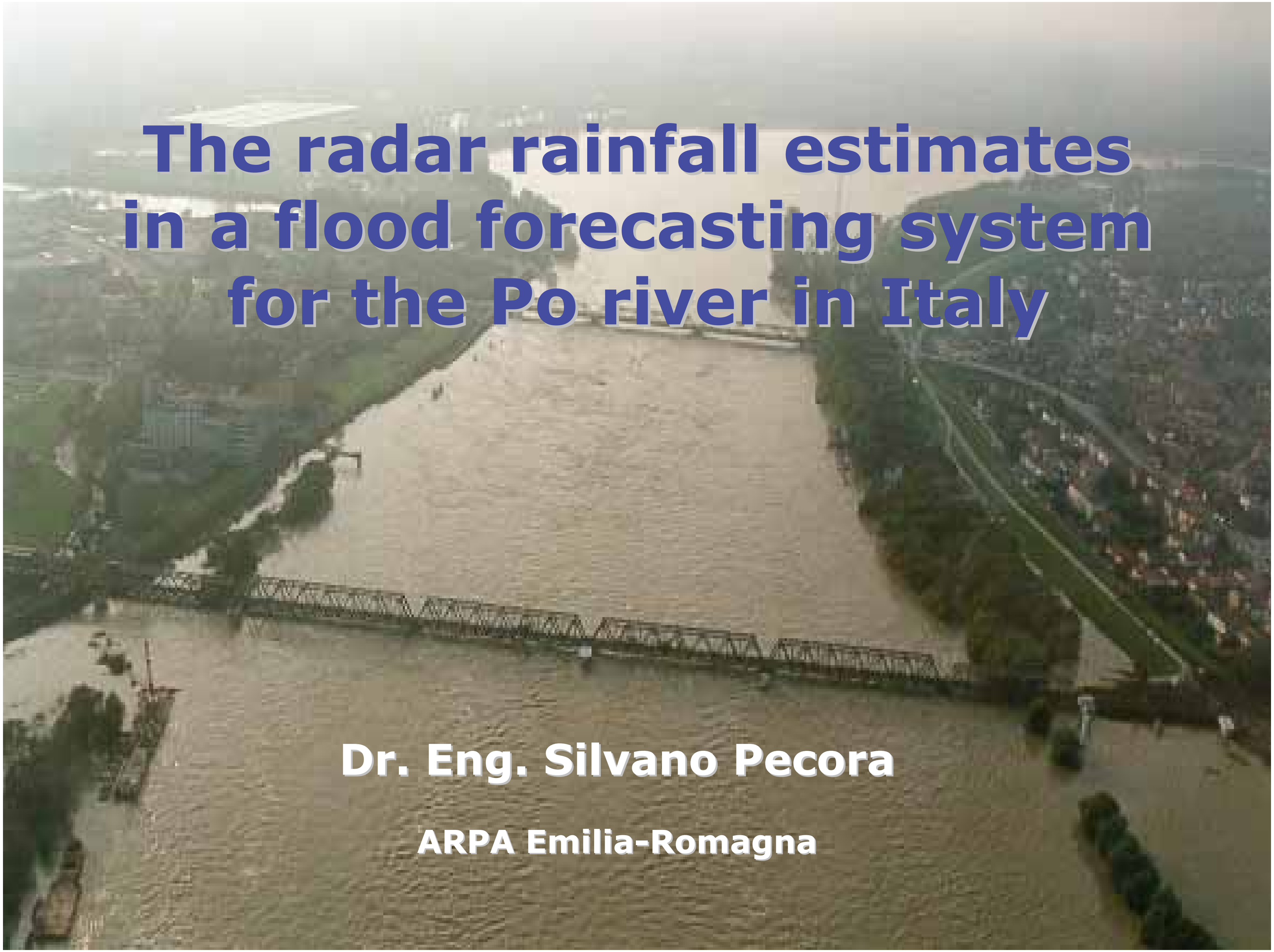


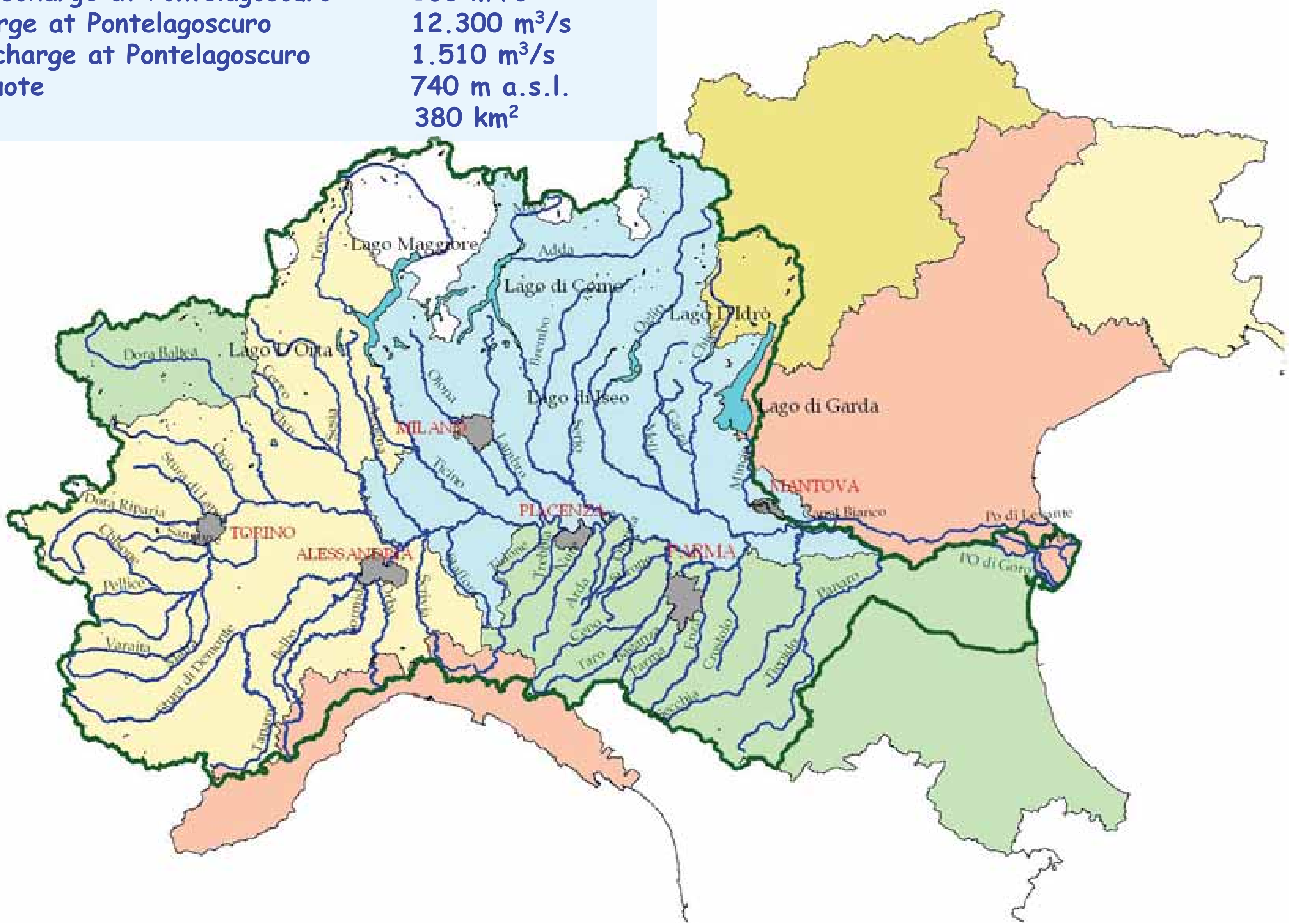
The radar rainfall estimates in a flood forecasting system for the Po river in Italy

