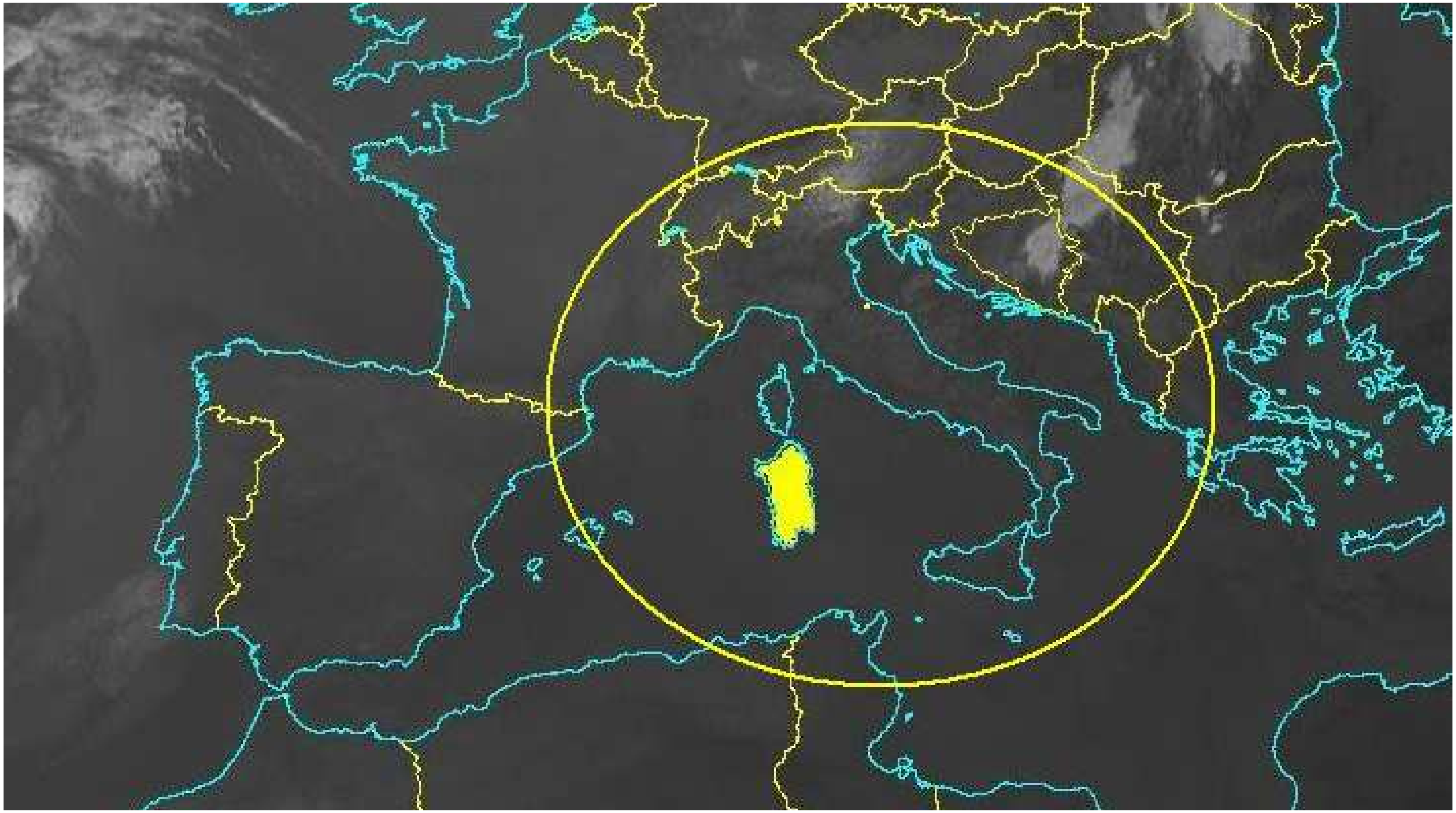
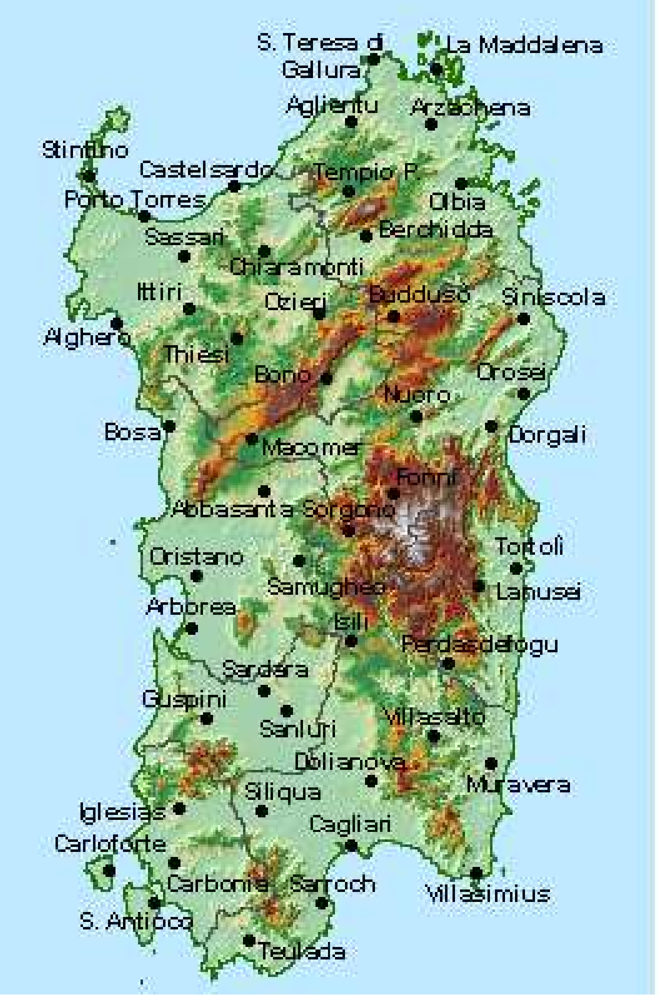
The problem



MSG2 H I039 31/JUL/07 06:00 UTC Consorzio S.A.R. Sardegna srl DATI EUMETSAT DATA

The problem


S. Teresa di
Gallura
La Maddalena
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Porto Torres
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Berchidda
Chiaramonti
Ittiri
Ozieri
Budduso
Siniscola
Alghero
Thiesi
Bono
Orosei
Nuoro
Bosa
Dorgali
Macomer
Fonni
Abbasanta Sorgono
Tortolì
Oristano
Samugheo
Lanusei
Arborea
Isili
Perdasdefogu
Sardara
Guspini
Villasalto
Sanluri
Dolianova
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Siliqua
Iglesias
Cagliari
Carloforte
Carbonia
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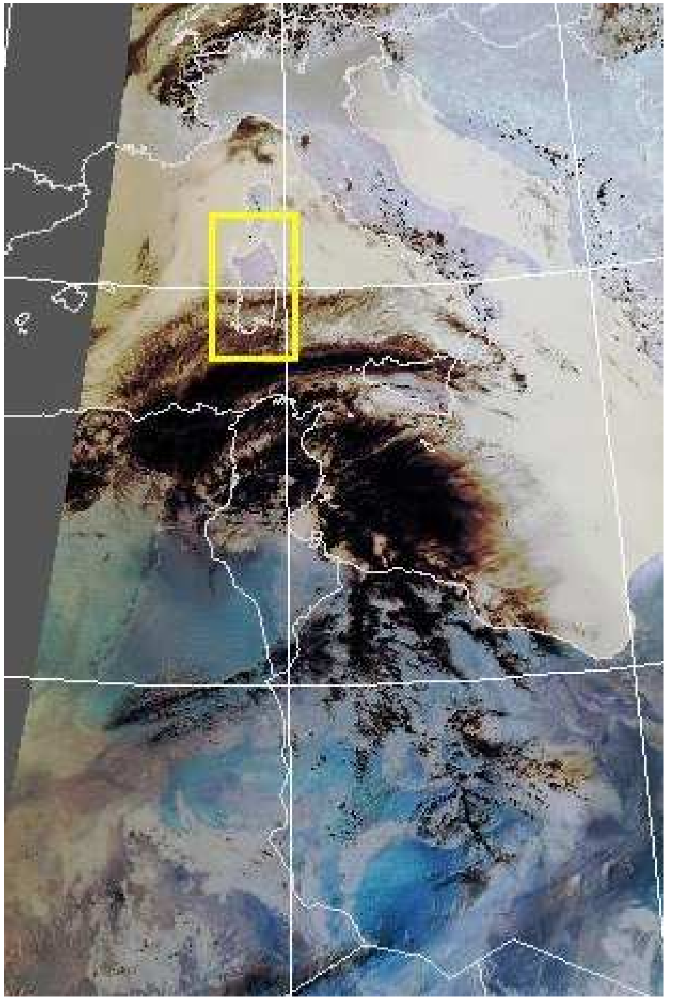
S. Antioco
Teulada



The problem

6–9 Dec. 2004,
Villagrande. Peak of
500 mm in 12 h.

