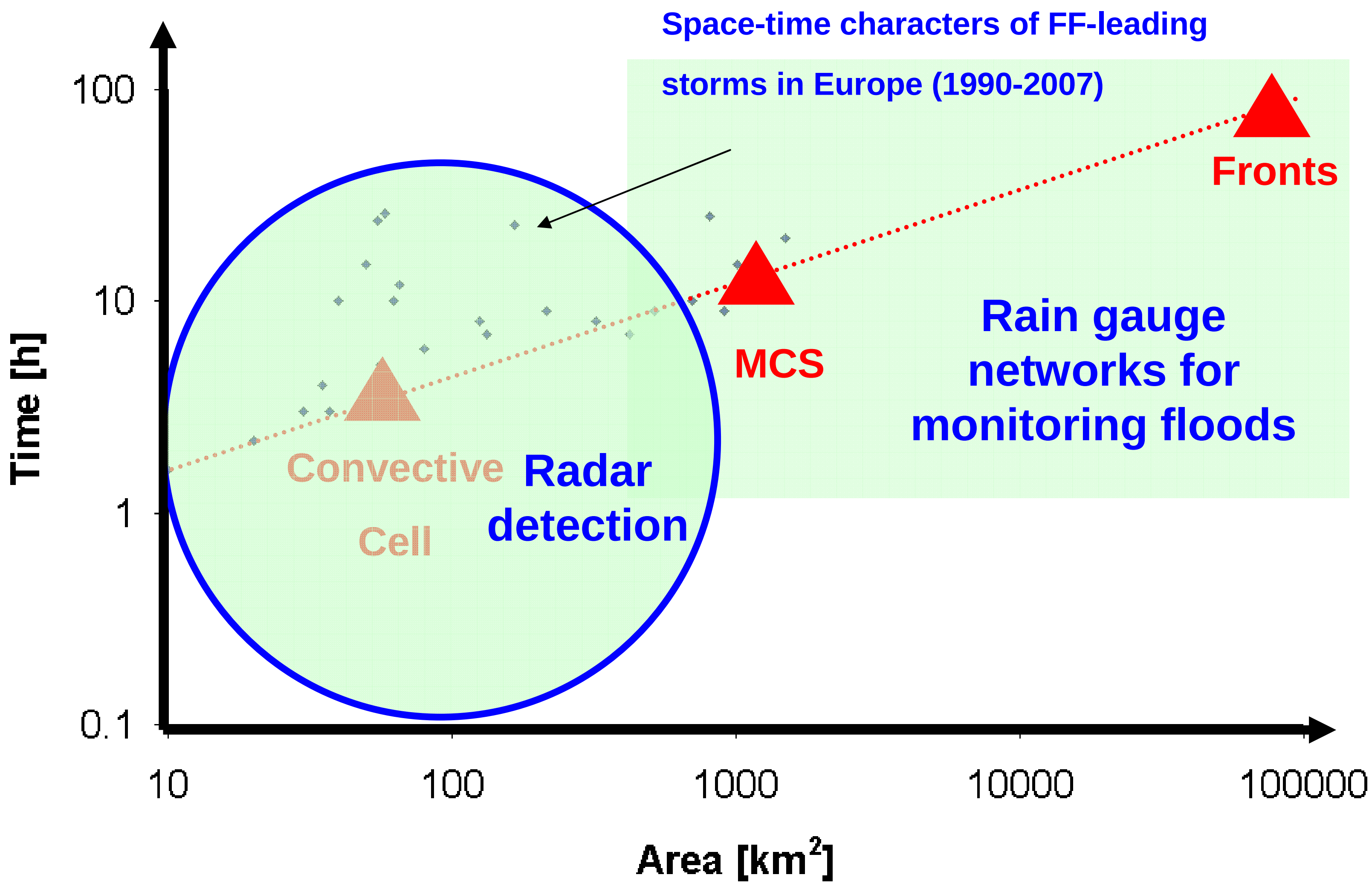
- **Use of radar-rainfall estimates to enable more understading by means of post-flash flood surveys**

- **Conclusions**

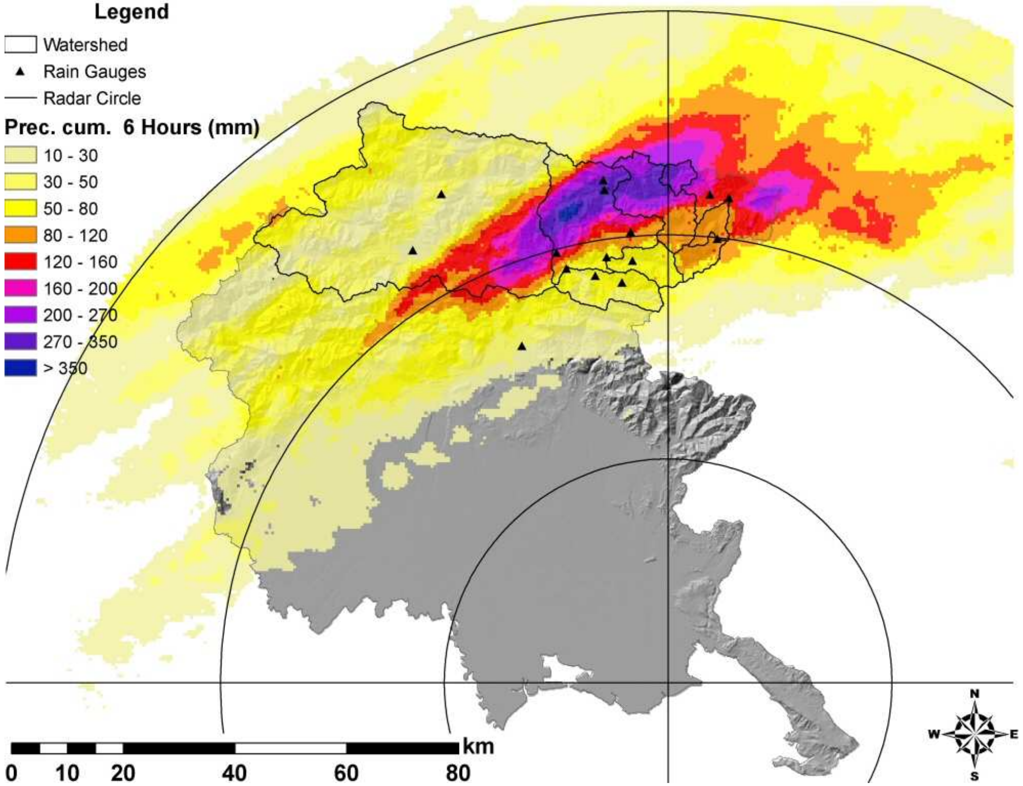
Flash-flood characteristics

- **Scales**
  - **Characteristic times in hours**
- **Intensities**
  - **Steep flood waves**
- **Coupling**
  - **Geomorphic effects in hilly-mountainous areas**
- ***Observation***
  - ***Ungauged watersheds (rainfall and levels)***
  - ***Radar detection***
- Forecasting
  - Coupling meteorology and hydrology
- Vulnerability
  - Point and distributed targets

Space-time scales of flash floods



An example:
The flash flood event of 29 August 2003
(north-eastern Italy)



Radar monitoring of flash flood generating rainfall

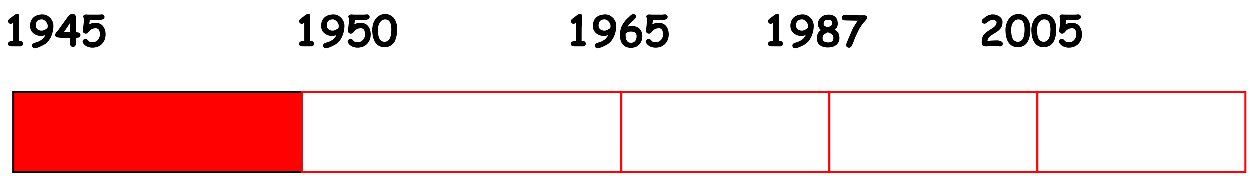
- Brief history of radar rainfall estimation
- Problems with heavy rainfall
  - Orography
  - Attenuation
  - Vertical profile of reflectivity
  - Z-R
- Adjustment with raingauges
  - Necessary? Advisable? Usable?

Brief history: Marshall-Palmer and Z-R relationship

- **The quantitative use of radar measurement motivated an important body of works starting in the late 1940s with the finding of a relationship between the radar reflectivity and the rain intensity (Marshall et al., 1947, Marshall and Palmer, 1948):**

  the Z-R relationship $Z = AR^b$

- **Unfortunately, in (too) many cases Z-R relationships were tuned to fit raingauge measurements**



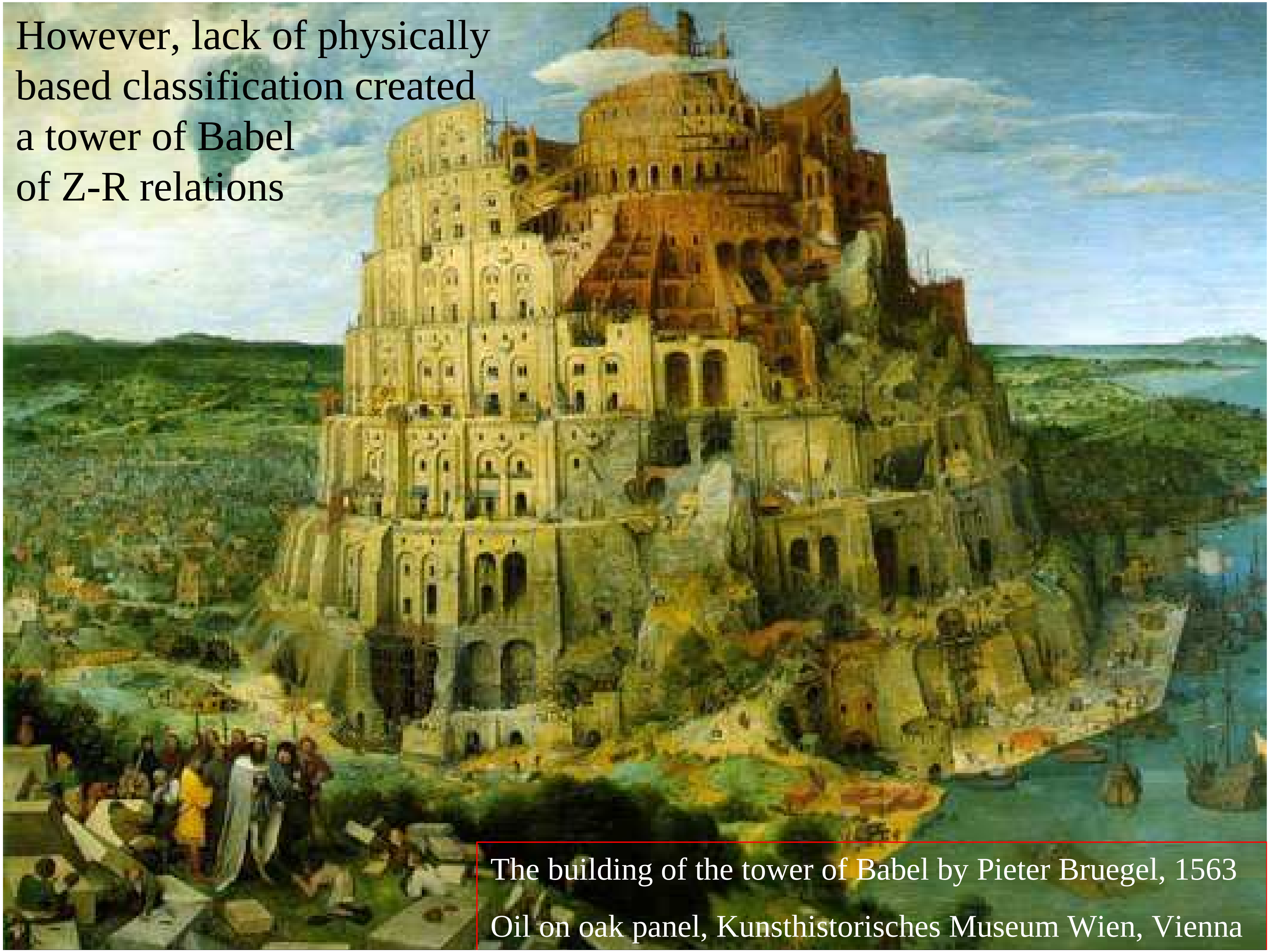
In the beginning (1947) Marshall and Palmer created the MP Drop Size Distribution And MP Z-R relationship