Dr. Eng. Silvano Pecora

ARPA Emilia-Romagna

Hydrographic limits

·Catchment Area	70.090 km^2
·Main river length	652 km
·Minimum daily discharge at Pontelagoscuro	168 m^3/s
·Maximum discharge at Pontelagoscuro	12.300 m^3/s
·Mean annual discharge at Pontelagoscuro	1.510 m^3/s
·Basin average quote	740 m a.s.l.
·Delta area	380 km^2



Po Basin And Public Administrations

Italian Department of Civil Protection

Po river basin Authority

Interregional Agency for the Po river basin

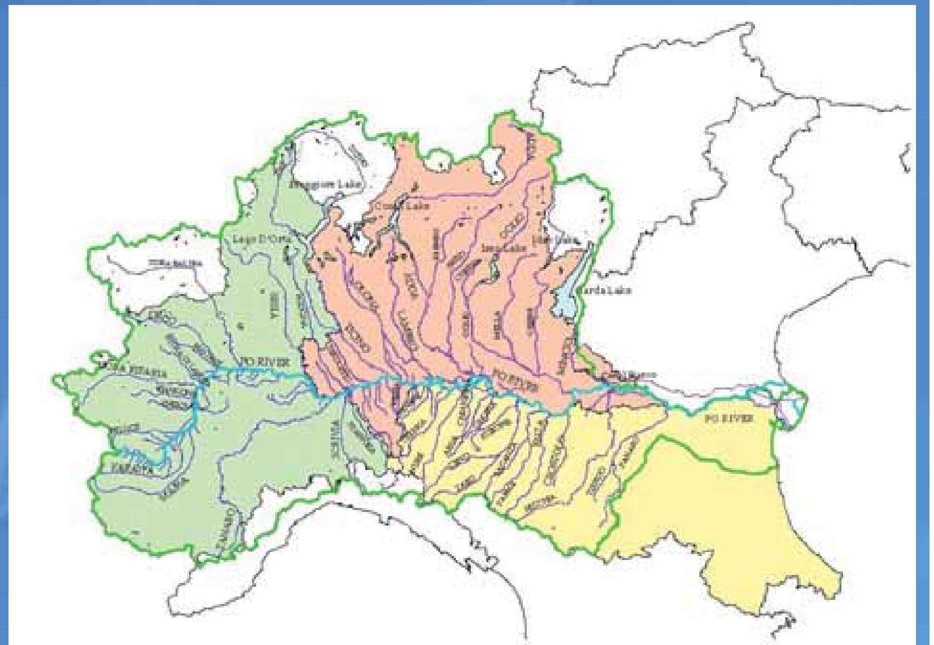
Emilia-Romagna Region

Lombardia Region

Piemonte Region

Valle d’Aosta Region

Veneto Region



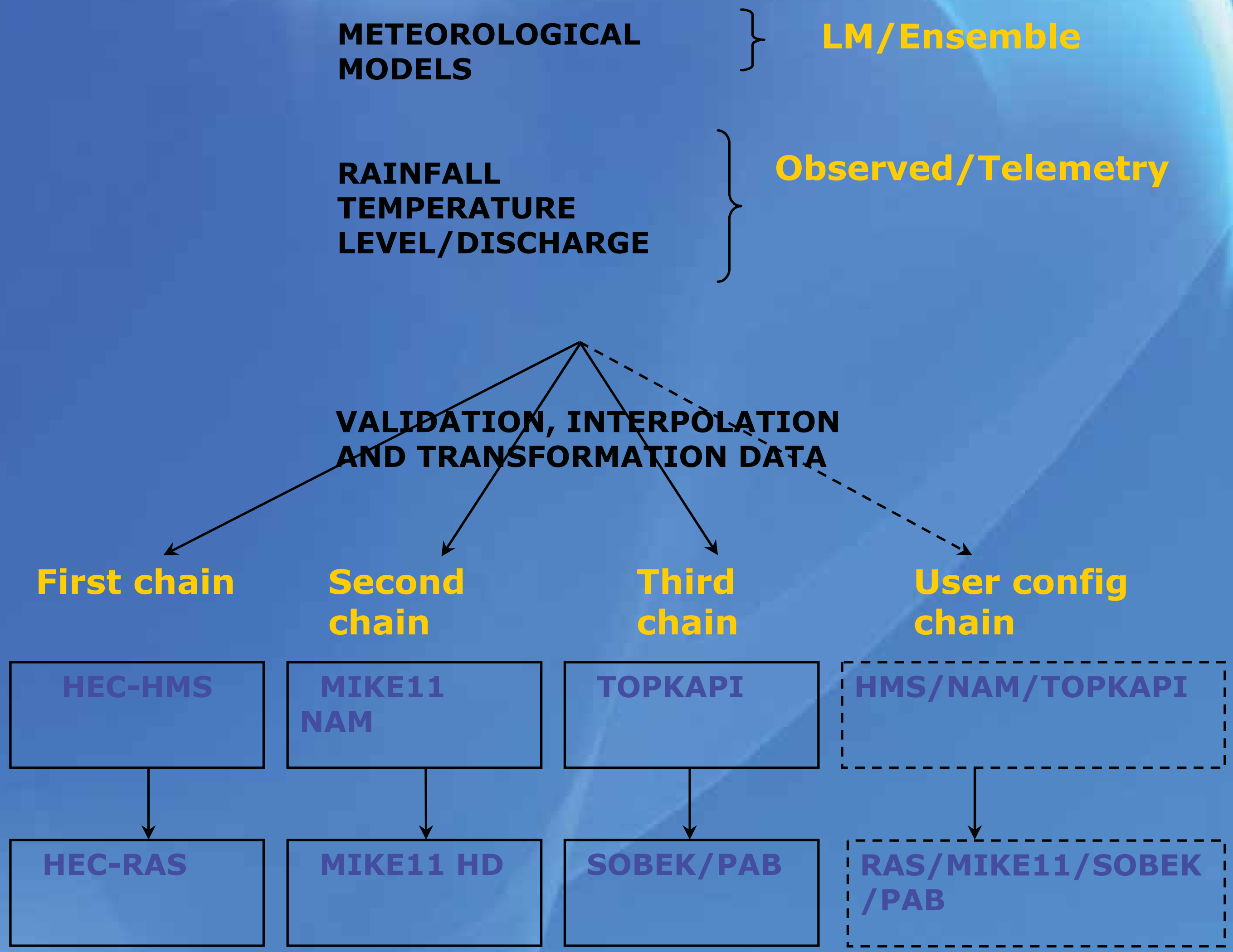
Project objectives

- To develop an adequate modelling system for planning and management
- To develop a suitable forecasting system in real time applications
- To help the organization of flood control services and soil defense services in advance, including civil protection measures to manage emergencies