Research activity

Literature:

- Climate of Sardinia: several references, for instance
  Serra and Sollai (1990)
  Benzi et al. (1997)
  Chessa et al. (1999)
  Delitala et al. (2000)

- Climatic change: less complete and more fragmented:
  Paleoclimatic analyses: Antonioli et al. (2003), Montagna et al. (2004).
  Possible effects of climate change on agriculture based on IPCC scenarios: Duce and co-authors.

  Brunetti and co-authors: 3 out of the about 200 meteor. stations available in Sardinia are considered (Capo Bellavista, Cagliari and Sassari).

Research activity

co–authors: B. Betrò, Q.A. Cossu, J. De Waele, L. Sanna

CNR-IMATI, SAR-Sardinia, Bologna University

Speleological Association Supramonte Project (A.S.Pro.S., Sardinia)

- characterization of the occurrence of extreme events in the seasonal rainfall path by a *Hidden Markov model* (4 stations in Ogliastra) (*done!*)
- study of geomorphic changes following flash floods triggered by extreme events (*in progress*)
- trend analysis:
  - daily rainfall data from 18 stations covering the area of Sardinia at the highest risk of extreme events (Ogliastra) (*done!*)
  - extension of the study to all the Island (*in progress*)

Research activity

- Bodini A., Cossu Q.A. (2008) – **Analysis of precipitation trends during 2nd half of the 20th Century in an area of Sardinia (Italy) at high hydrogeological risk.** Subm. to *Theoretical and Applied Climatology*
- Betrò B., Bodini A., Cossu Q.A. (2008) – **Using a hidden Markov model to analyse extreme rainfall events in Central-East Sardinia.** *Environmetrics*, in press
- Cossu Q.A., De Waele J., Di Gregorio F. (2007) – **Coastal karst geomorphosites at risk? A case study: the floods of 6-9 december 2004 in central-east Sardinia.** From: Parise, M. & Gunn, J. (eds). Natural and Anthropogenic Hazards in Karst Areas: Recognition, Analysis and Mitigation. Geological Society, London, Special Publications, 279, 85-95
- Cossu Q.A., De Waele J., Bodini A., Sanna L., (2007)– **The three exceptional winter flash floods of 2004-2006 in Central-East Sardinia (Italy) and their geomorphological consequences.** European Geosciences Union 2007. Geophysical Research Abstracts, Vol. 9, 01842.

The talk

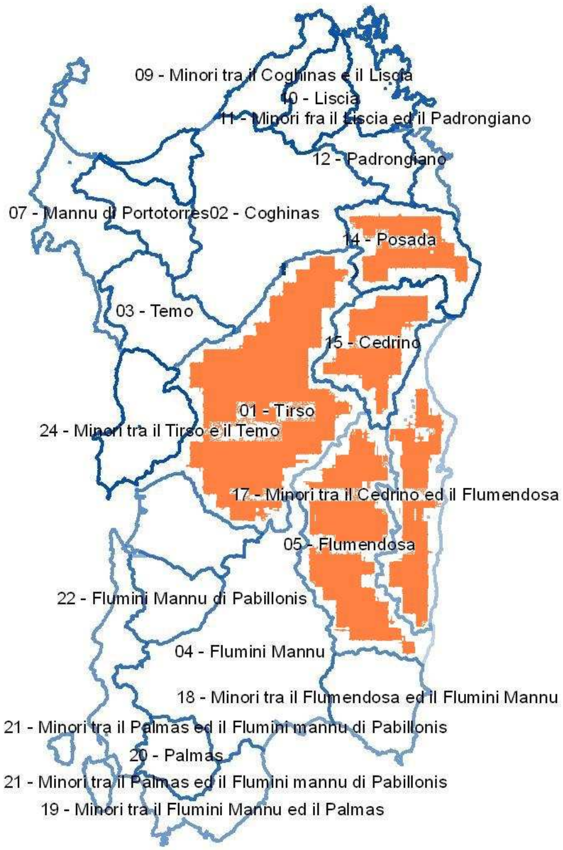
Trends of heavy rainfall in the mountainous area of East Sardinia

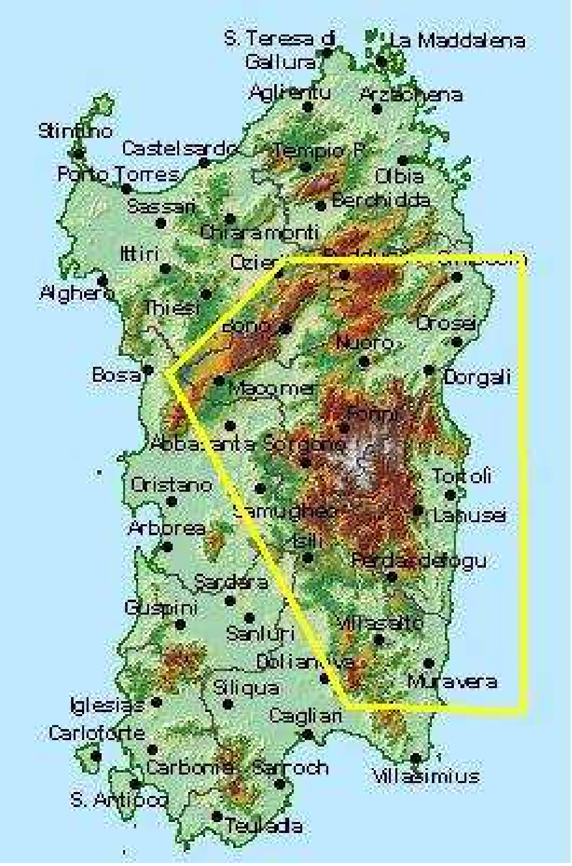
Antonella Bodini
Institute of Applied Mathematics and Information Technology (CNR–IMATI), Milan, Italy

Antonello Cossu & Valeria Biglio
Regional Agro Meteorological Service–Sardinia, Sassari (Italy)