And we said that the ZR was good, and created more…

TABLE 7.1 Empirical Relations between Reflectivity Factor, Z(Mm^6/M^3), and Precipitati

Equation	Reference	Location	
$320R^{1.44}$	Wexler, R. (1947)	Washington, D.C.	8 rain inter 10 storm
$214R^{1.58}$	Wexler (1948)	Washington, D.C.	98 storms –
$224R^{1.54}$		Ynyslas, Great Britain	5 rainstorm
$630R^{1.45}$		Shoeburyness, England	4 rainstorm
$208R^{1.53}$		Hawaii	50 storms,
$190R^{1.72}$	Marshall, Langille, and Palmer (1947)	Various locations	Various typ
$220R^{1.60}$	Marshall and Palmer (1948)	Various locations	Various typ
$295R^{1.612}$	Hood (1950)	Canada	270 sample 1–3 mm/
$180R^{1.55}$	Boucher (1951)	Cambridge, Mass.	63 rain sam uniform a thunderst
$127R^{2.87}$	Higgs (1952)	Australia	Showers, 8
$16.6R^{1.55}$	Blanchard (1953)	Hawaii	Orographic
$31R^{1.71}$			Orographic
$290R^{1.41}$			Nonorograp
$396R^{1.35}$	Jones (1955)	Central Illinois	1,270 1-min
$486R^{1.37}$			560 1-minut
$380R^{1.24}$			330 1-minut
$313R^{1.25}$			380 1-minut
$150R^{1.54}$	Litvinov (1956)	Mount El'brus, USSR	Rain (melte granulated
$257R^{1.55}$			Rain (melte 367 spect
$398R^{1.47}$			Rain (melte spectra, 4
$162R^{1.16}$	Atlas and Chmela (1957)	Lexington, Mass.	Stratiform r
$215R^{1.34}$			Stratiform r
$350R^{1.42}$			Stratiform r
$310R^{1.34}$			Stratiform r

However, lack of physically based classification created a tower of Babel of Z-R relations



The building of the tower of Babel by Pieter Bruegel, 1563

Oil on oak panel, Kunsthistorisches Museum Wien, Vienna

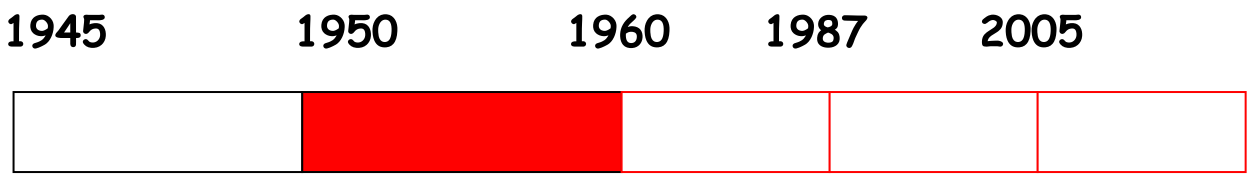
Brief history: work on attenuation, bright band, rain advection..

- At the same time, some work is focused on the physical understanding of radar measurement.

- Works on (among many others):
  - attenuation by rain (Hitshfeld and Bordan, 1953),
  - the bright band due to the melting layer (Austin, 1950, Lhermitte, 1952)
  - the rain advection by the wind (Gunn and Marshall, 1955).

- An important result: spatial organization of radar errors

- Unfortunately, the limited possibilities of signal processing and archiving at that time, made this knowledge almost impossible to apply for meteorological and hydrological applications.

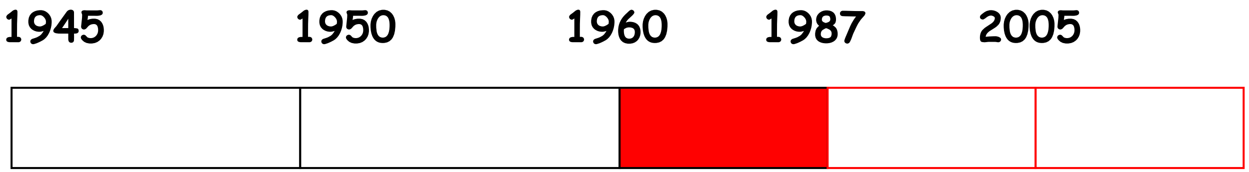


Brief history: radar-raingauge camplementarity (calibration factor, assessment factor, cokriging).

- During the following two decades the main question explored by hydrologists has been the complementarity between rain gauge networks and radars (Wilson and Brandes in 1979, and more recently Collier, 1986, Creutin et al., 1987, Krajewski, 1987).

- In spite of the quality of the theoretical frameworks used, the answers were somewhat discouraging:
  The calibration techniques in some cases (Wilson and Brandes, 1979) were only able to reduce the bias between gauge and radar measurements, in other (cokriging based approaches) too weigth was on raingauge measures.

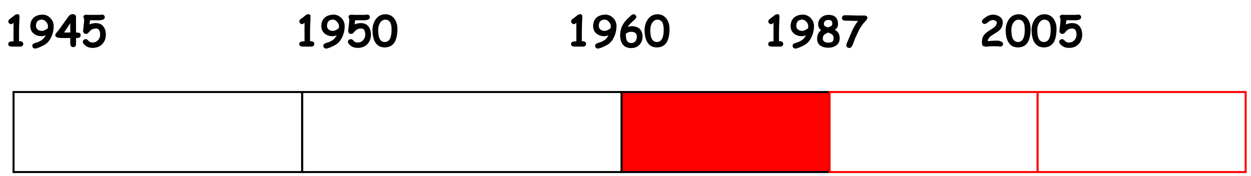
- Exploiting only the radar-raingauge complementarity leads to forgot the spatial organization of radar errors



Brief history: understanding of radar error and capability (hw-sw) to cope with them

- **Development of new radar systems with volumetric scanning and the digitisation of the signal processing.**

- **In a key paper published in 1984, I. Zawadski started a new direction on understanding radar rainfall estimation: "The accuracy of radar estimates at ground will only be improved by addressing the various sources of error in a painstaking and a meticulous manner. The combination of hardware and software made available by the technology of today permits a complexity of radar data processing which should be helpful in reducing the errors discussed here" (the paper established the relative importance of the different sources of errors).**



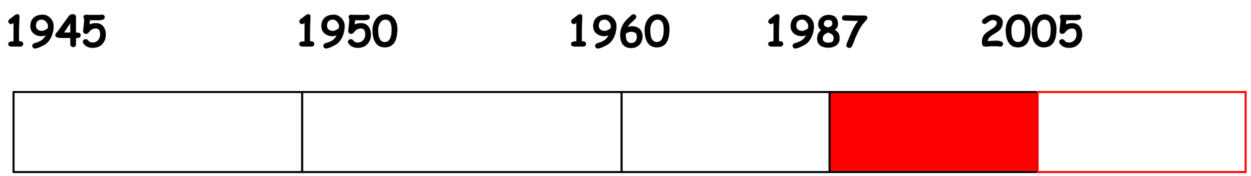
Brief history: development of comprehensive algorithms for radar-rainfall estimation

- Development of comprehensive algorithms (Joss and Waldvogel, 1990; Andrieu and Creutin, 1995; Krajewski et al., 1999; Anagnostou and Krajewski, 2000; Borga et al., 2002);

- The considered error sources belong (generally) to three broad areas :
  i) the electronic stability of the radar system,
  ii) the determination of the detection space and,
  iii) the fluctuation of the atmospheric conditions.

- A number of algorithms are structured as assimilation procedures

- Additional remote sensing capability was added in the 1990s: Dopplerization, dual-polarization capability…



The electronic stability of the radar system:

It has to be ensured by the service managing the radar system;
Can be checked by using ground clutter.

The determination of the detection space:

- **Shielding by orography (specialised SW);**
- **Ground clutter (Doppler).**

The fluctuation of the atmospheric conditions:

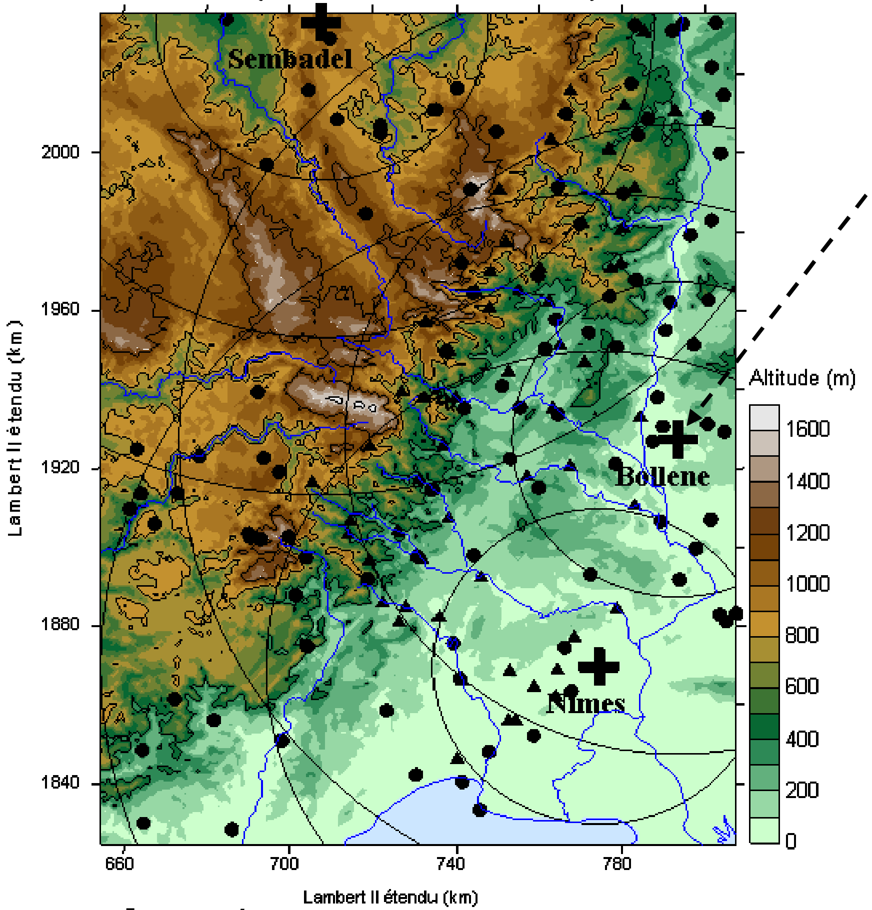
- **Z-R variability**
- **Attenuation**
- **Vertical profile of radar reflectivity**
- **Hail!**

QUESTION 1:

How can we cope with errors in radar observatios, for the case of flash flood producing storms? Which is the impact of the different error sources?