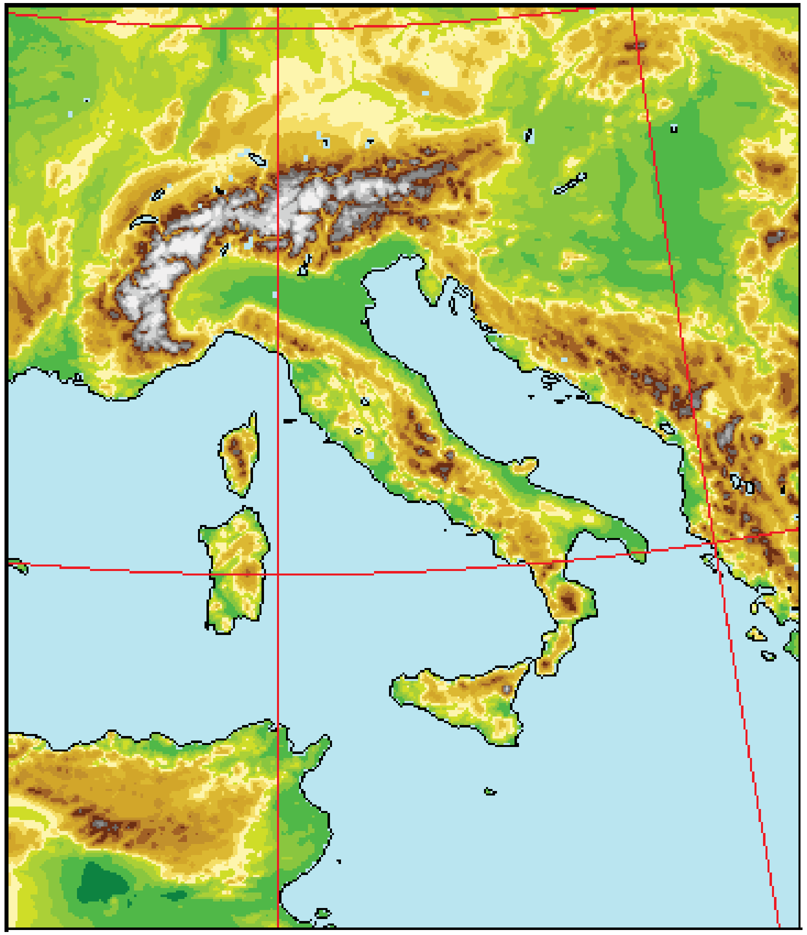
Po flood modelling system

- Identification of observed hydrologic values from the monitoring network;
- Identification of the basin closures where each Centro Funzionale will provide results of their modelling system;
- Identification of geometric schemes for flood propagation;
- Analysis of frequency of data acquisition;
- Realization of a number of forecasting modelling chains;
- Calibration and validation of modelling systems;
- Realtime data assimilation;
- Realizations of user interfaces;
- Realizations of tools for simulated scenarios of possible actions;
- Realization of output system: fax, sms, web, ...

Schematic overview of the Po project



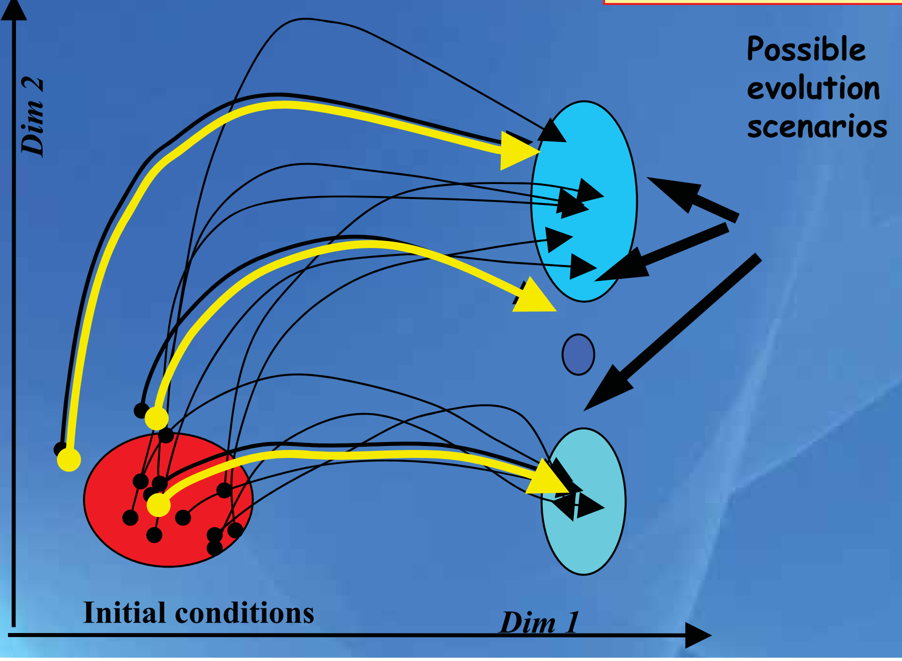
The LAMI Model



- The Hydro-Meteorological Service of Emilia-Romagna, ARPA-SIM, has been using LM as the operational forecast model since 2001;
- LM is run twice a day (at 00UTC and 12UTC) for 72 hours with a spatial horizontal resolution of 2.8 km and 40 layers in the vertical.
- The boundary conditions for LM are supplied by the global model of the DWD (one-way nesting) every hour. The initial condition is provided by a mesoscale data assimilation based on a nudging technique

From deterministic to probabilistic forecasting: Ensemble Prediction System (EPS-LEPS)

Weather forecast → One input → **Forecasting System** → One output → **Flood forecast**