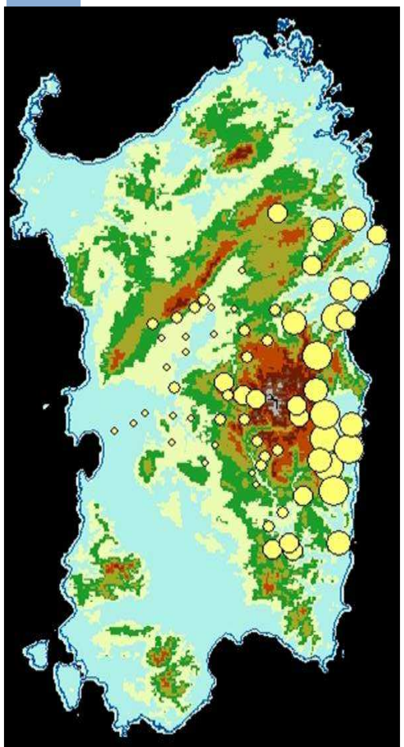
The study area

5 Hydrologic basins: (Posada, Cedrino, Minori tra Cedrino e Flumendosa, Flumendosa and Tirso)





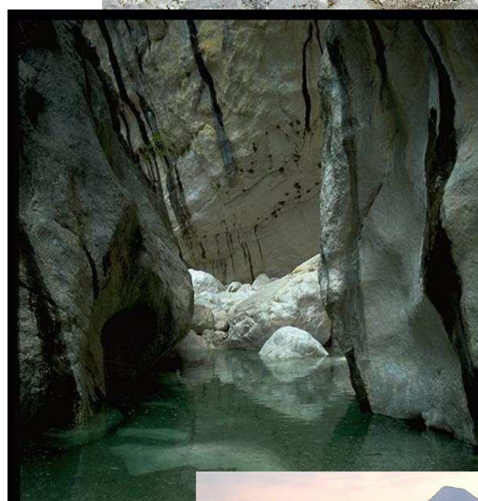
The study area

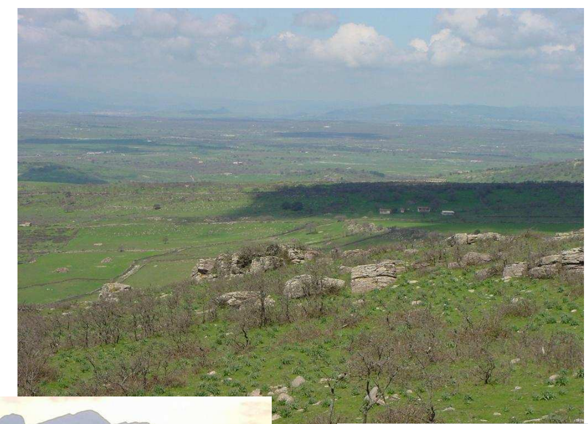


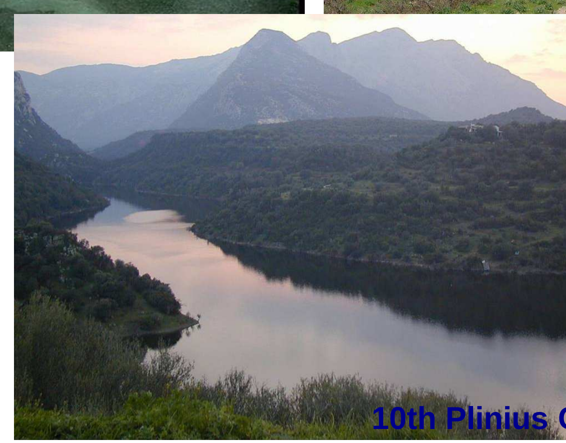
climatic

$q_{0.95}$

$('51 -' 99)$

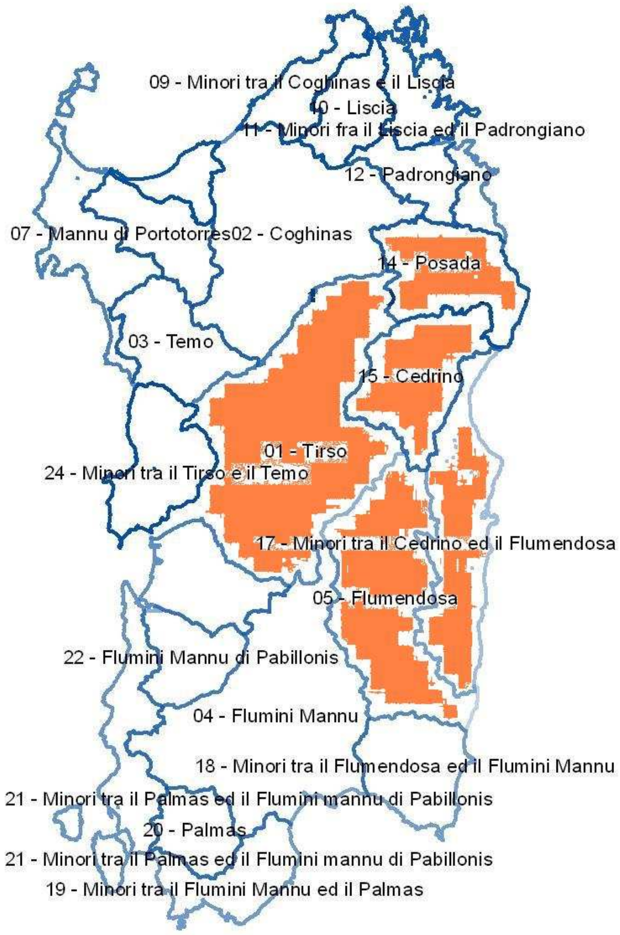






The study area

5 Hydrologic basins:



- Daily rainfall data collected at **over 60** Governmental Hydrographic Service pluviometric stations
- Period from **1951-1999** (location changes in recent years)
- Stations with $\geq$ **40** complete annual records

Methods

- A threshold of 1 mm has been applied to define a rainy day.

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  - ∗ lack of metadata
  - ∗ relevant differences between stations in different hydrologic basins
  - ∗ a procedure for each index

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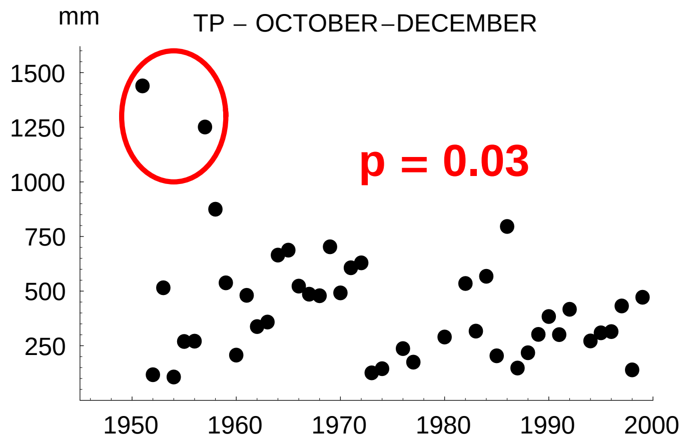

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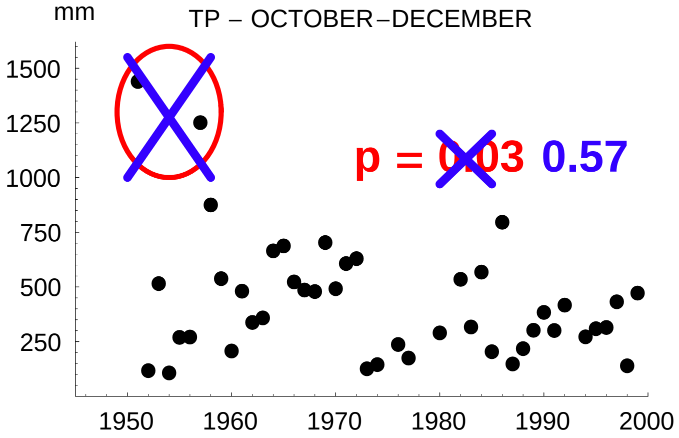

Indices

- frequency of rainy days ($\geq$1 mm), **F** ;
- total precipitation, **TP**;
- mean precipitation in a rainy day, or precipitation intensity, **PI**; $(*)$
- standard deviation of rainy days, **SD**;
- annual maximum, **M**;

Indices

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- total precipitation, **TP**;
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- maximum 5-day precipitation total; **R5D**; (∗)
- percentile of order 0.95 computed on rainy days only, **q95**;
- annual cumulate of **extreme events**, defined as **daily events ≥ climatic q95**, **TEP** (*total extreme precipitation*);
- proportion of annual cumulate due to extreme events (TEP/TP), **EP** (*extreme proportion*);
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- mean of extreme events, **EI** (*extreme intensity*);
- maximum number of *consecutive dry days* ($<$ 1 mm), **CDD**. ($*$)

($*$) WMO–CCL & CLIVAR, Frich et al. (2002)