Investigation with the dataset of the Bollène 2002 experiment

Window of the OHM-CV pilot site
(160 x 200 km²)



✚ *Radar*
▲ *Hourly raingauge*
● *Daily raingauge*

Bollène radar

- S-band weather radar of Météo France (negligible attenuation)
- Calibration (stable)
- Ground clutter processing (pulse to pulse variability of Z)
- Volume scanning : 8 PPI/5min (rain typing + VPR identification)

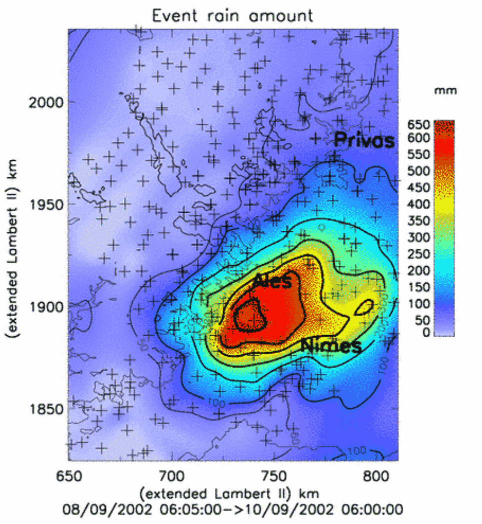
Raingauge network

- 400 daily raingauges
- 160 hourly raingauges

➡ **critical analysis based on geostatistics tools**

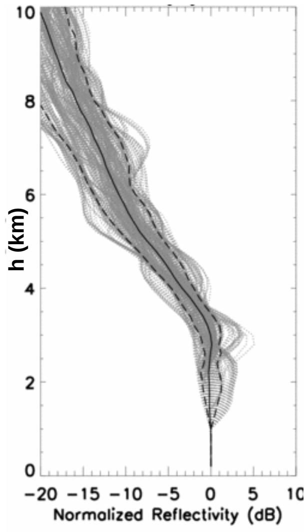
Two examples of heavy events in 2002

8-9 September 2002

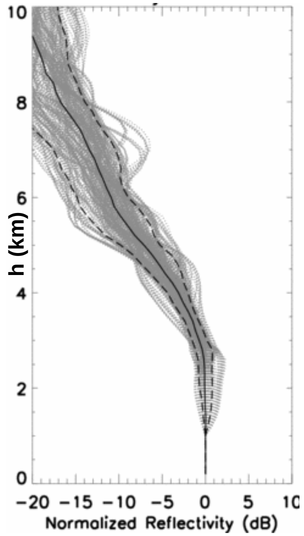


Deep Convection

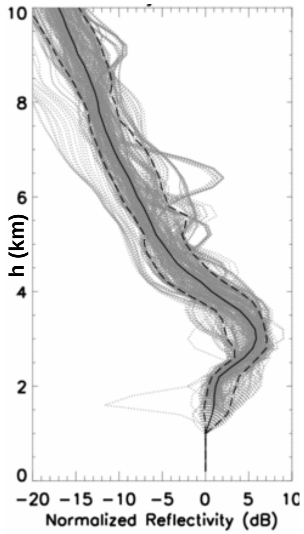
VPR global



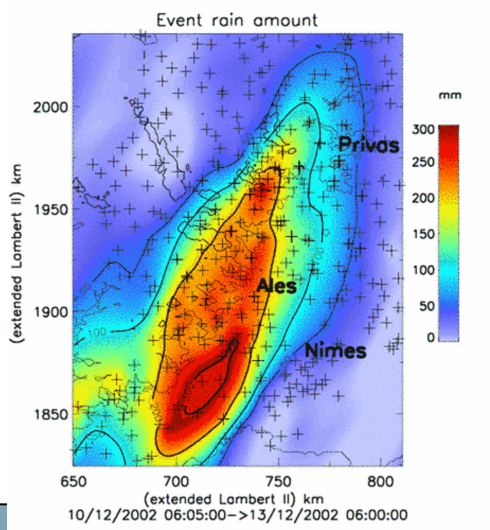
VPR convective



VPR stratiform

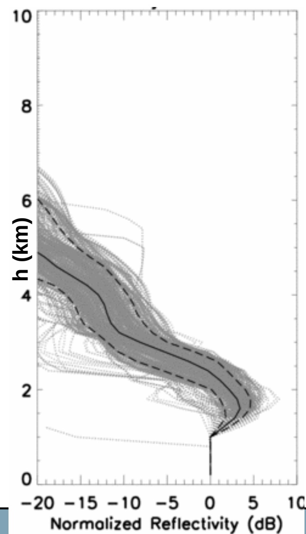


10-13 December 2002

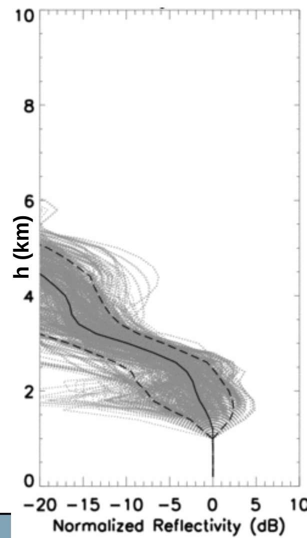


Shallow Convection

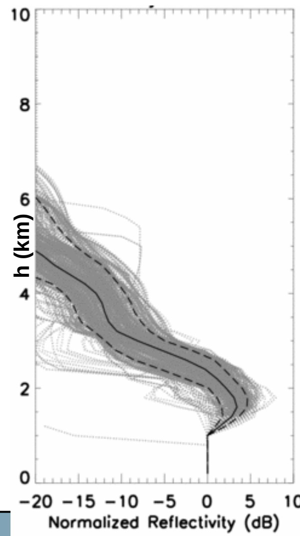
VPR global



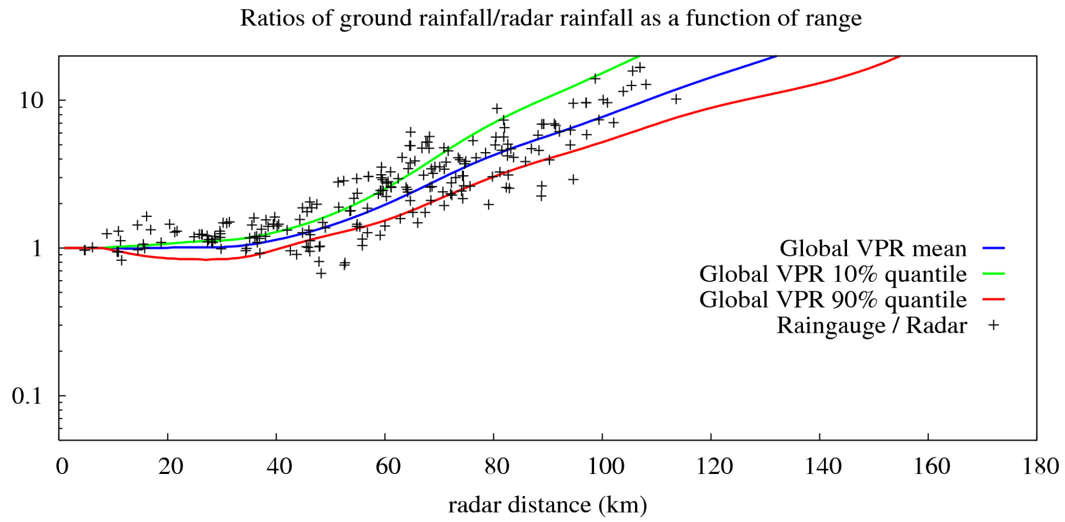
VPR convective



VPR stratiform



Comparison of ratios of ground rainfall/radar rainfall (G/R) as a function of range



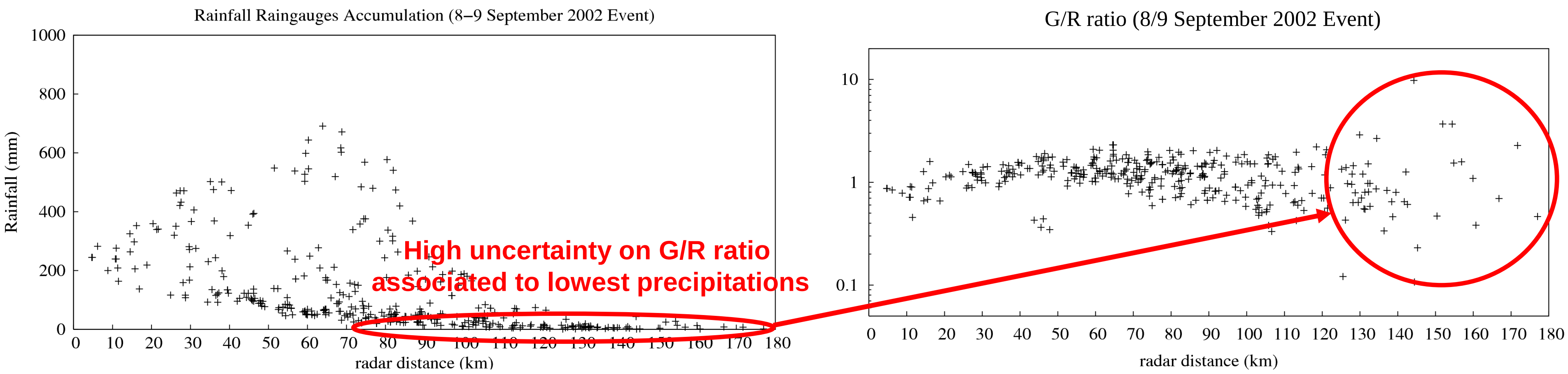
- Example for the 8-9 September event
- 3.6° elevation
- Use of the $Z = 200\ R^{1.6}$ relationship

2 estimators :

- **VISHYDRO procedure**
  - DTM
  - Operating protocol
  - identified VPR's
- **G/R derived from radar and raingauge data**
  - for a given elevation angle
    - ground clutter suppression
    - conversion of measured reflectivity with a given Z-R relationship
    - accumulation at the event time scale

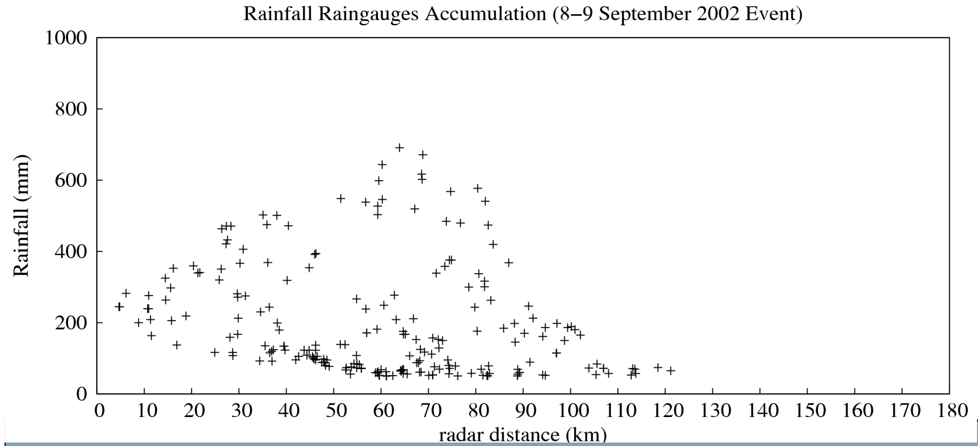
→ ***G/R ratio at the event time scale***

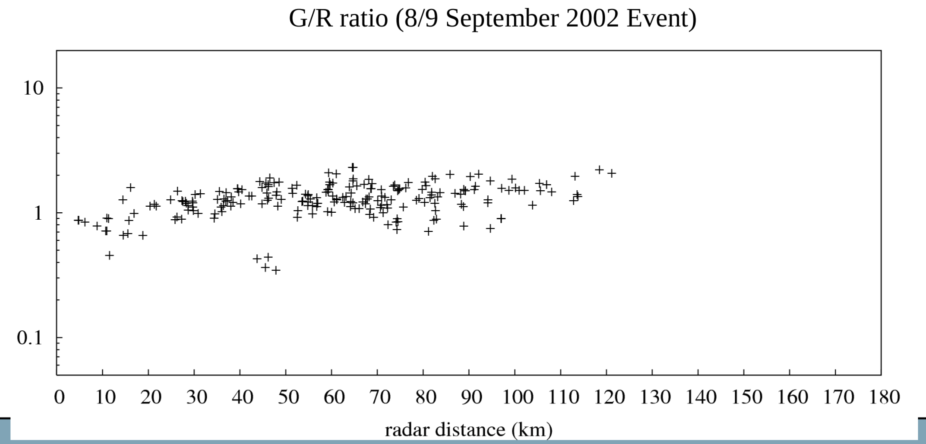
Need for conditioning



Need for conditioning the measured G/R according to the ground measured rainfall (G) to limit G/R ratio uncertainty :