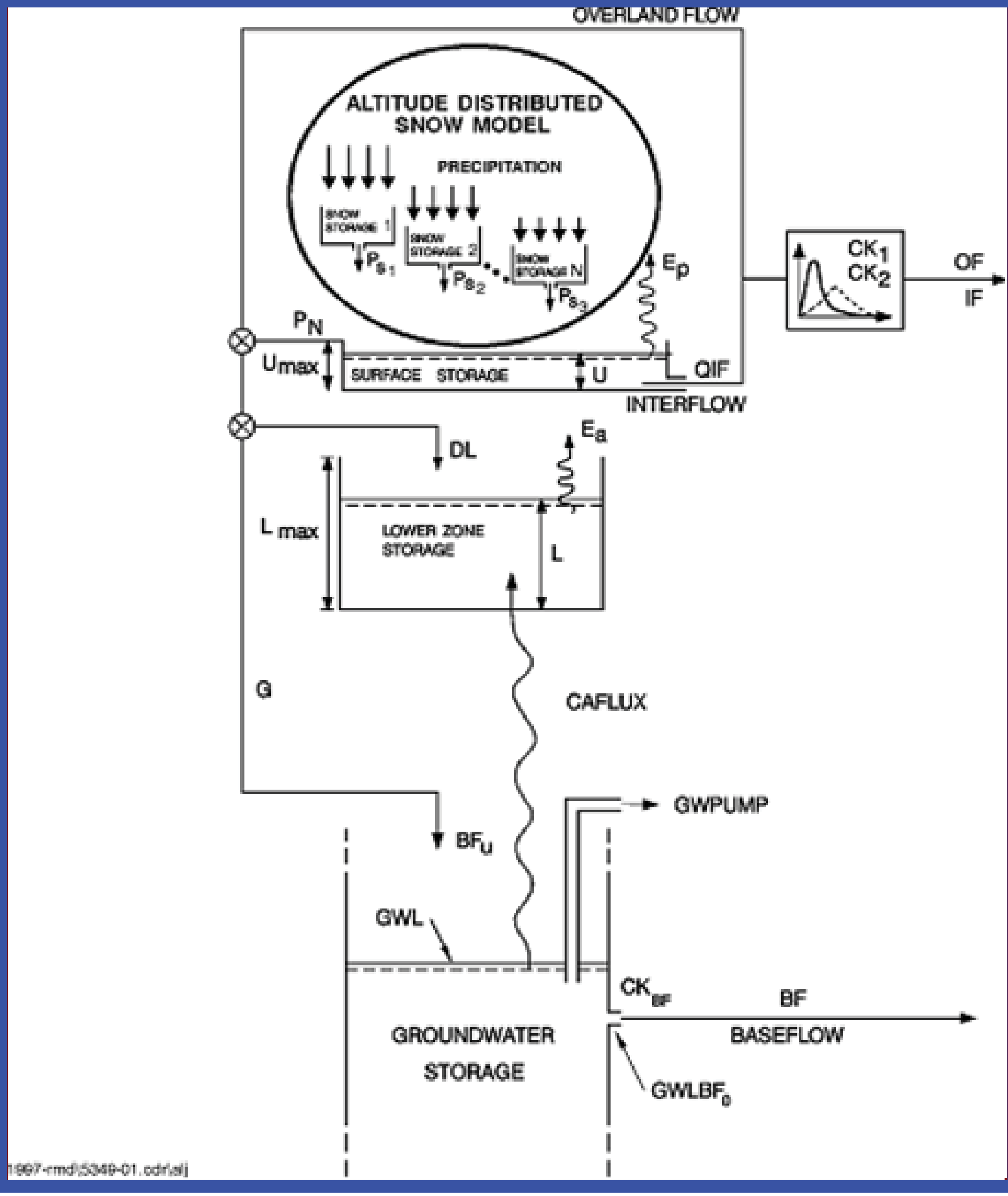
BUT:

atmosphere is a chaotic system

⇒ small errors in initial conditions (different states of the atmosphere) and numerical forecast model uncertainties can lead to different results