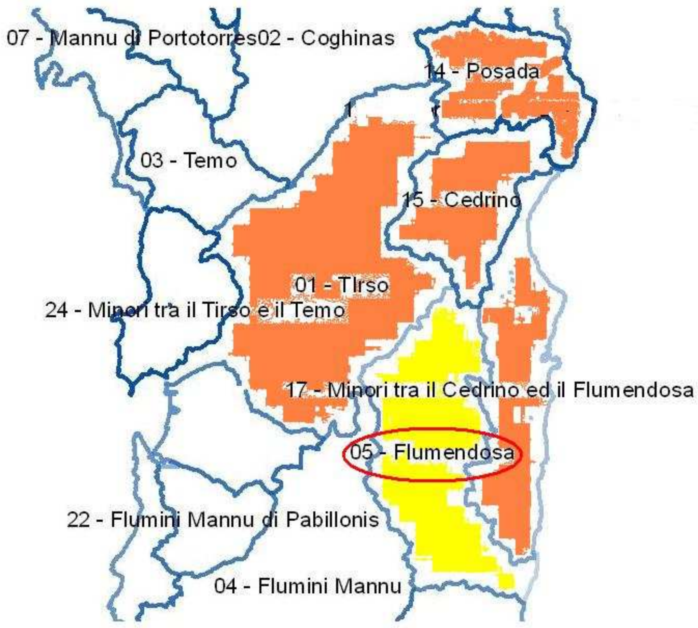
Indices, contd

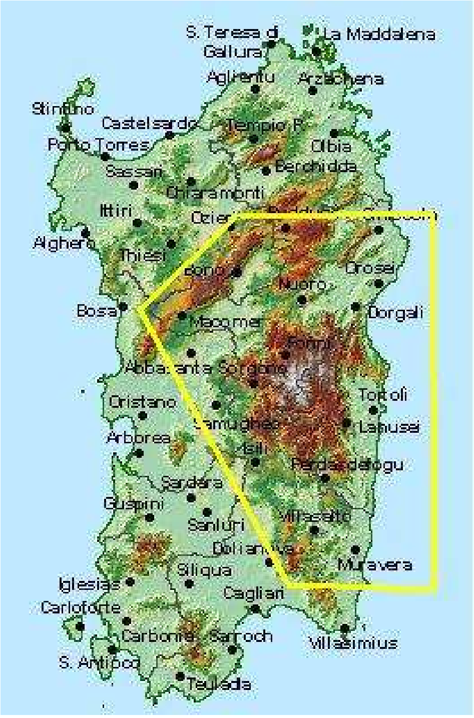
- Annual scale
- Seasonal scale:
  - January–March, winter
  - April–June, spring
  - July–September, summer
  - October–December, autumn

  - **TP/y & F/y**: seasonal contribution to the annual values
- (a few) missing years $\Rightarrow$ no hydrological year

Results: annual scale

- diffuse trends are mainly observed in the **Flumendosa Basin** and concern both general and extreme indices





Results: annual scale

- diffuse trends are mainly observed in the **Flumendosa Basin** and concern both general and extreme indices

	M	*TP*	*F*	*PI*	*SD*	*R5D*	*CDD*	*q0.95*	*EI*	*TEP*	*EP*
Bau Muggeris					-	-			-	-	-
Cossatzu											
Escalaplano		-		-		-		-		-	
Esterzili		-	-	-	-						
Goni				-				-			-
S. Nicolò G.								-			-
Nurri											
Perdasdefogu				-		-		-		-	-
Sadali				-			-				
Seui						-					
Seulo		-		-		-			-		
Villanovatulo											
Villasalto	-			-	-	-	-	-		-	-
Armungia	-			-		-			-		
Bau Mela		-	-			-					

(shaded cells) decreasing trend

Results: annual scale

- diffuse trends are mainly observed in the **Flumendosa Basin** and concern both general and extreme indices
- substantial lack of trends is observed at Cedrino, Posada and **Minori** basins; general indices show some trends at Tirso Basin

MINORI	*M*	*TP*	*F*	*PI*	*SD*	*R5D*	*CDD*	*q0.95*	*EI*	*TEP*	*EP*
Jerzu		-									
Barisardo				-			-	-			
Baunei											
Cala Gonone											
Genna Cresia											
Genna Silana.			-								
S. Barbara			+	-			-	-			
Sa Teula											
Talana		-	-		-	-					
Tertenia				-			-				
Tortolì							-	-			

decreasing

increasing

Results: annual scale

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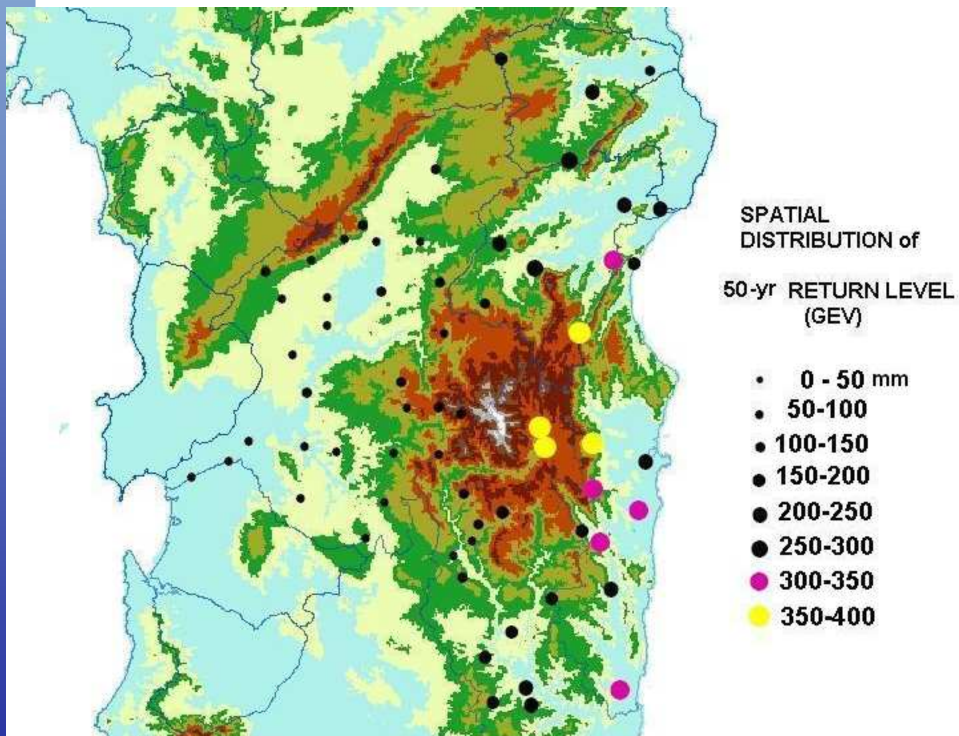
- substantial lack of trend is observed at Cedrino, Posada and Minori basins; general indices show some trends at Tirso Basin
- annual maximum **M** does NOT show any trend $\Rightarrow$ **GEV analysis**

Results: annual scale



The highest values correspond to stations located in the narrow area between the coast and the mountains slopes. The two more inland stations (Bau Mela and Bau Muggeris) showing a return level ≥ 350mm are close to the Flumendosa dam.

GEV analysis, 50-yr return levels map

Results: annual scale

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- annual maximum **M** does NOT show any trend $\Rightarrow$ **GEV analysis**
- by fitting a Generalized Pareto distr. (GPD) to *high* daily rainfall amounts we can improve estimates of return levels, for instance

Results: annual scale

GENERALIZED PARETO distribution

Let X_i be i.i.d daily rainfall amounts. Based on asymptotic theory

$$P(X_i > u + x | X_i > u) = \begin{cases} (1 - \xi\, x/\sigma)^{-1/\xi} & \xi \neq 0 \\ \exp(-x/\sigma) & \xi = 0 \end{cases}$$

approximates the distribution of exceedances $X_i - u$ for a large enough threshold u.