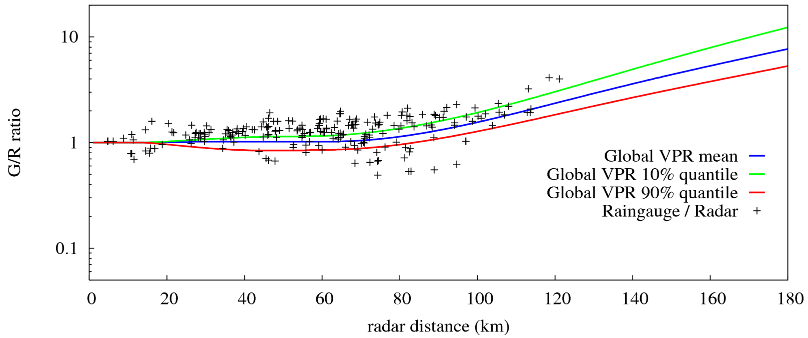
- G > 50 mm for the 8-9 September event
- G > 20 mm for the 10-13 december event



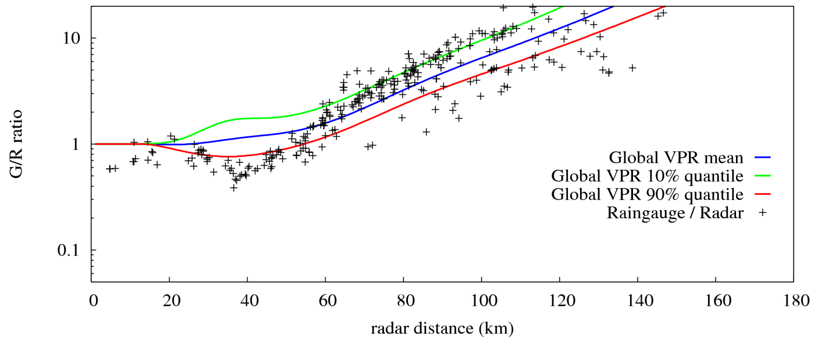


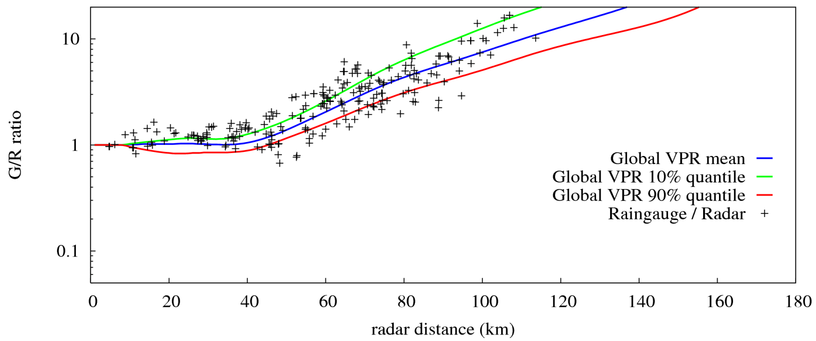
First results with global VPR

Deep convection | Shallow convection

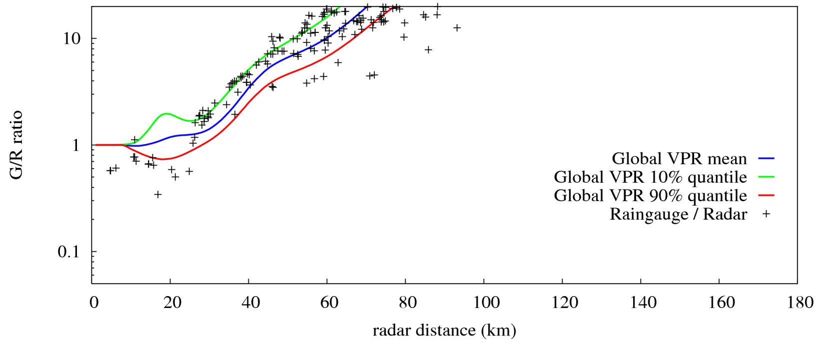


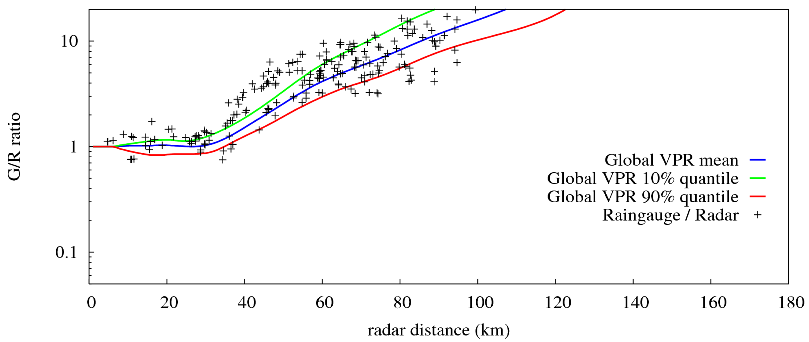
1,7°



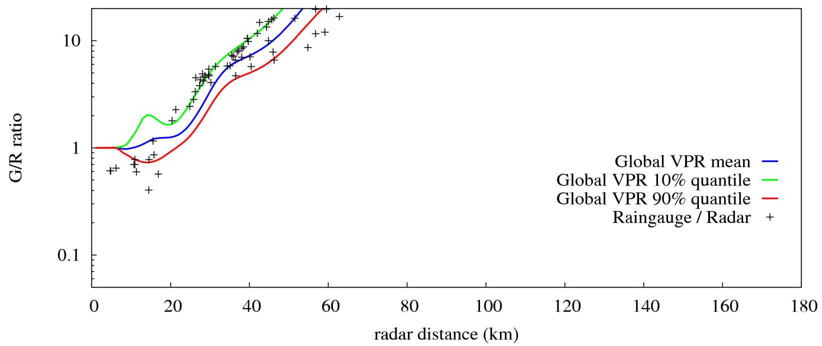


3,6°





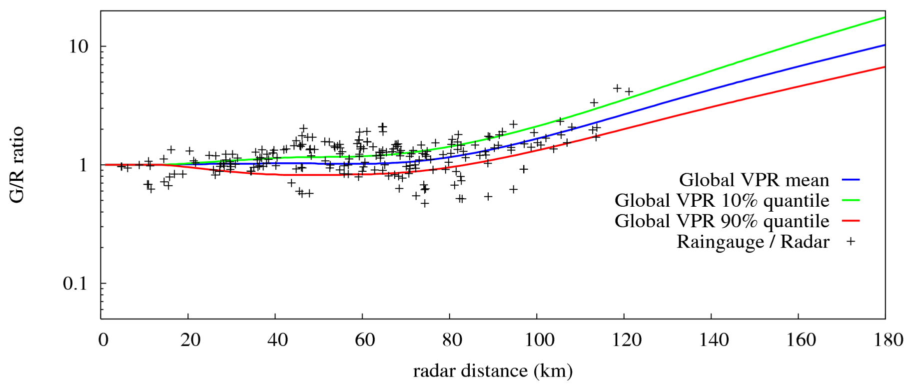
4,8°

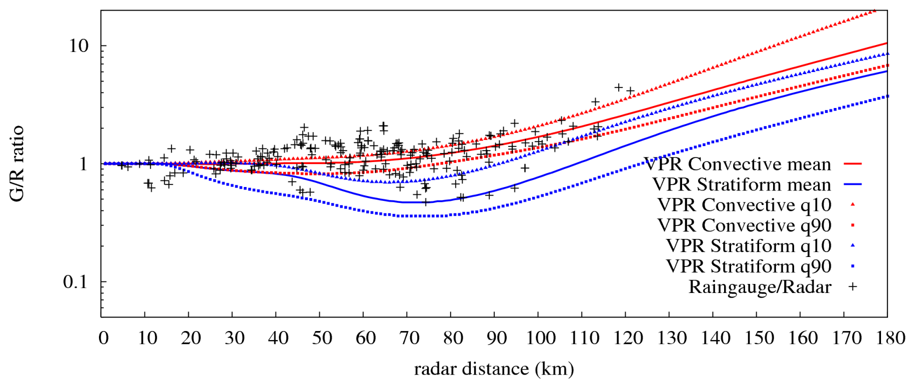


➡ **VPR = First-order control of raingauge/radar ratio**

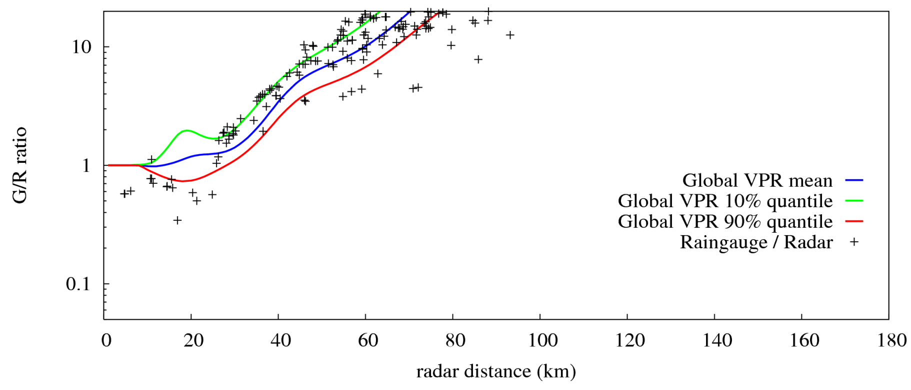
Effect of the VPR type

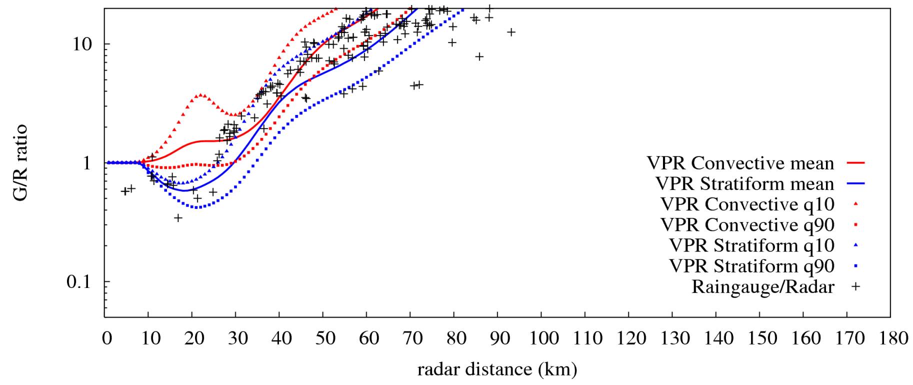
Deep convection (1.7°)





Shallow convection (3.6°)



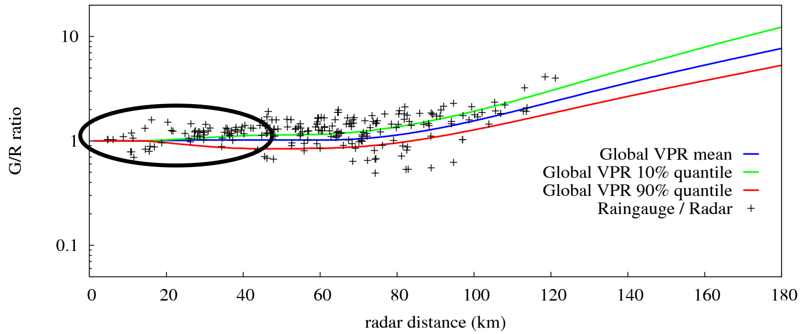


→ **Global VPR may not be sufficient to account for the impact of the spatial variability of the VPR**