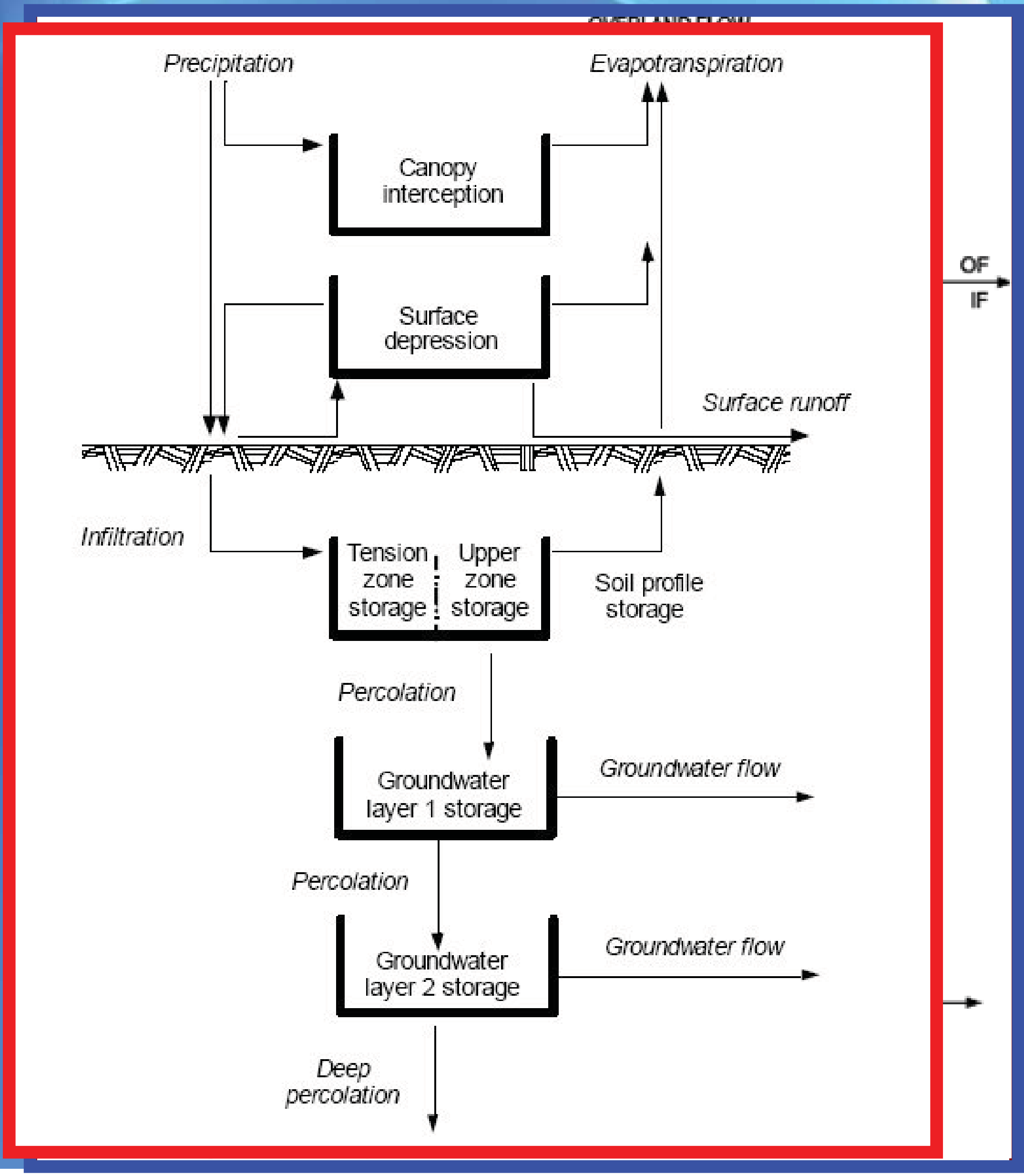
Hydrological models

- MIKE11-NAM



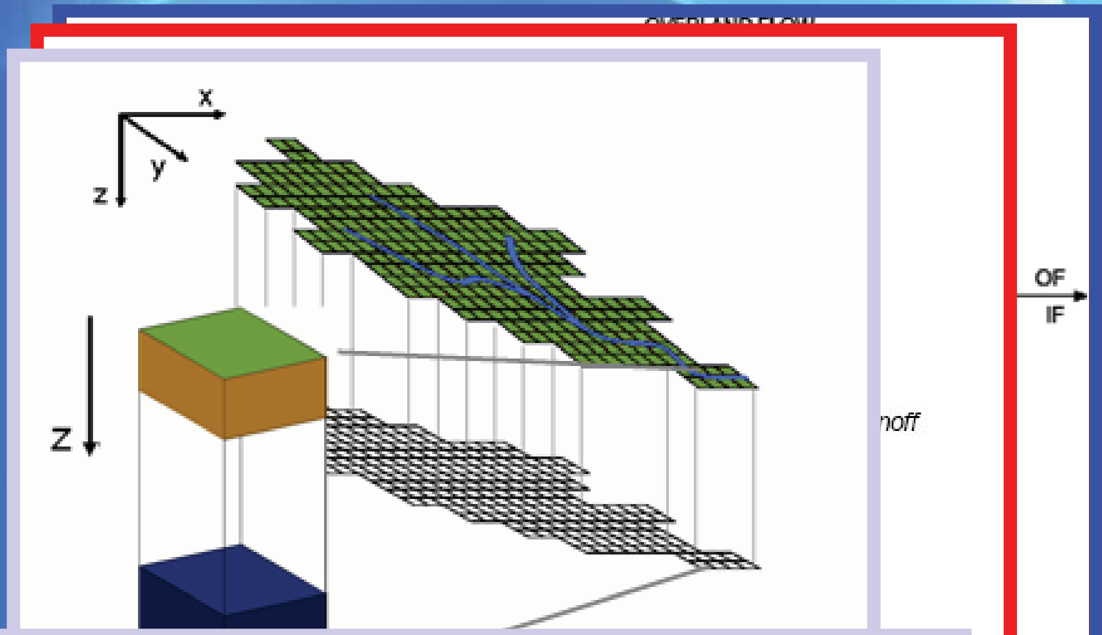
Hydrological models

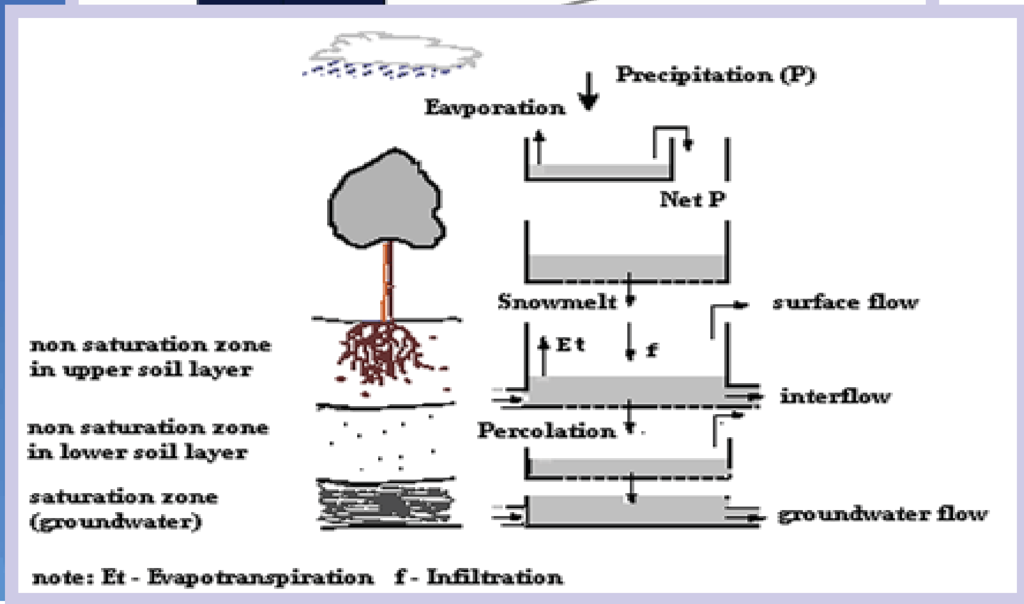