ξ has the same meaning of the shape parameter in the GEV distr. ($\xi = 0$ Gumbel, $\xi > 0$ Fréchet, $\xi < 0$ Weibull)

Let

F$_u$: frequency of daily values $> u$

TP$_u$: cumulate of daily values $> u$

check of trends

Results: annual scale

FLUMENDOSA

	u	ξ	50yr-RL	F_u	TP_u	F	TP
A	20	0.23	226.2		■ decreasing		
BMe	30	0.25	387.6	■ decreasing	■ decreasing	■ decreasing	■ decreasing
BMu	30	0.39	447.0	■ decreasing	■ decreasing		
C	20	0.01	104.8				
Esc	30	0.31	328.8	■ decreasing	■ decreasing		■ decreasing
Est	25	0.07	126.0	■ decreasing	■ decreasing	■ decreasing	■ decreasing
G	X	X	X	X	X	X	X
SNG	X	X	X	X	X	X	X
N	27.5	0.19	148.8				
P	27.5	0.08	175.9				
Sa	25	0.12	133.7				
Sei	27.5	0.19	194.7				
Sel	20	0.15	145.0	■ decreasing	■ decreasing		■ decreasing
Vin	X	X	X	X	X	X	X
Vis	20	0.22	231.0				

MINORI

	u	ξ	50yr-RL	F_u	TP_u	F	TP
Br	25	0.24	309.7				
Ba	30	0.16	369.9				
CG	27.5	0.01	167.9				
GC	35	0.24	396.5				
GS	35	0.15	395.9			■ decreasing	
J	25	0.14	232.6				■ decreasing
ST	35	0.21	390.1				
SB	27.5	0.45	471.6			■ increasing	
TA	25	0.34	469.5	■ decreasing	■ decreasing	■ decreasing	■ decreasing
TE	27.5	0.11	257.5				
TO	27.5	0.18	272.3				

■ **decreasing trend** ■ **increasing trend**

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- the GPD analysis
  - improves estimates, in absence of trends
  - presents troubles in presence of trends
  - suggests how to evaluate "*heavy*" when we say that *heavy rainfall* is decreasing

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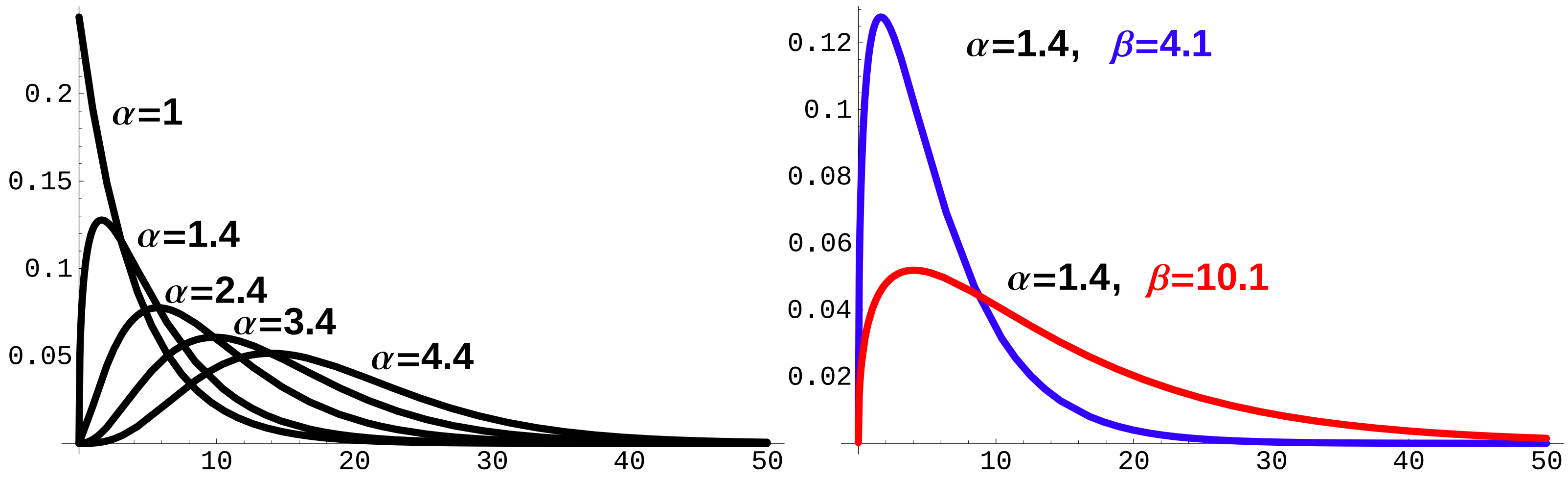
- trends in parameters of Gamma distributions fitting annual daily values (not only extreme values)

Results: annual scale

Osborn & Hulme (2002) (UK data)

annual wet-day amounts modelled by Gamma distribution

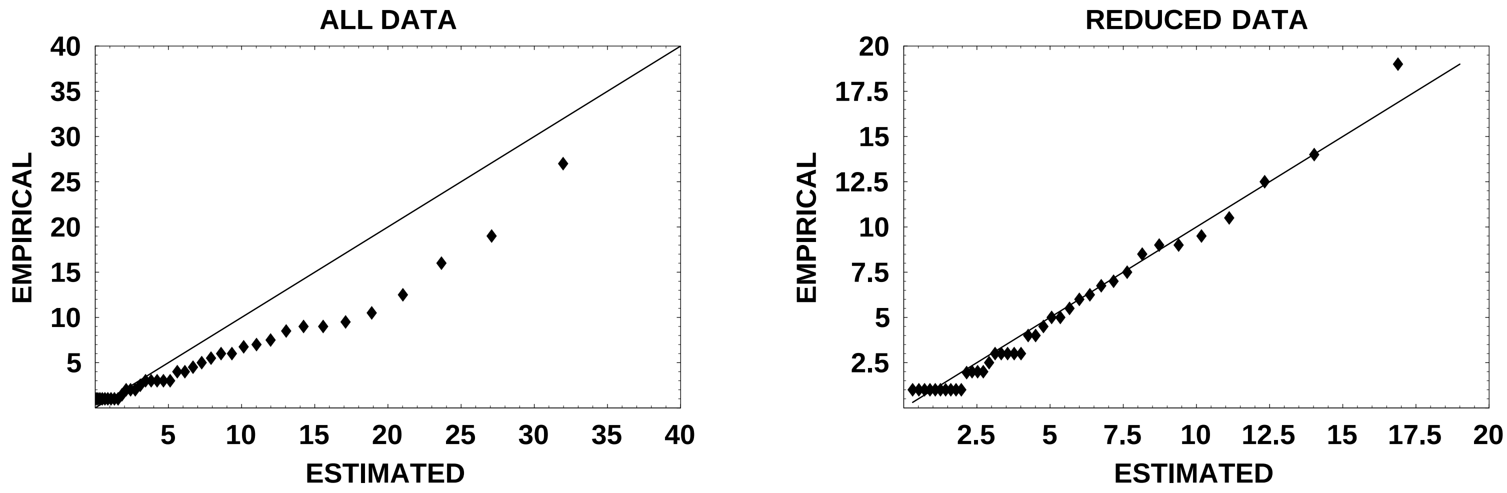
$$\mathbf{f}(\mathbf{x}) = \frac{\mathbf{1}}{\beta^{\alpha}\boldsymbol{\Gamma}(\alpha)}\mathbf{x}^{\alpha-\mathbf{1}}\exp\{-\mathbf{x}/\beta\}$$



“it is variations in β, the scale parameter, that explain most of the seasonal, spatial, interannual and *climate-change-related* variability in precipitation (though, over large spatial distances, or *in regions with strong seasonality, the shape parameter can become important*).”