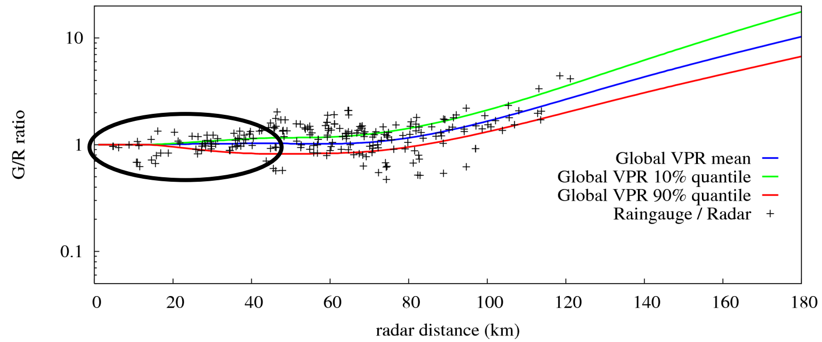
Effect of the Z-R relationship

Example for the deep convection event of 8-9 september

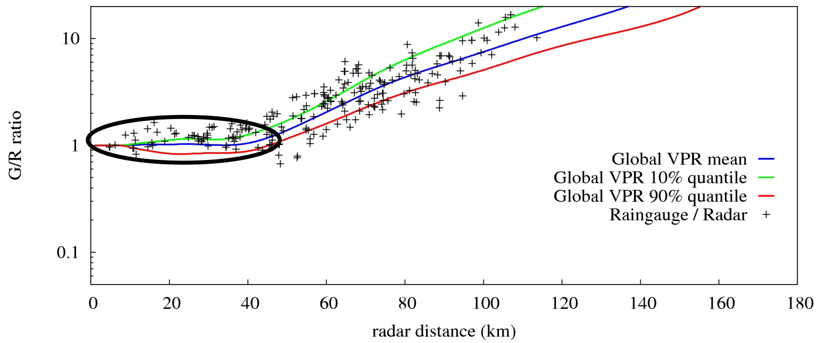
$Z=200\ R^{1,6}$

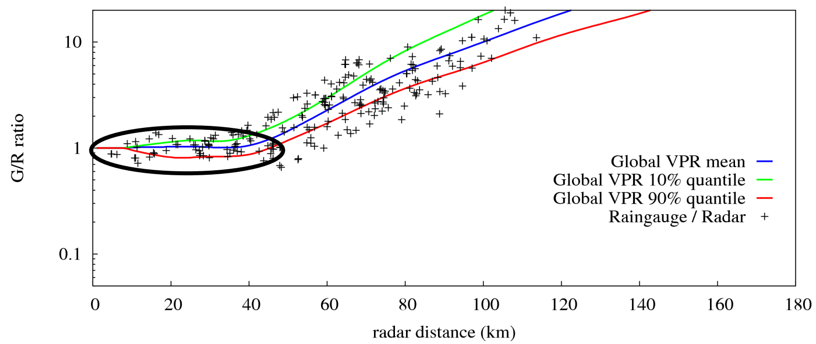


$Z=300\ R^{1,4}$



1,7°





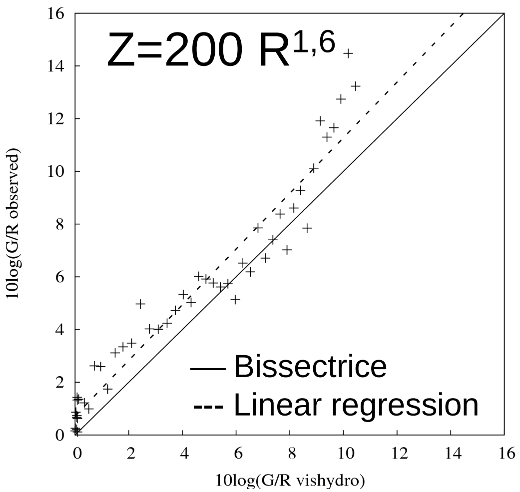
3,6°

- **Some small differences**
- **$Z=300\ R^{1,4}$ seemed to be better but difficult to conclude with certainty**
- **Need to carry on analysis**

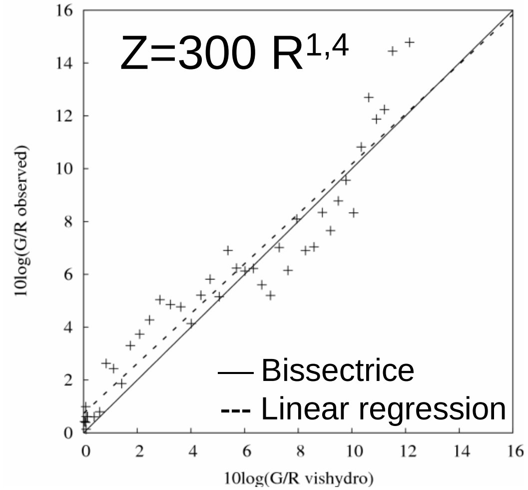
Z-R relationship and calibration error

Global analysis (e.g. all the elevation sites)

September 2002

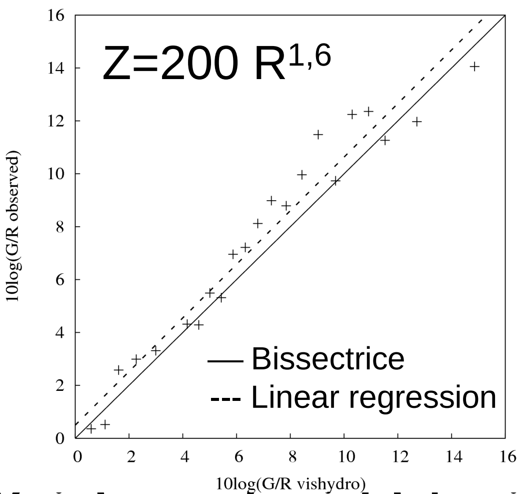


Nash = 0.87
ΔZ = 0.7 dBZ

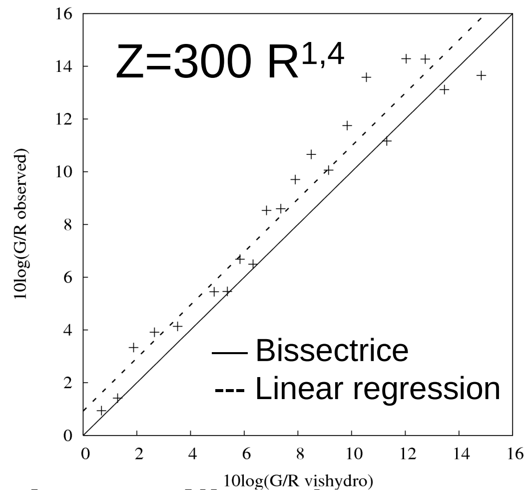


Nash = 0.92
ΔZ = 0.4 dBZ

December 2002



Nash = 0.91
ΔZ = 0.5 dBZ



Nash = 0.92
ΔZ = 0.9 dBZ

- Y-intercept might be interpretated as calibration error (knowing the Z-R relationship)
- Explore systematically the space of parameters to optimize the Z-R relationship

Main results - 1

- VPR is the first-order control of raingauge /radar ratios
- Importance of the spatial variability of the VPR and rain typing
- Influence of the Z-R relationship must be studied according to the event type
- Results are encouraging:
  possibility to extract from the procedure the Z-R relationship and the calibration error

QUESTION 2:

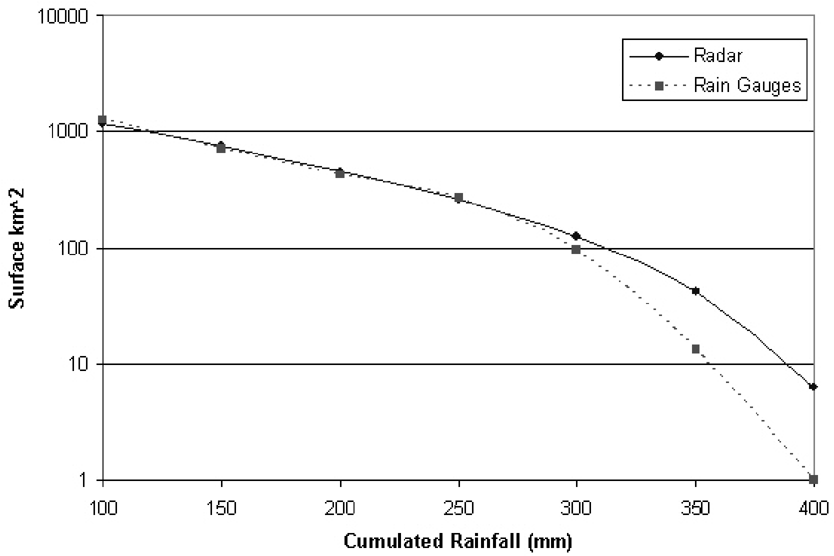
Given the adjustment of radar observations, accounting for the physics of the radar sensing, are radar rainfall observations feasible with runoff models?

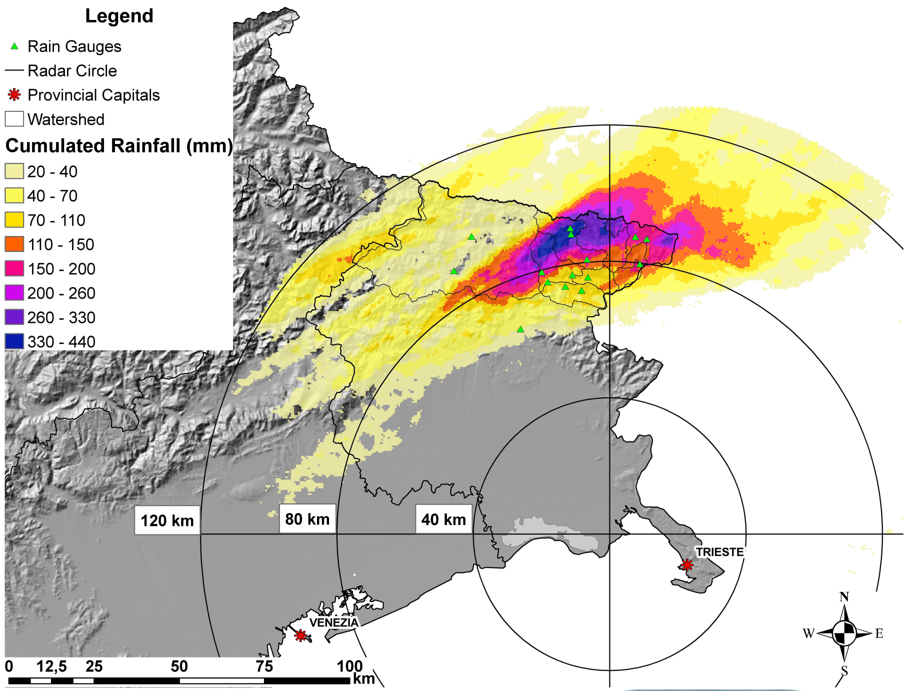
- Val Canale Flash Flood 29.08.2003:

  - Precipitation analysis
  - Hydrological analysis and modelling:
    - Flood peak analysis
    - Flood response analysis

NEI HO Case Study: Val Canale FF 29.08.2003 - 1

Radar accumulations up to 400 mm in 6 hrs (> 500 yrs return time)