- MIKE11-NAM
- HEC-HMS



Hydrological models

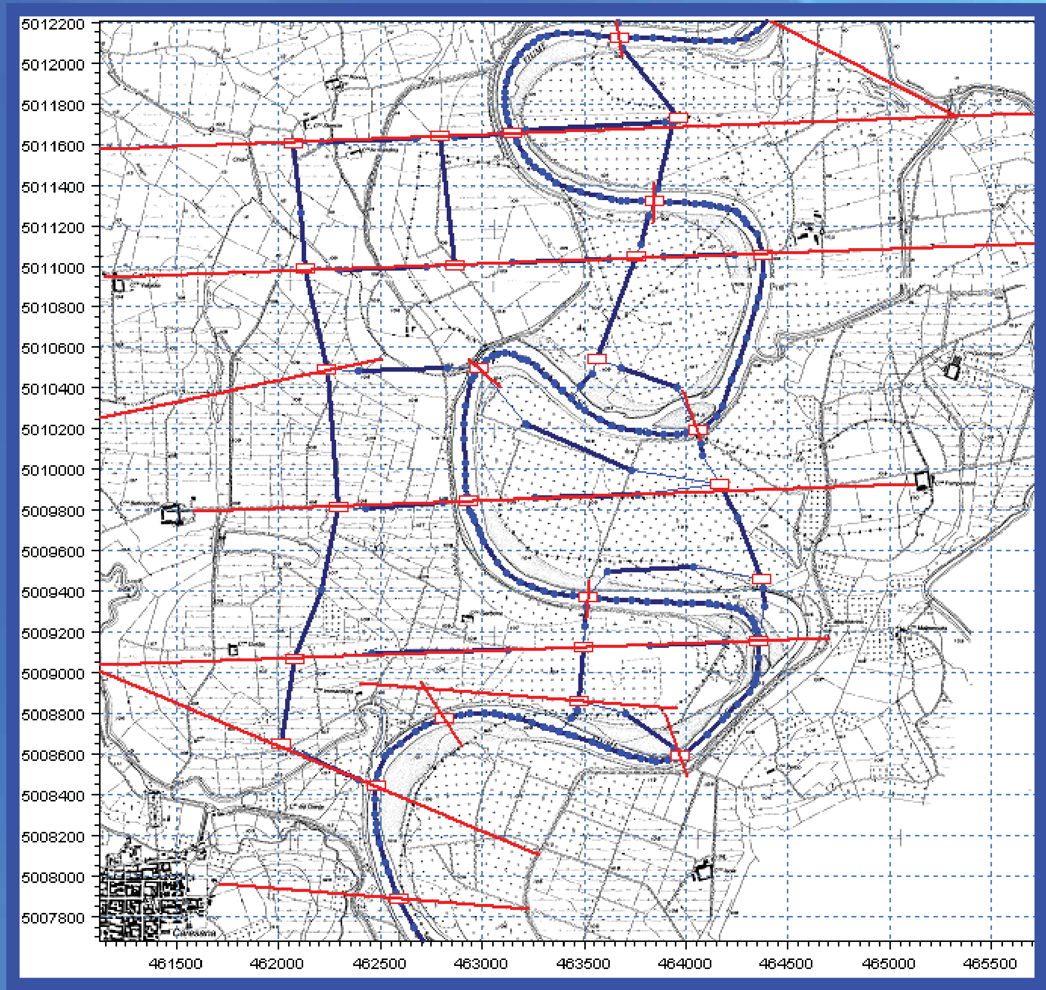
- MIKE11-NAM
- HEC-HMS
- TOPKAPI





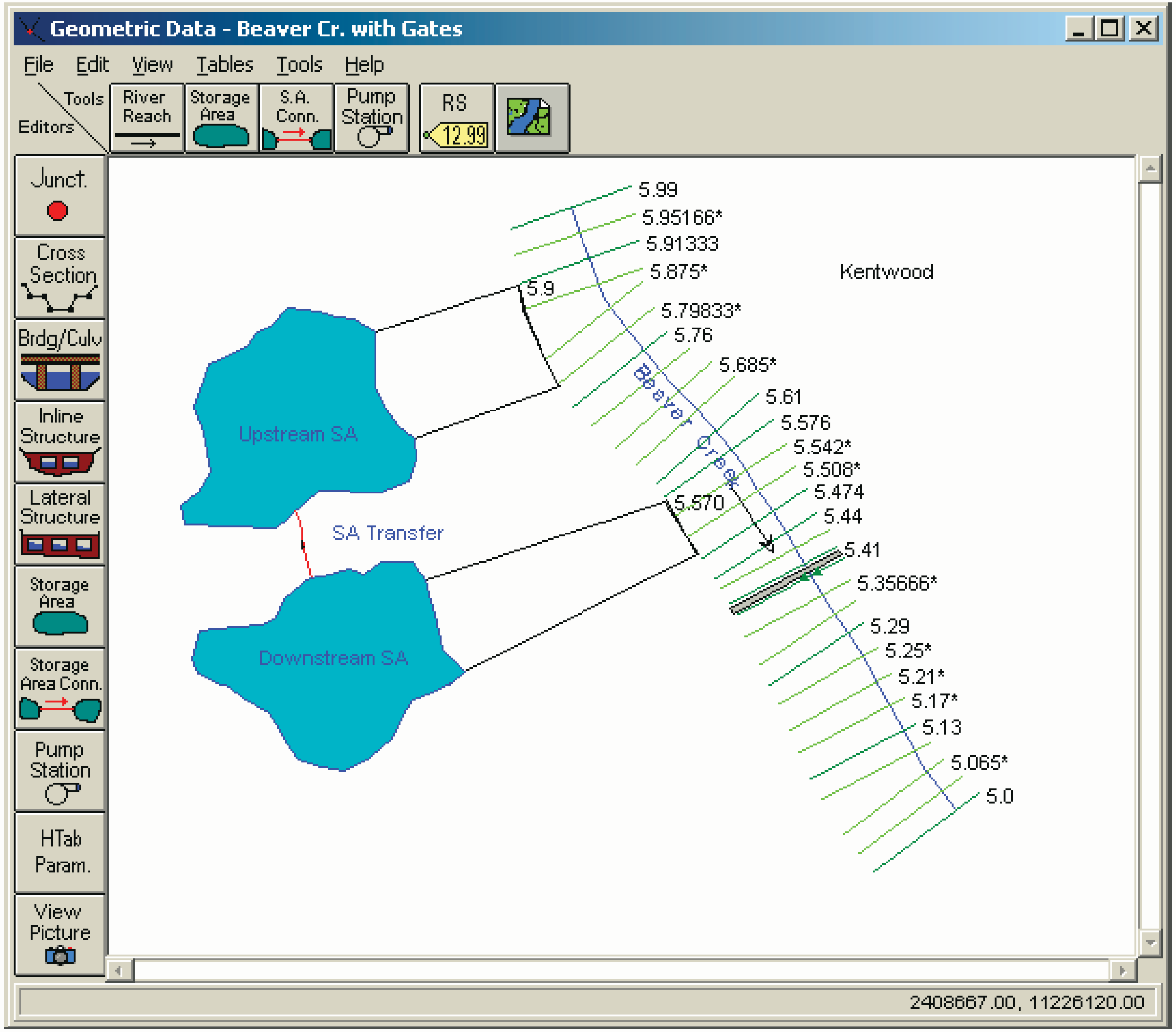
Hydrodinamic models