Results: annual scale

- Fitting is improved by removing data $> q_{0.95}$

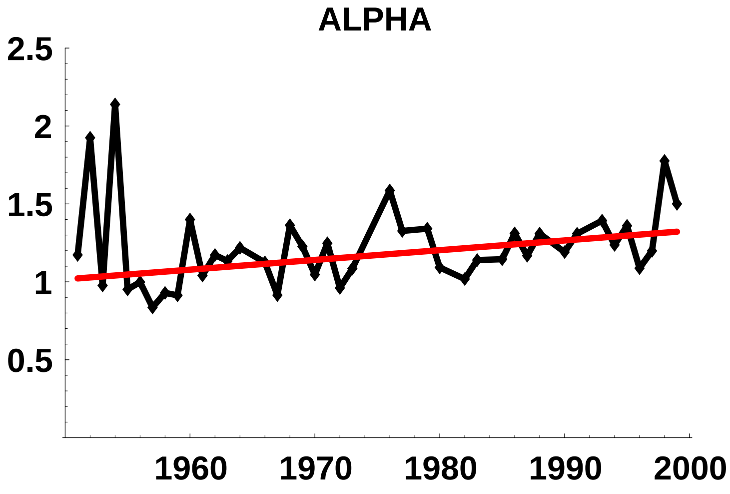


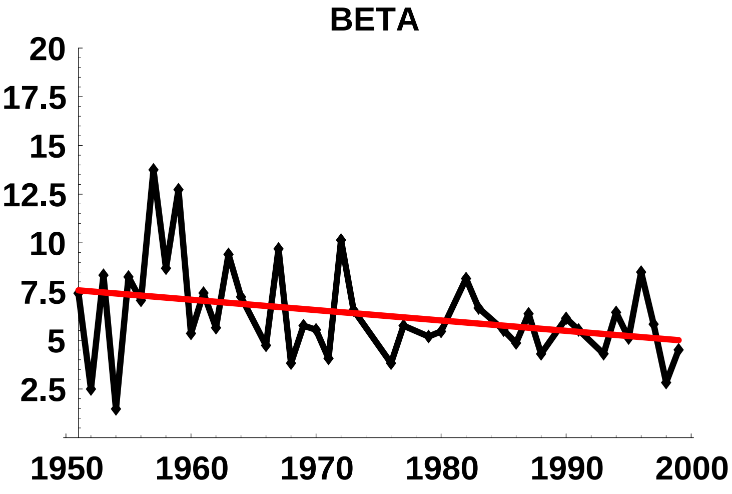
(but this requires to slightly modify the interpretation in Osborn & Hulme)

Results: annual scale

- Fitting is improved by removing data $> q_{0.95}$

- trends in both parameters are obtained, even in basins where standard indices do not show variations





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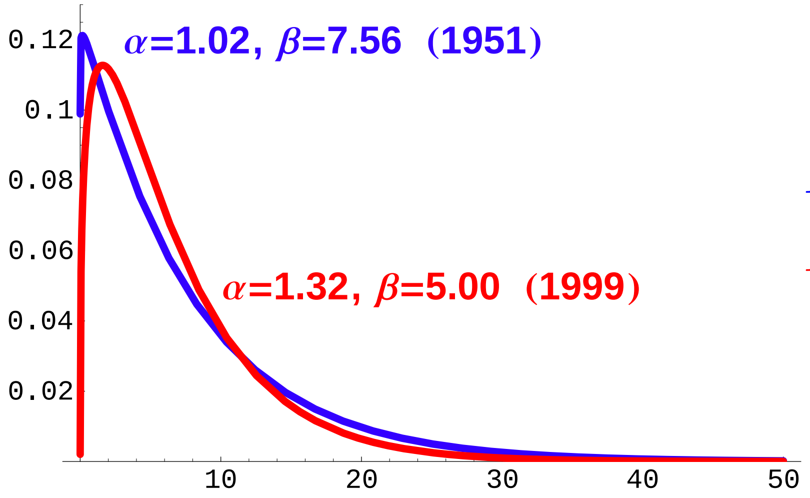
BAU MUGGERIS



$$P(X \leq 20) = 0.93$$
$$P(X \leq 20) = 0.97$$

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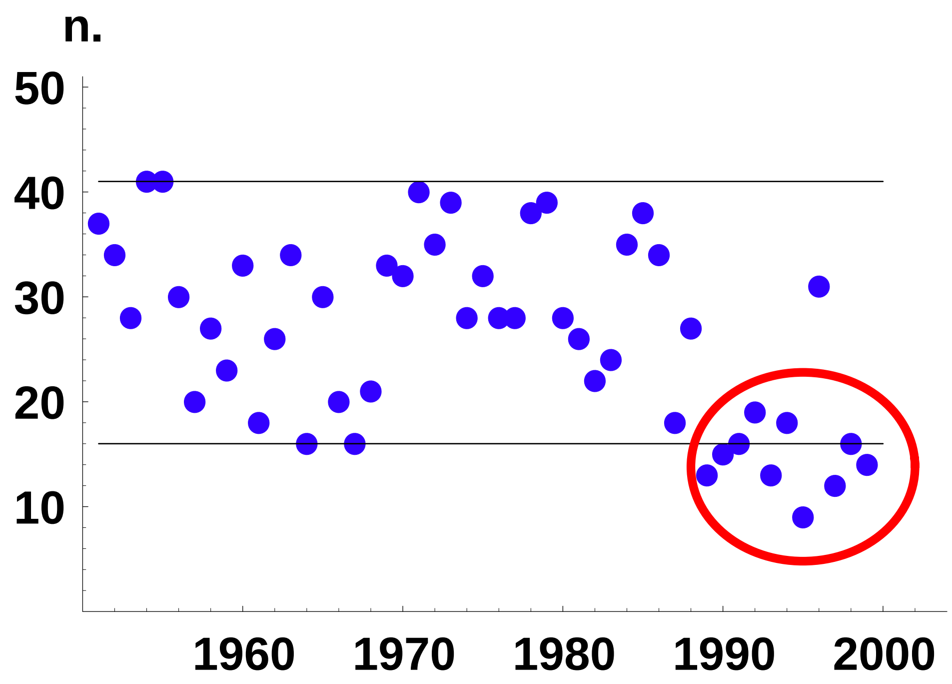
- the GPD analysis
  - improves estimates, in absence of trends
  - presents troubles in presence of trends
  - suggests how to evaluate "*heavy*" when we say that *heavy rainfall* is decreasing
- trends in parameters of Gamma distributions fitting annual daily values (not only extreme values)
- decreasing trends can be highly influenced by data of Nineties, particularly low

Results: annual scale

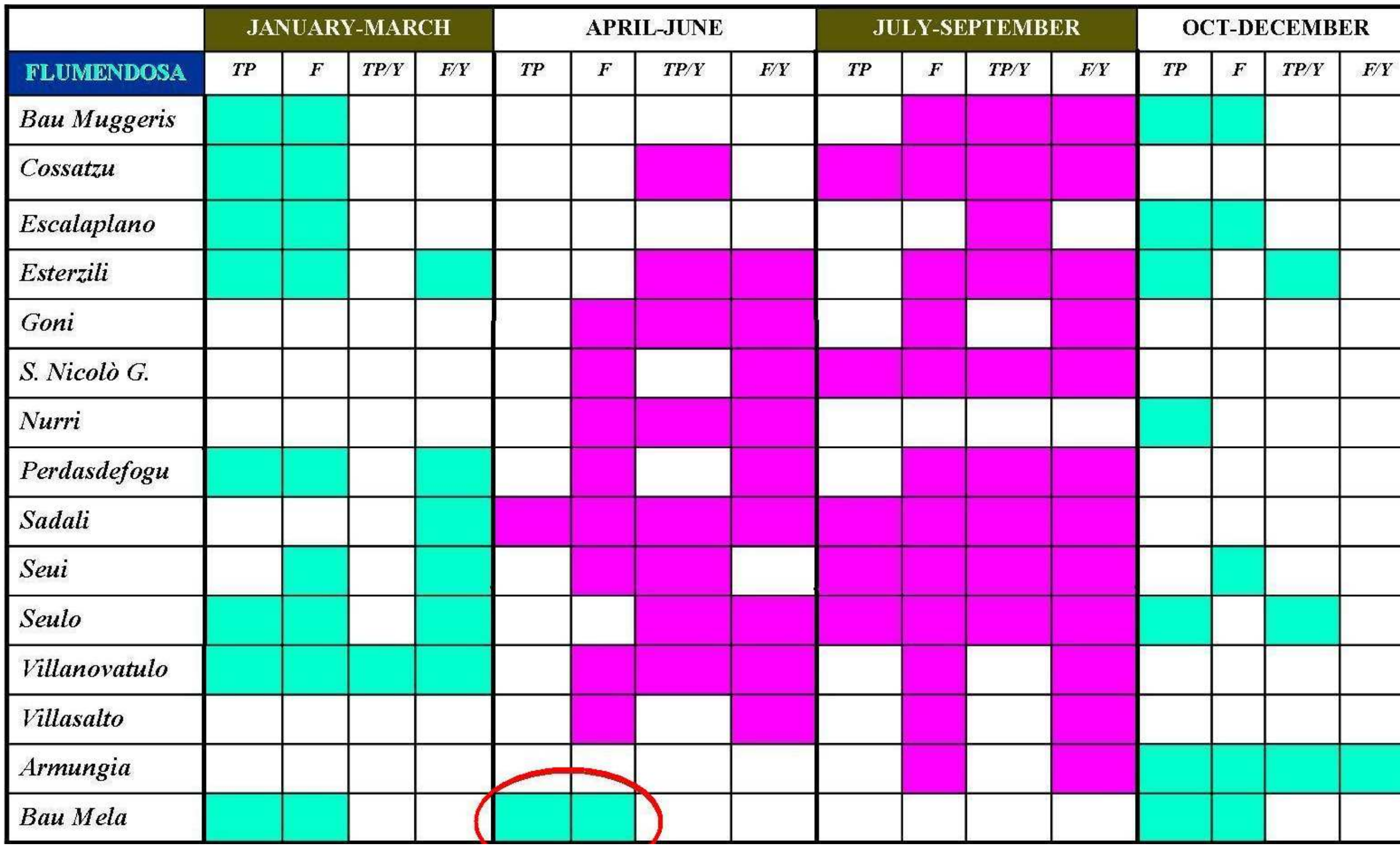
F JANUARY-MARCH



open question ...