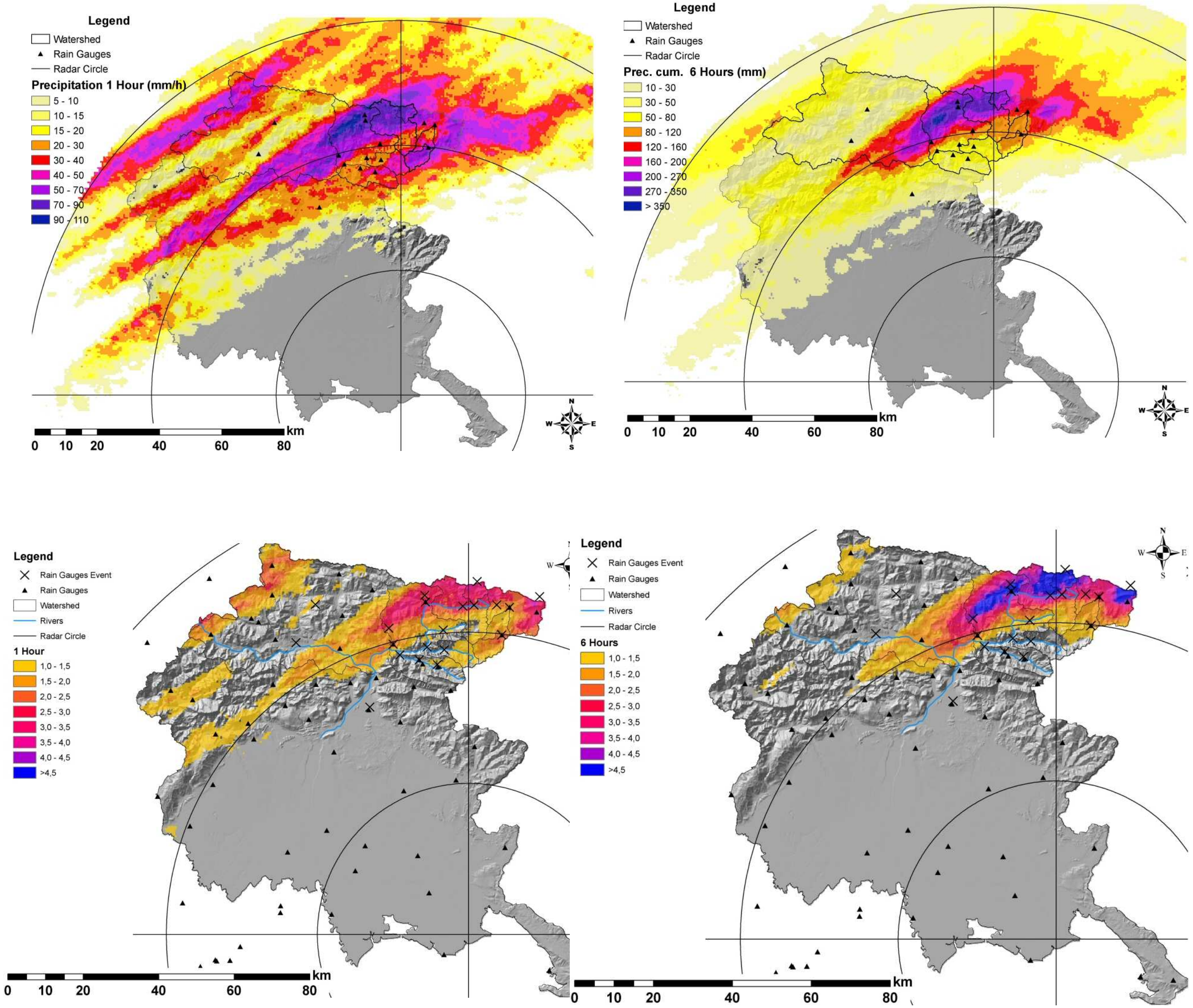


Analysis of rainfall maxima:

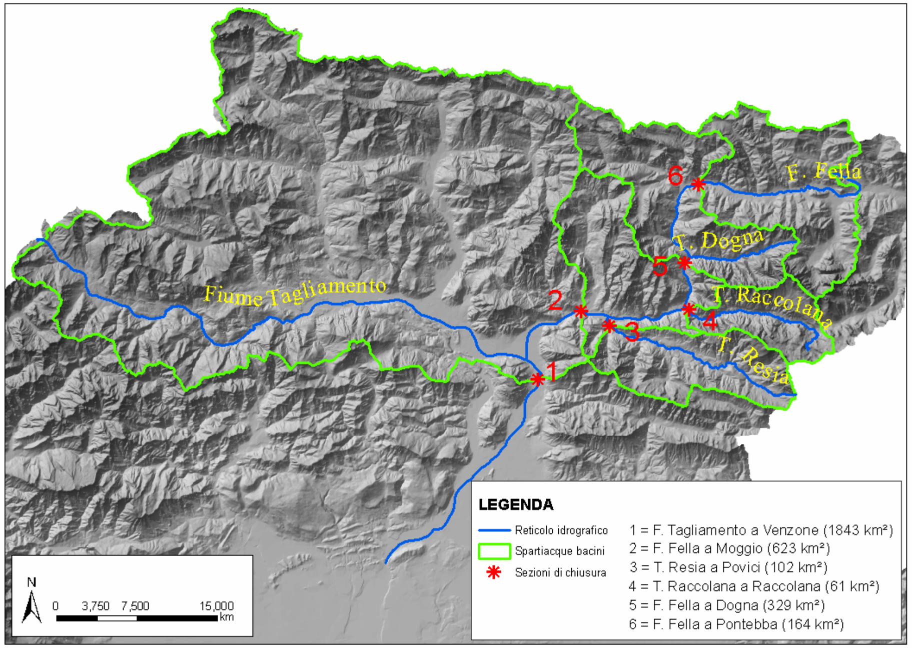
spatial patterns for rainfall maxima over 1 hour (a) and 6 hours (b);

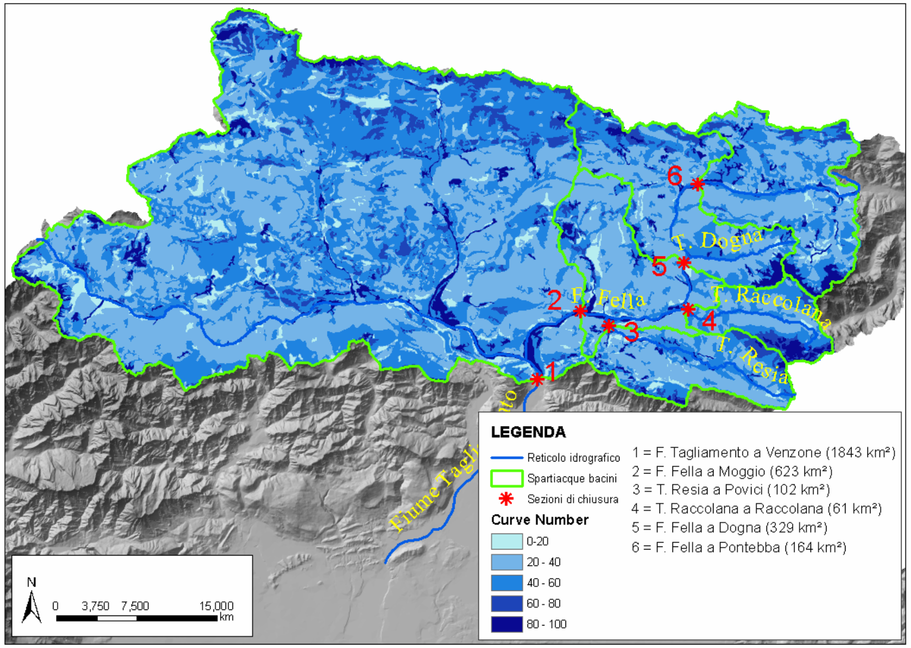
ratio of the event rainfall maxima to the local average of annual rainfall maxima for for 1 hour (e) and 6 hours (f) (values of ratio < 1 are not displayed).

f)