- MIKE11-HD



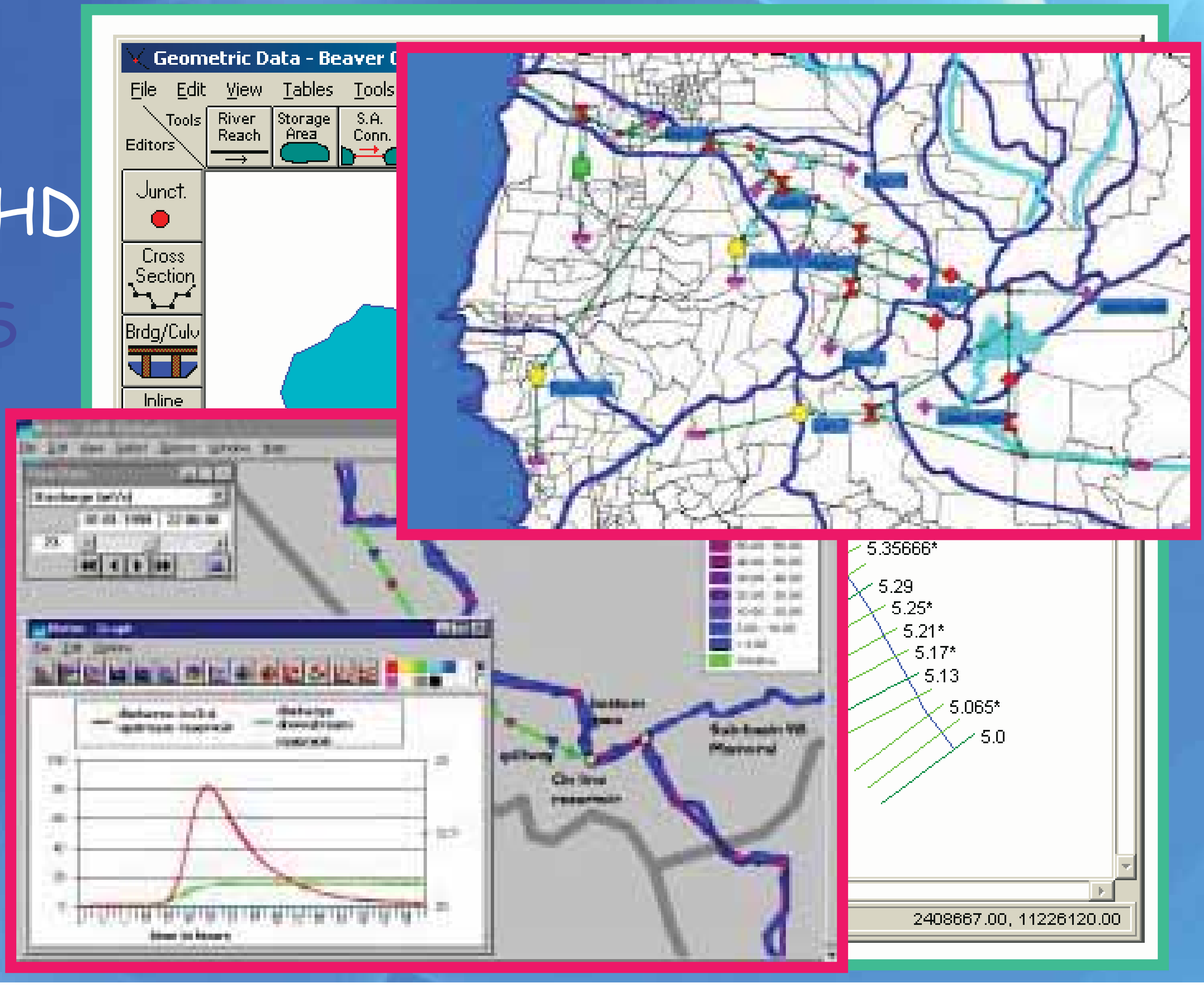
Hydrodinamic models

- MIKE11-HD
- HEC-RAS

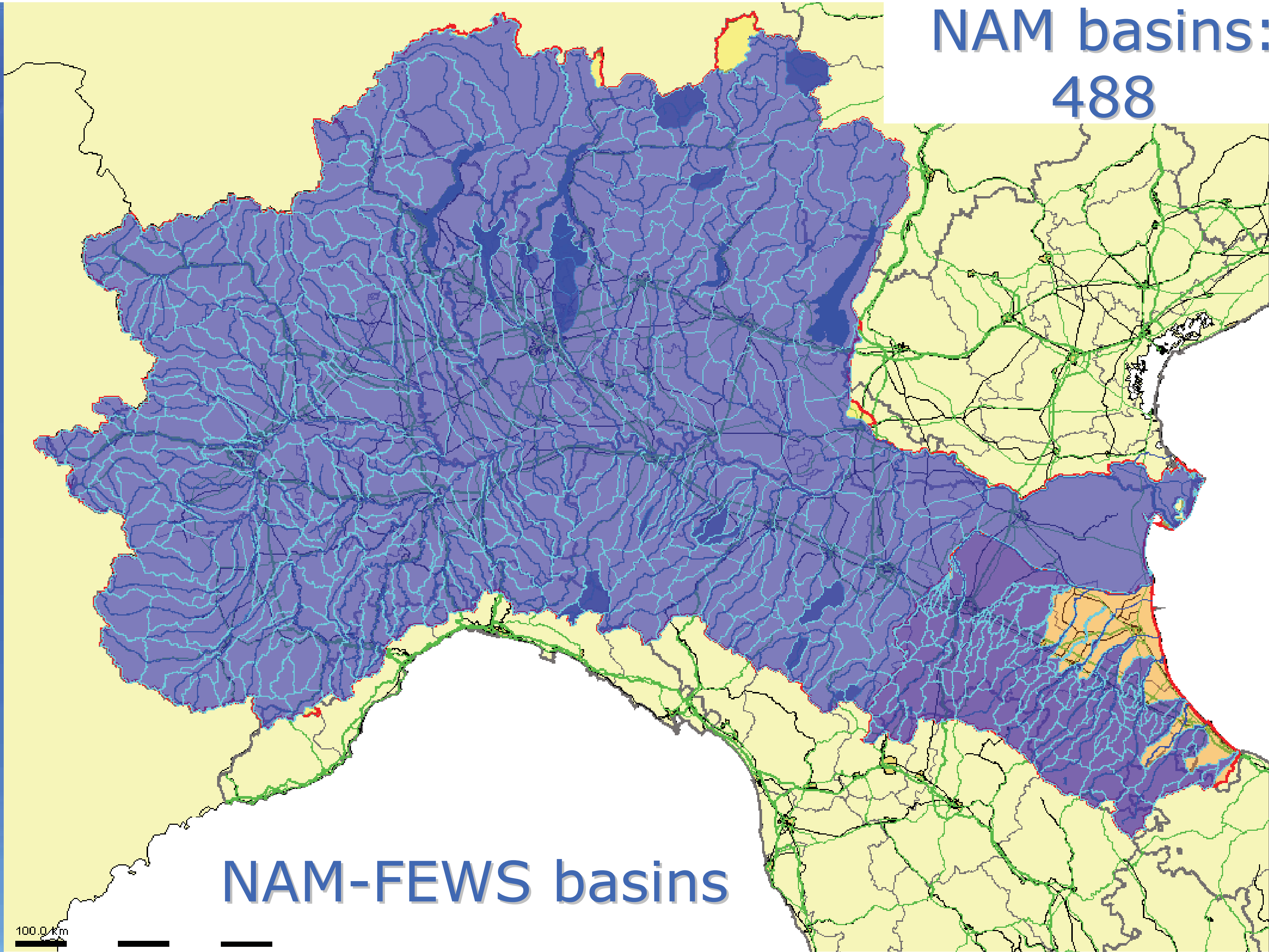


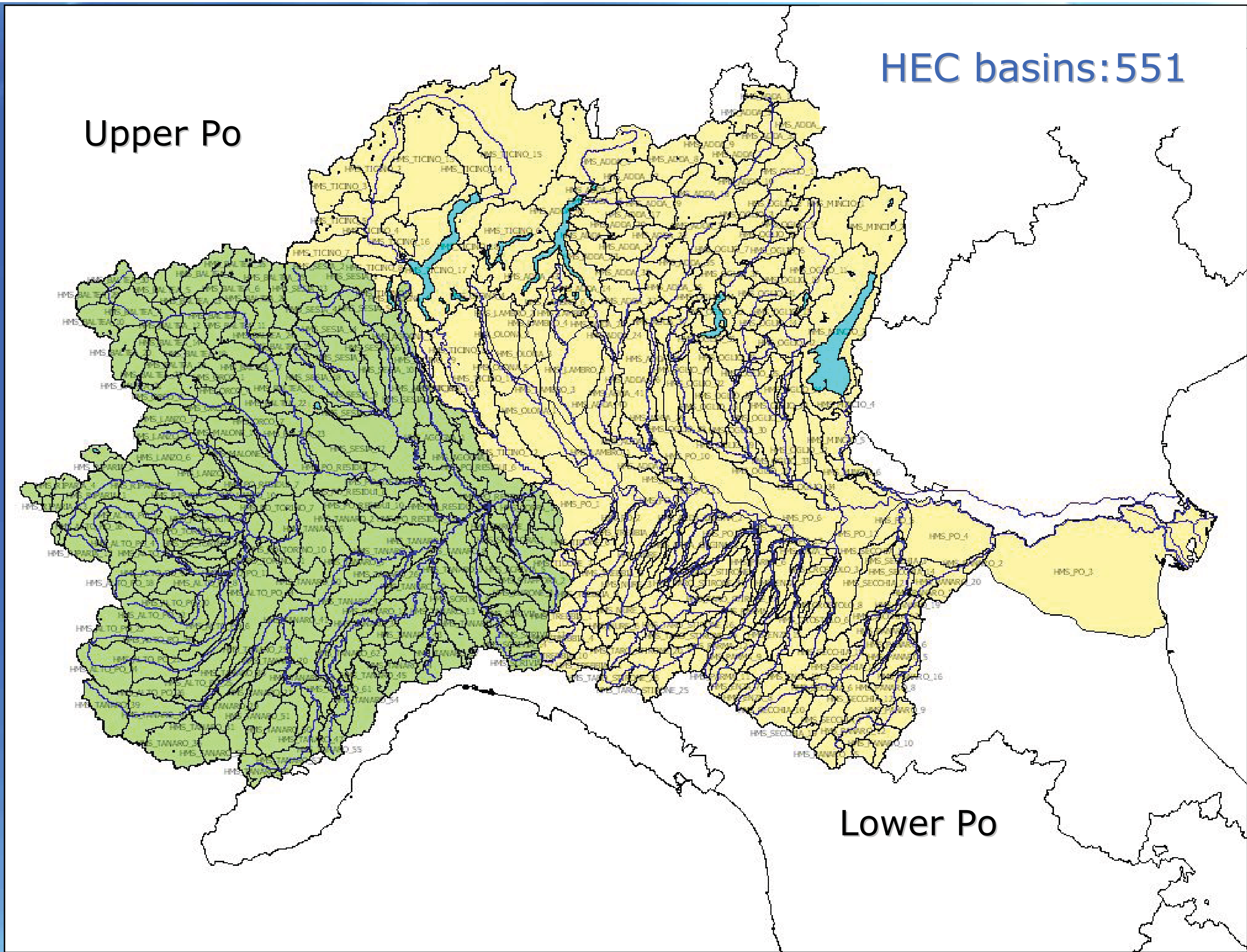