Results: seasonal scale

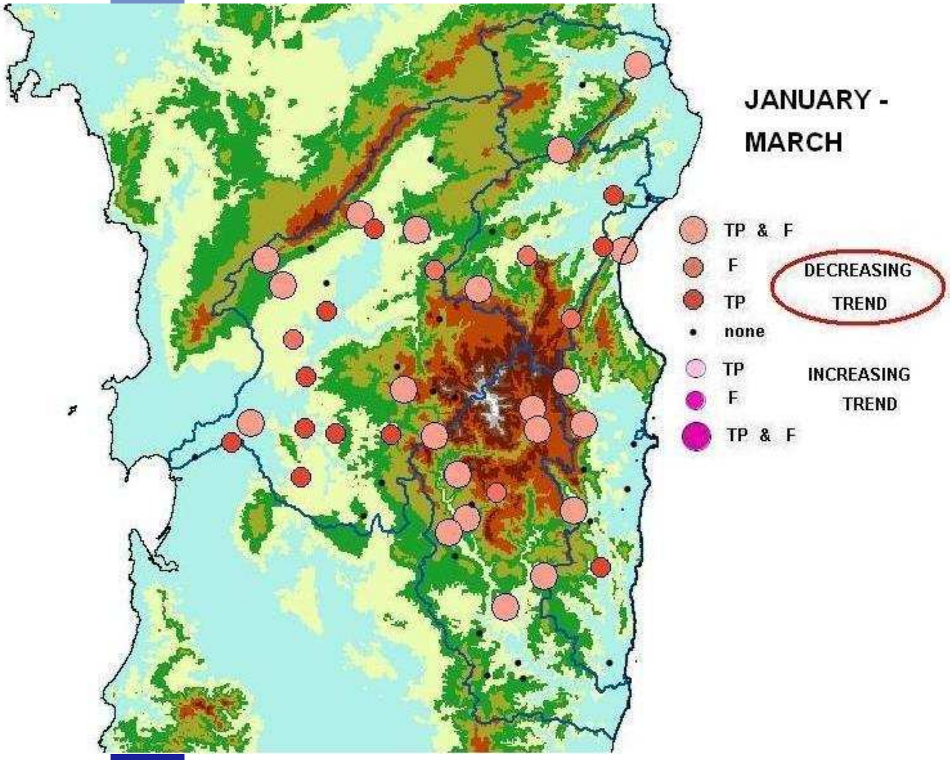
Indices: **TP, F & TP/y, F/y**

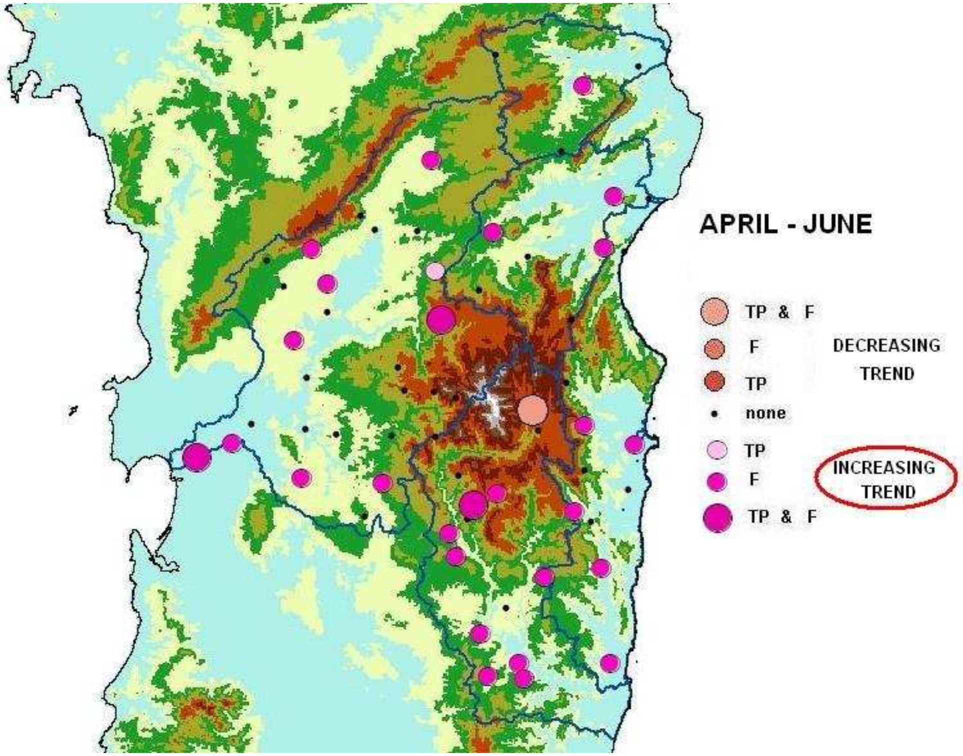


decreasing trend **increasing trend**

Results: seasonal scale

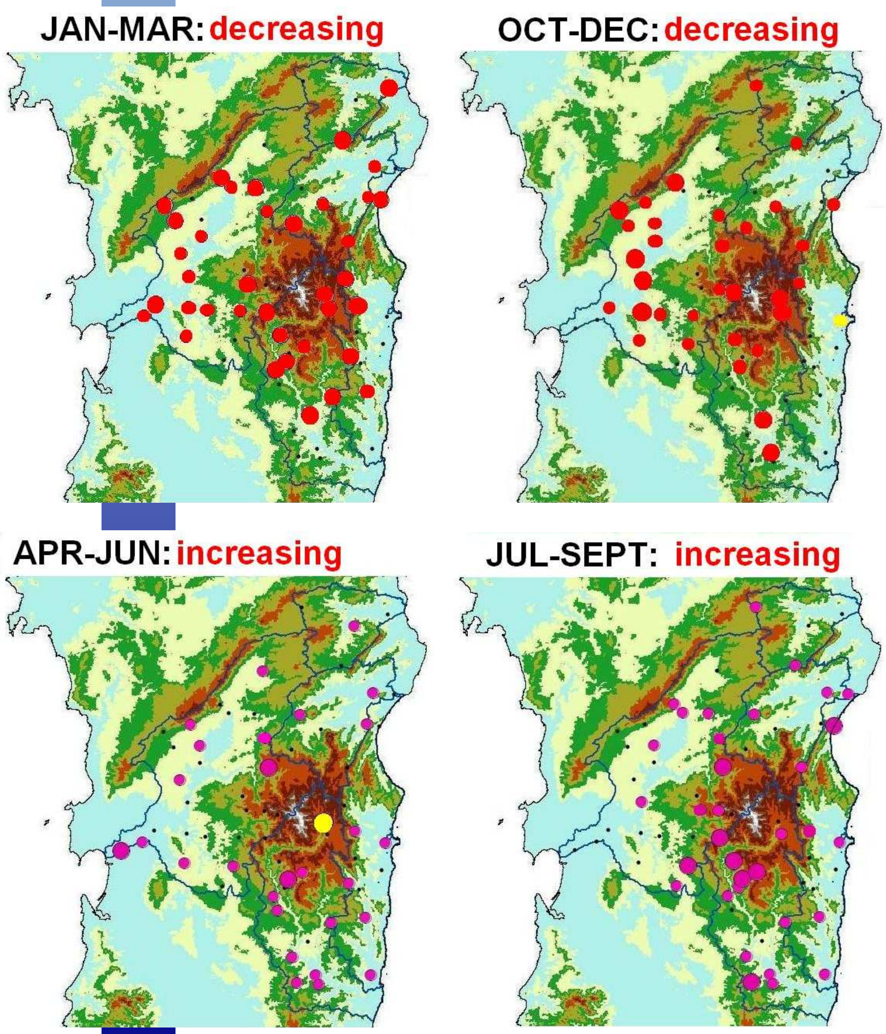
Indices: **TP, F**





Results: seasonal scale

Indices: **TP, F**



- **Jan–March & Oct–Dec: decreasing trends.**

Stations showing a trend in both TP and F are located on the mountains slope.