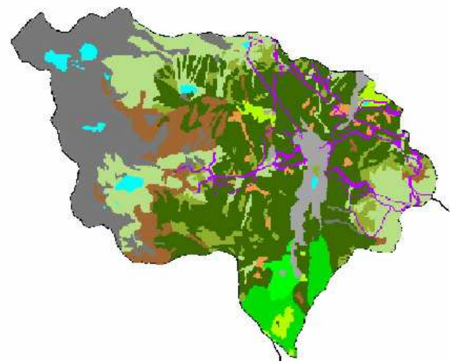
HYDROLOGICAL MODELLING





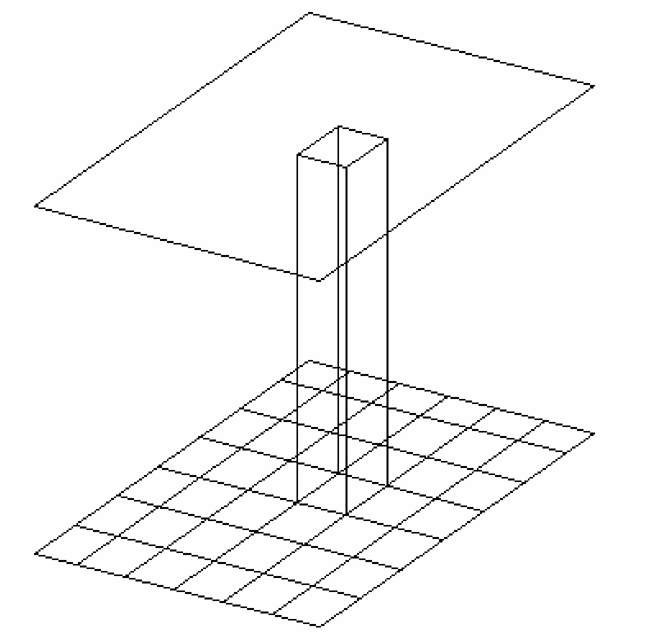
THE HYDROLOGICAL MODEL

Land use



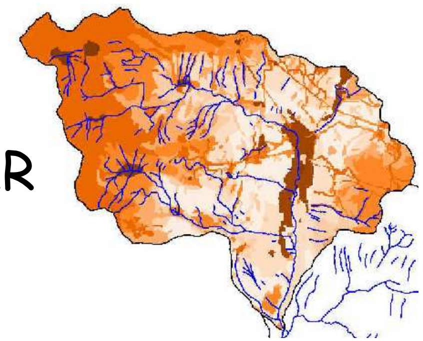
Hydrological group

Weather radar grid



DEM element

Conceptual RR model at the grid scale

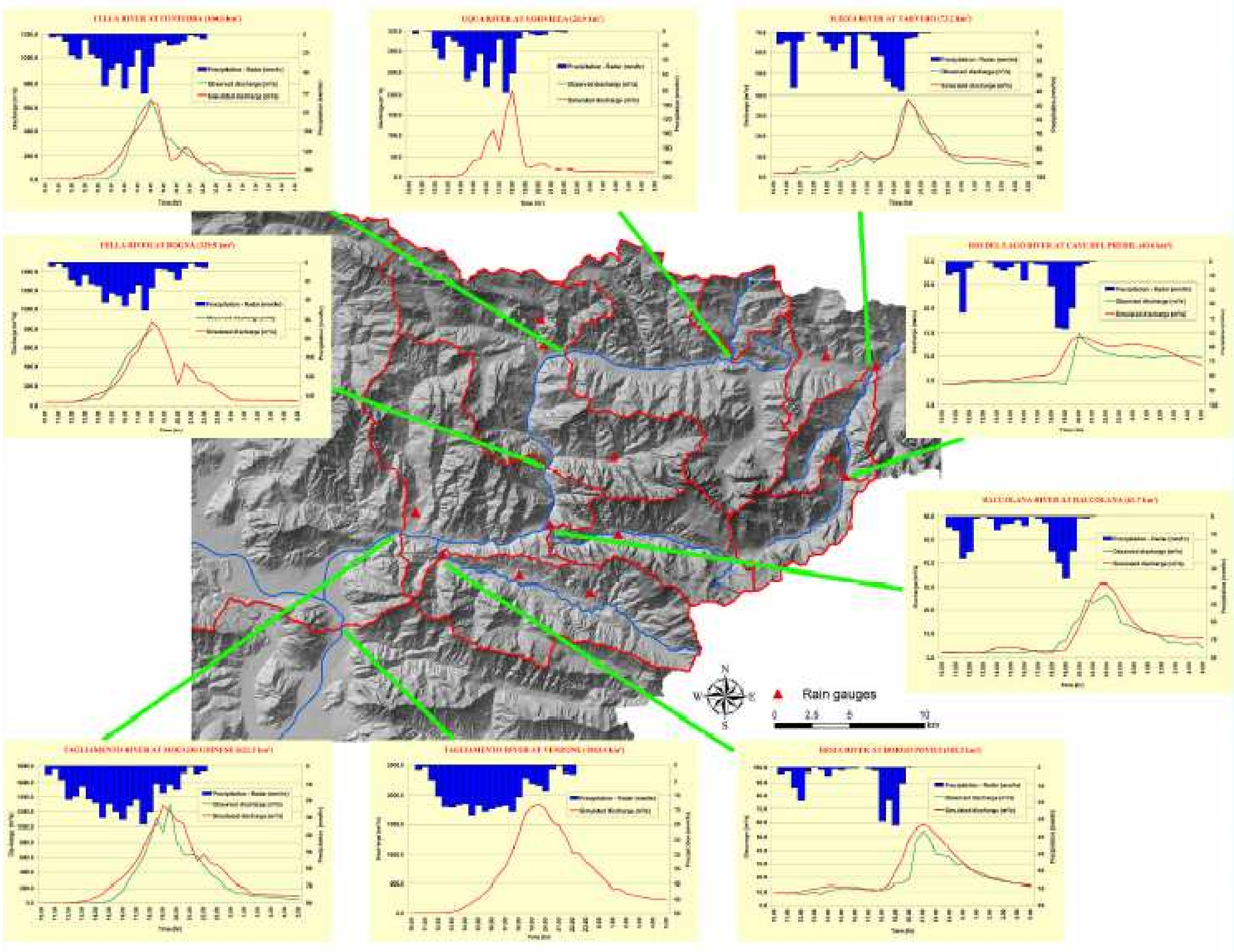


Parameter estimation of runoff model

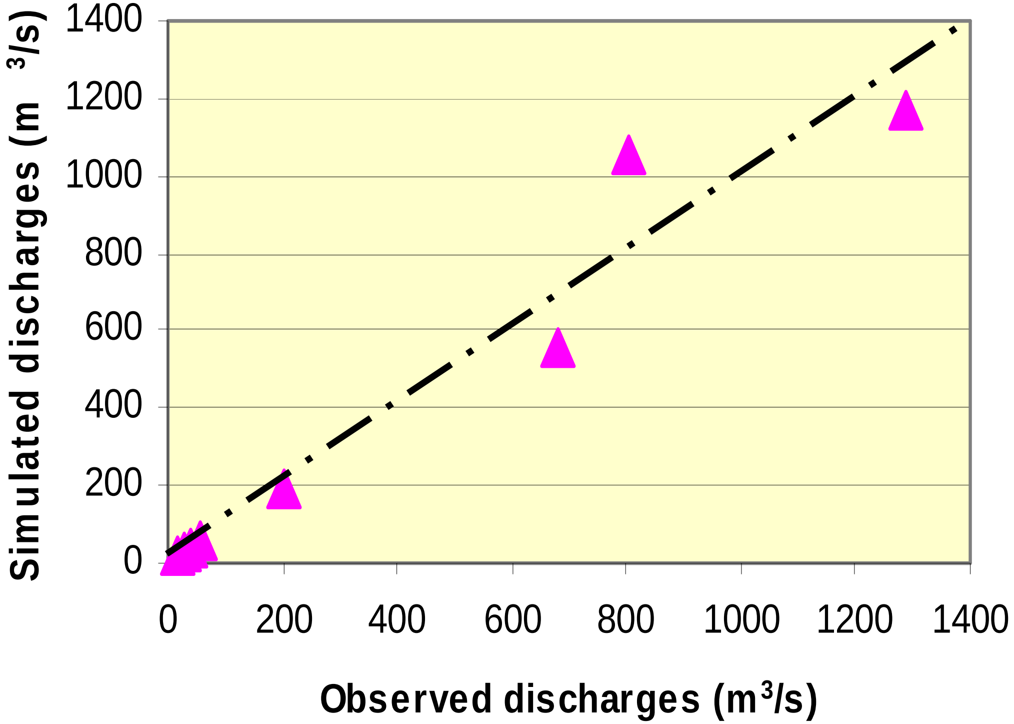
1st Step: a priori parameters
2nd Step: fine tuning spatial patterns by spectral unmixing
3rd Step: parameter calibration (fine tuning)
4th Step: fine tuning model structure
5th Step: plausibility check of simulated spatial patterns

→ Constrains parameter uncertainty significantly beyond simply calibrating them to runoff

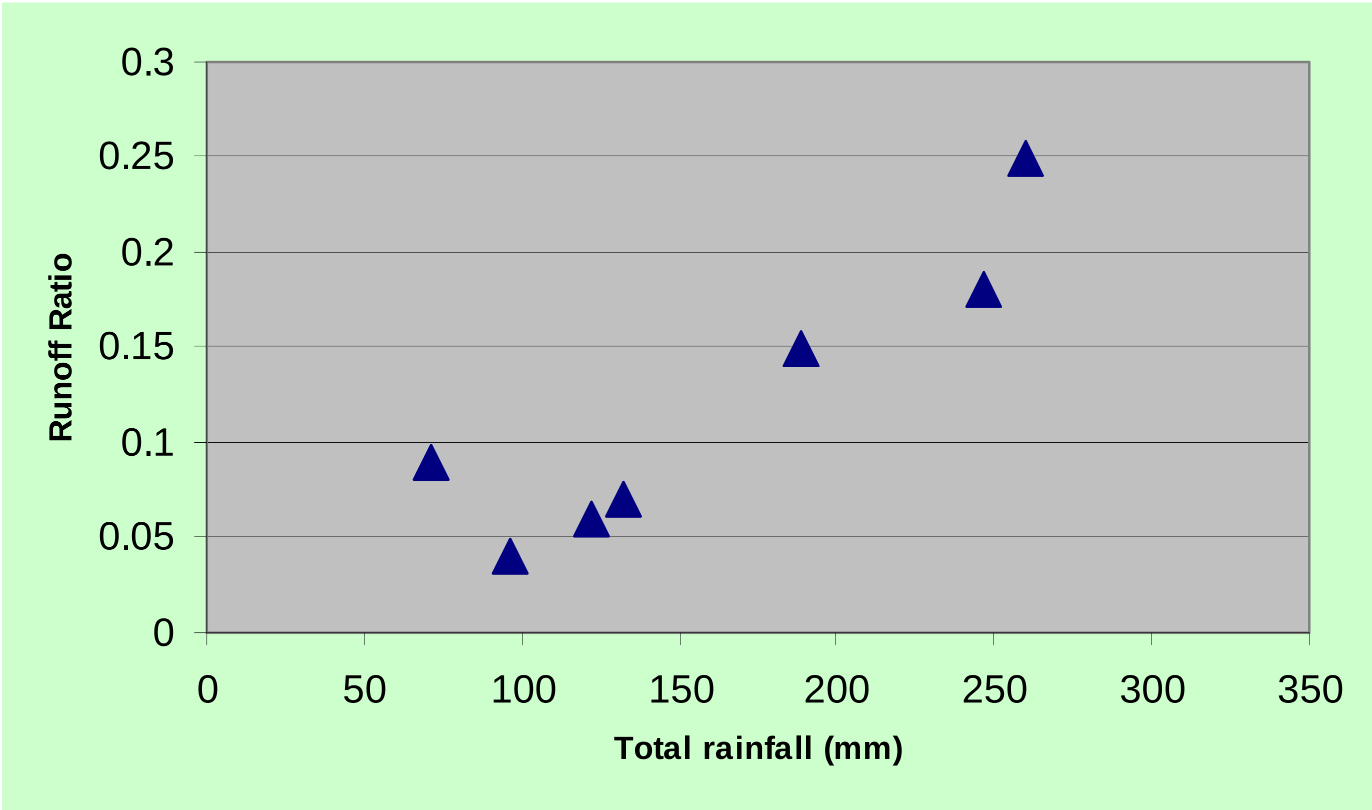
Hydrological analysis and modelling



Flood peak analysis:
What about the general accuracy of the model?



Flood response analysis:
The impact of antecedent soil moisture conditions



Main results - 2

- Given the adjustment of radar rainfall observations according to physics of radar sensing, radar estimates can provide relatively unbiased rainfall estimates, at the correct space and time scale (but: no atteuation; close to the radar site < 80 km).

- In the case of flash floods, these observations can be the only available (rain gauges too sparse)

- In the case of flash flood, the problem is (again) mainly in the runoff model (which needs to be applied without a priori calibration).

QUESTION 3:

Given the availability of radar observations,
Can we improve the understanding of extreme flood of flash flood events?

Need to observe the ungauged events!

- Val Canale Flash Flood 29.08.2003:

  - Precipitation analysis
  - Hydrological analysis and modelling:
    - Flood peak analysis
    - Flood response analysis

Hydrometeorological observatories (HOs)…
….and a methodology

- Flash flood are locally rare phenomena. We need to observe flash floods where they happens in a wide region!

- Establishment of observatories over large geographical areas (about 10 000–30 000 km^2 area wide), sufficiently large to have a good probability of observing flash-flood events.

- Over HOs, operational and research observation systems are implemented to attain high space-time resolution.

Development of a flash flood observation methodology

The principles:

- **To benefit from the density and the quality of the radar coverage as well as from dense rain and river gauging networks in order to collect physical variables.**

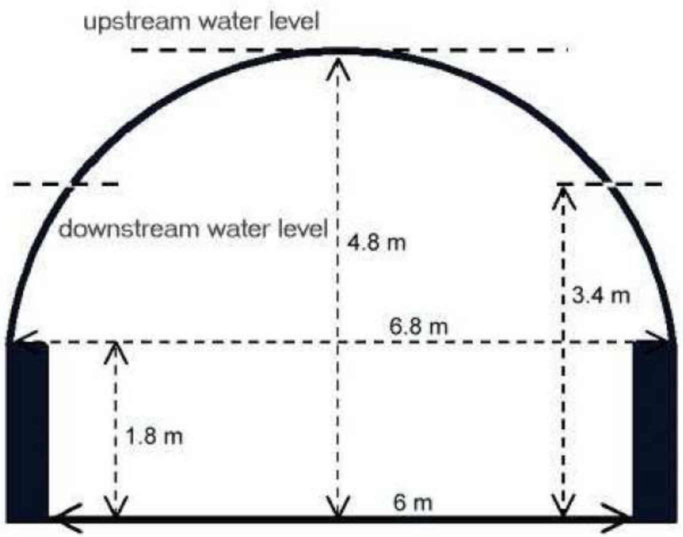
- **To collect complementary information from field investigations carried out during the days following the event (*hazard* and *vulnerability*).**

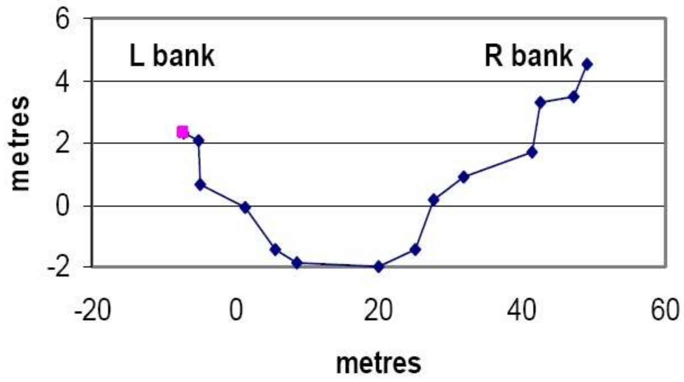
post-event analysis - 1

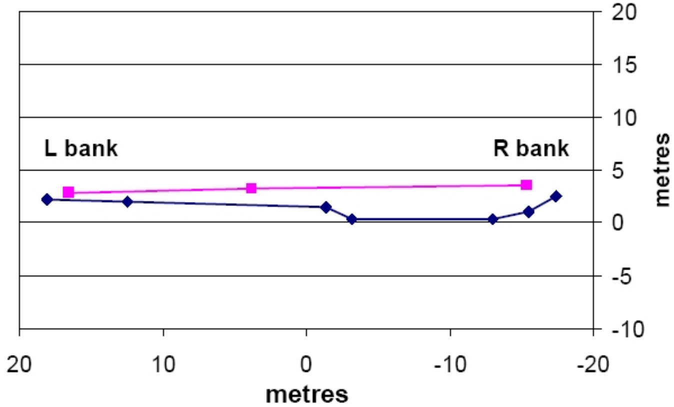
- **Data**
  - Flood traces
  - Witnesses accounts

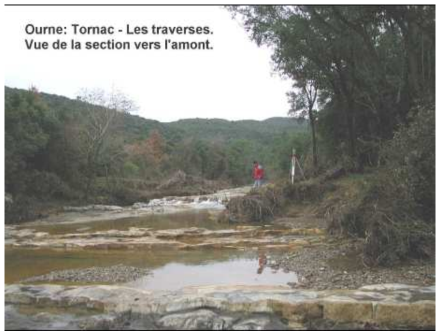
Post-event analysis - 2

- **River sections survey**

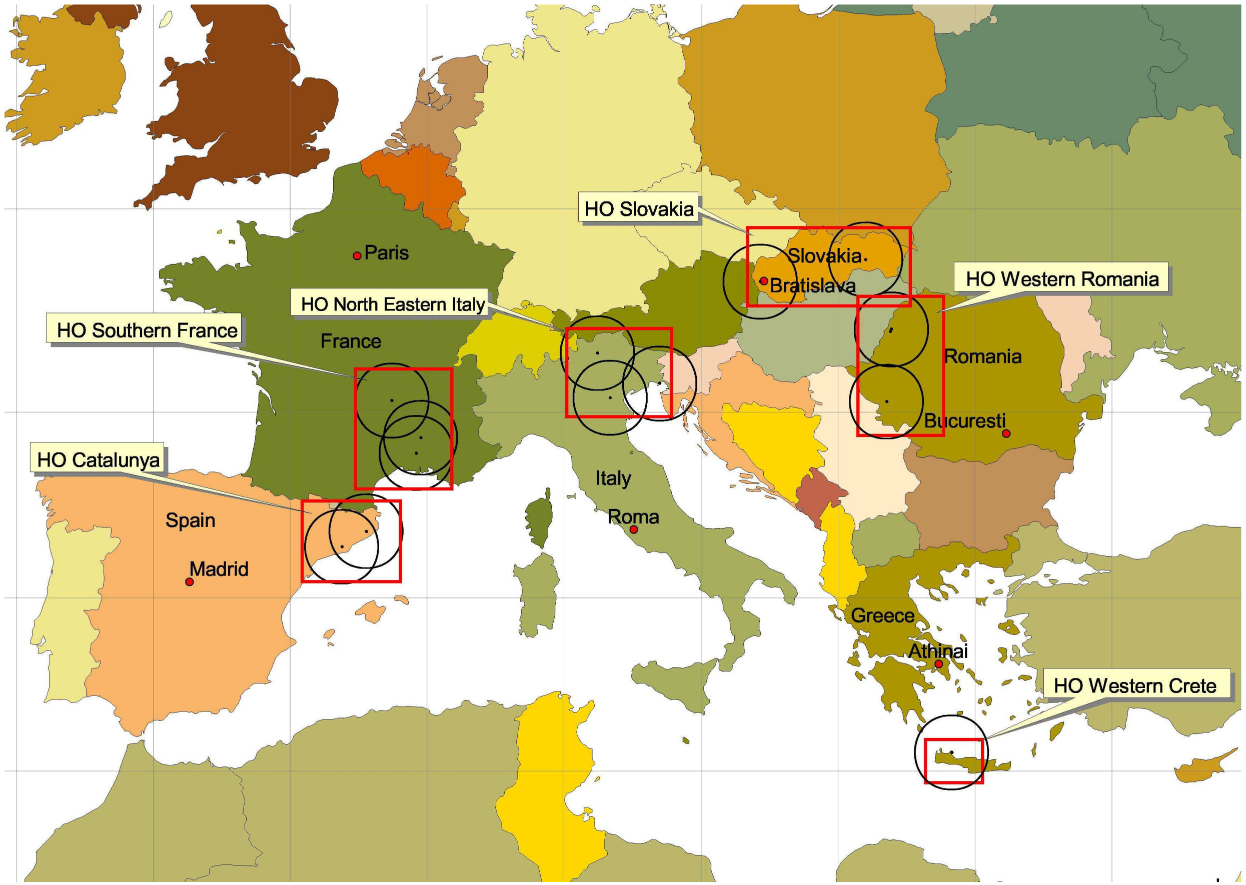






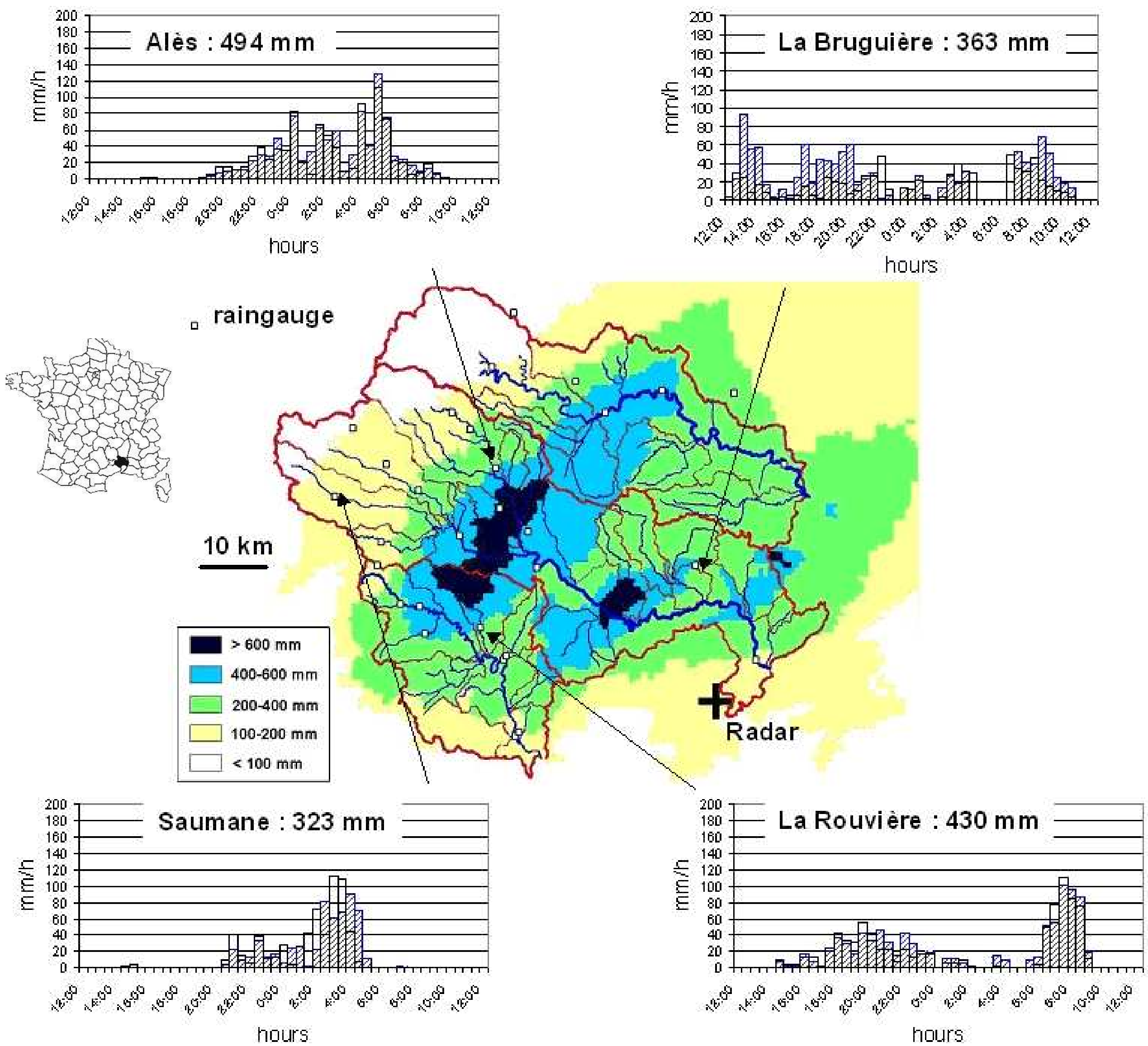


Six HOs are being developed in Europe…
(FLOODsite and HYDRATE R&TD EU Projects)

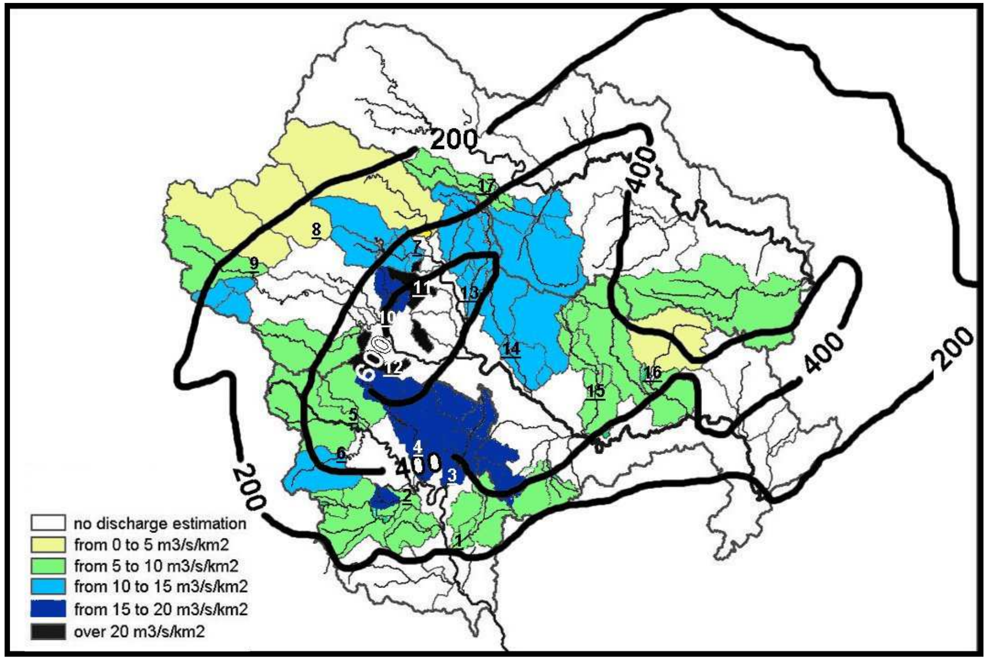


Cevennes Vivarais Case Study: Gard FF 9/9/2002

(qui dire che si tratta di una piena di durata più lunga e più estesa rispetto a Fella)



Peak discharges

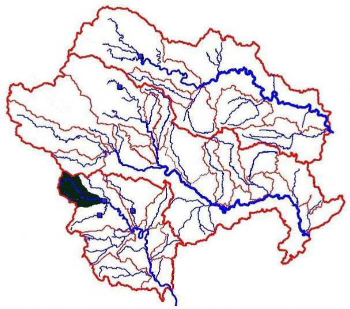


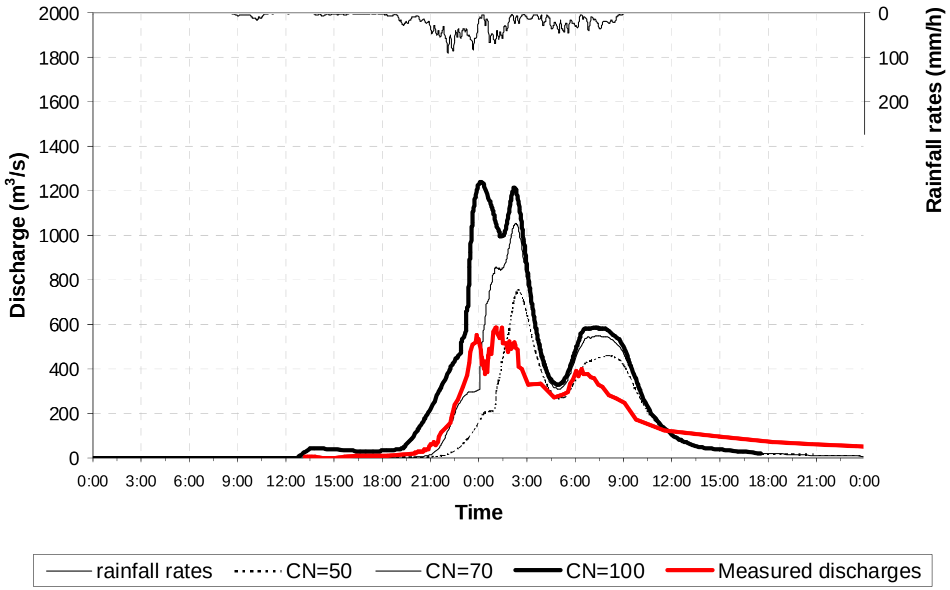
- The spatial repartition of the peak discharge corresponds to the repartition of the total rainfall amount

- Many upstream small catchments (area<300 km^2) exceeded 10 $m^3/s/km^2$ and almost all the tributaries produced more than 5 $m^3/s/km^2$

Rainfall-runoff dynamics

Vidourle (80 km²)





- Runoff coefficient does not exceed 50%
- Karstified geology explains large retention capacity and rapid release of water stored in the karst after the flood.

Main results - 3

- Post-event analysis can provide fudamental observations for the understanding of the major controls on flash flood development (antecedent conditions, topography, soil properties, land use, geology,..)

- Capability to generate a more complete picture of the storm and flood environment than would otherwise be available on ungauged basins.

Questions...