- **In Oct–Dec the results are more sparse than during winter and, in general, they concern different stations.**
- **spring and summer: increasing trend.**
- **The frequency of rainy days seems to have increased during the summer mainly. In spring, this trend is observed in the external part of the study area, while the mountainous area shows trends in the summer, when rainfall is mainly due to convective showers.**
- **Increasing total precipitation in spring and summer does not balance the decreasing precipitation in autumn and winter**

Results: seasonal scale

A decreasing trend in **TP** is *rarely* associated to a decreasing trend in **TEP** and **R5D**; similarly, a decreasing trend in **F** does not mean an increasing trend in **CDD**, and anal. for opposite trends

$\Longrightarrow$

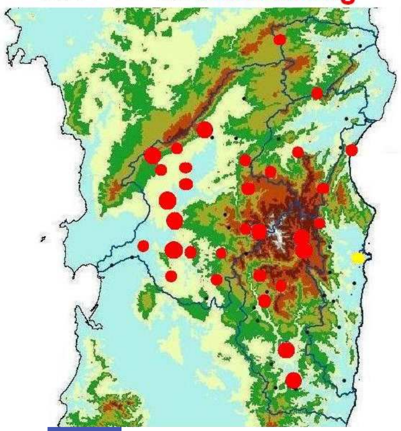
the intensity and frequency of heavy rainfall events do not vary, so that the negative impact of extreme events can increase depending on the degree of vulnerability of the territory

Results: seasonal scale

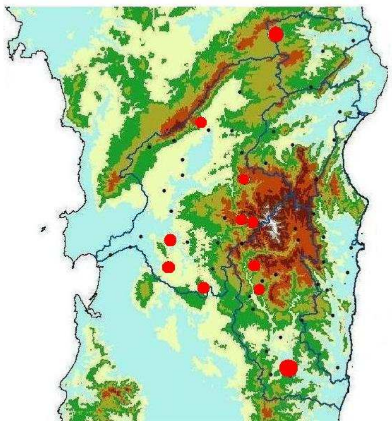
Indices: **TP, F** vs **TP/y, F/y**:

ABSOLUTE **PROPORTION**

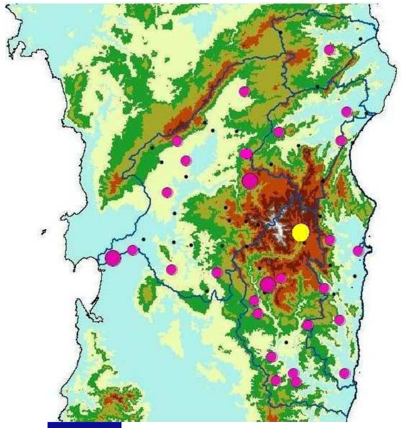
OCT-DEC: decreasing



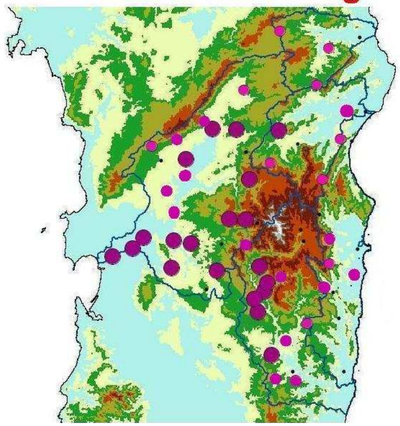
OCT-DEC: decreasing



APR-JUN: increasing



APR-JUN: increasing

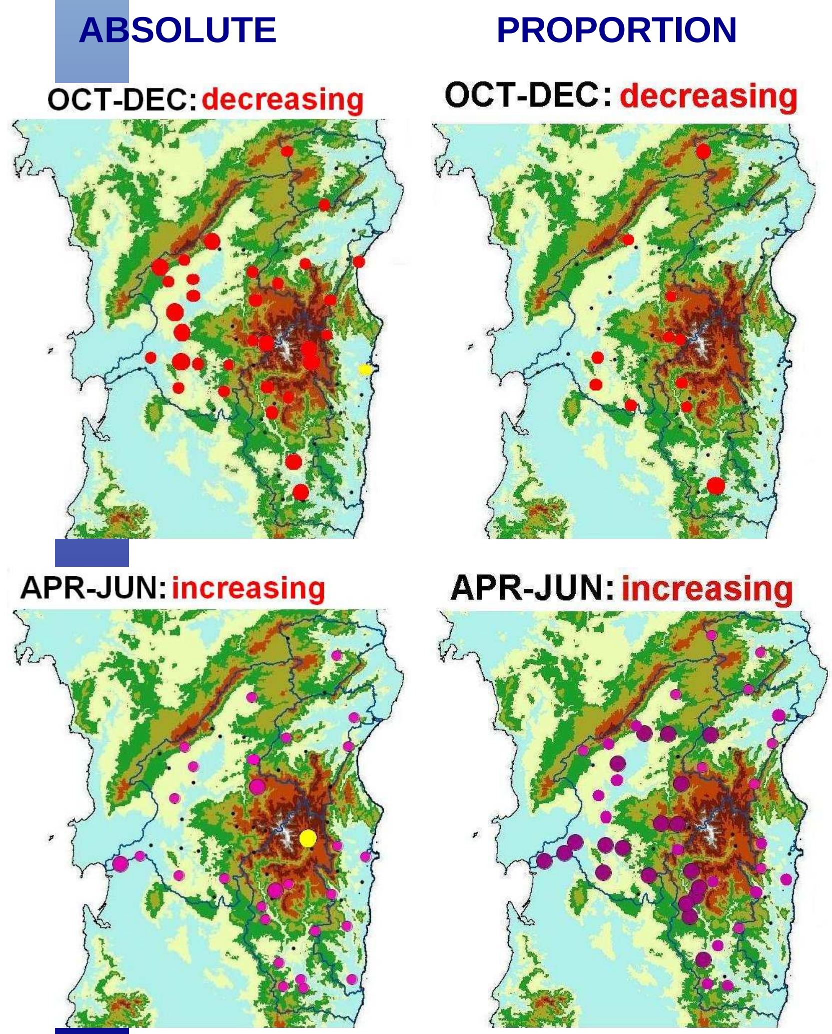


Trend signs are confirmed. Wrt annual results:

- **in autumn and winter a smaller number of sites showing trends are highlighted.**
- **in spring and summer: a higher ...**

Results: seasonal scale

Indices: **TP, F** vs **TP/y, F/y**:



Trend signs are confirmed. Wrt annual results:

- **in autumn and winter a smaller number of sites showing trends are highlighted.**
- **in spring and summer: a higher ...**

WHAT DOES IT MEAN ?

IS IT RELEVANT FOR IMPACT EVALUATION OF EXTREME EVENTS ?

Current and future work ...

- ... complete the trend analysis over all Sardinia
- ... try to answer the following questions:
  - is the scarcity of precipitation from about 1985 to 1999 correlated to any variability in some large-scale index? (probably, yes)
  - how to incorporate trends in an Extreme Value Analysis at its best?
  - to what extent the observed trends have (negative) effects on the territory?

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Thank you for your attention

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