Hydrodinamic models

- MIKE11-HD
- HEC-RAS
- SOBEK

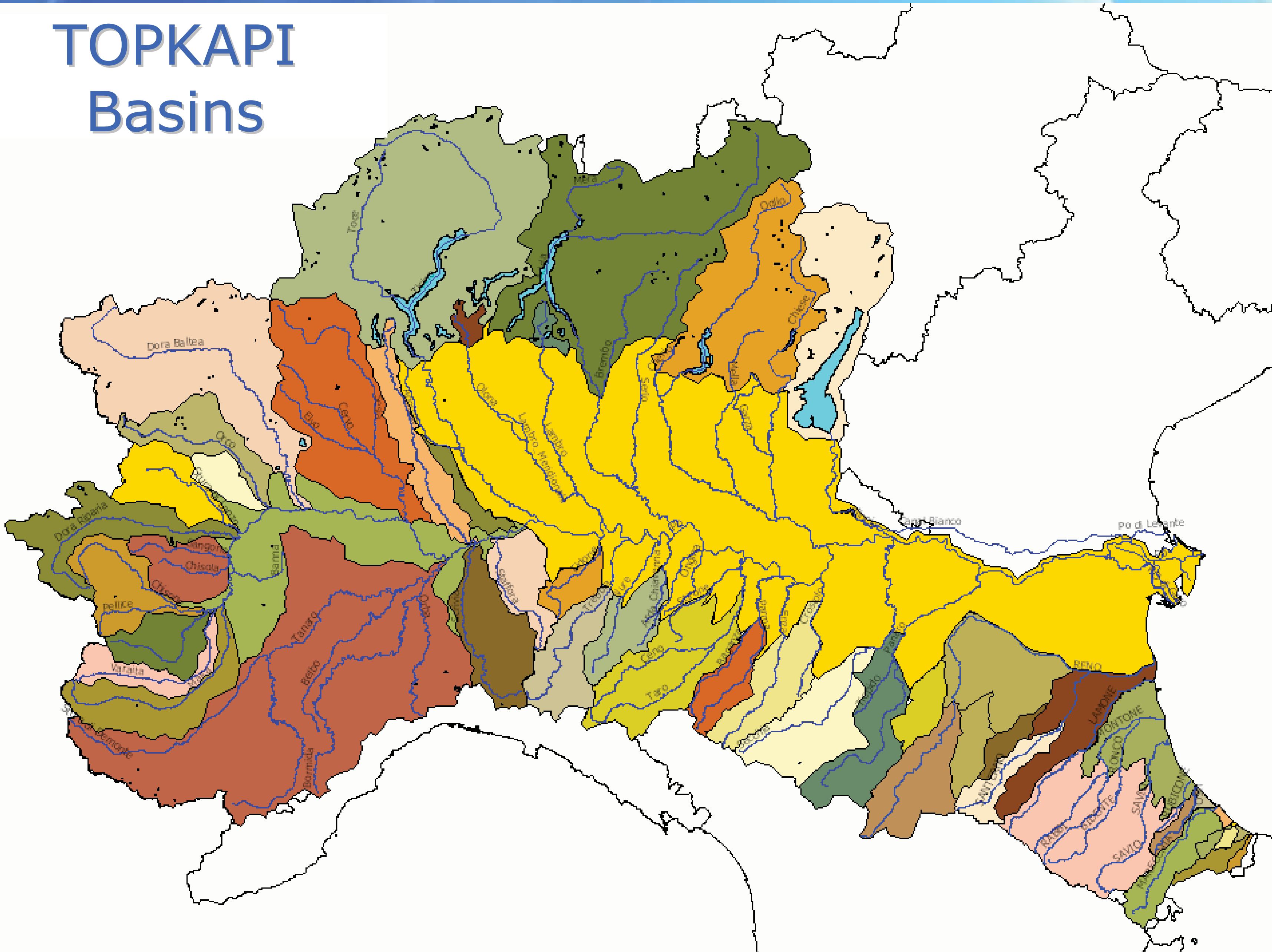


NAM basins: 488



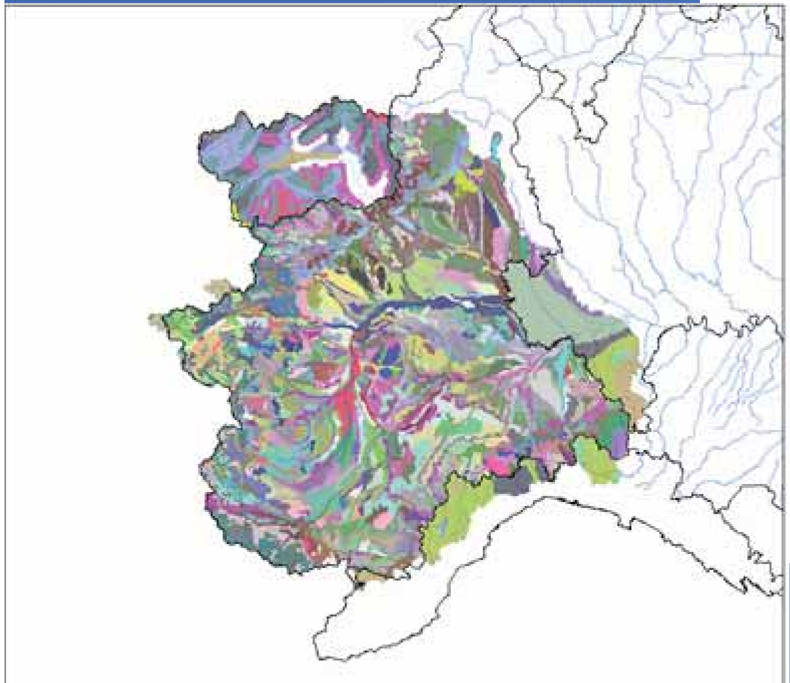

HEC basins:551
Upper Po
Lower Po

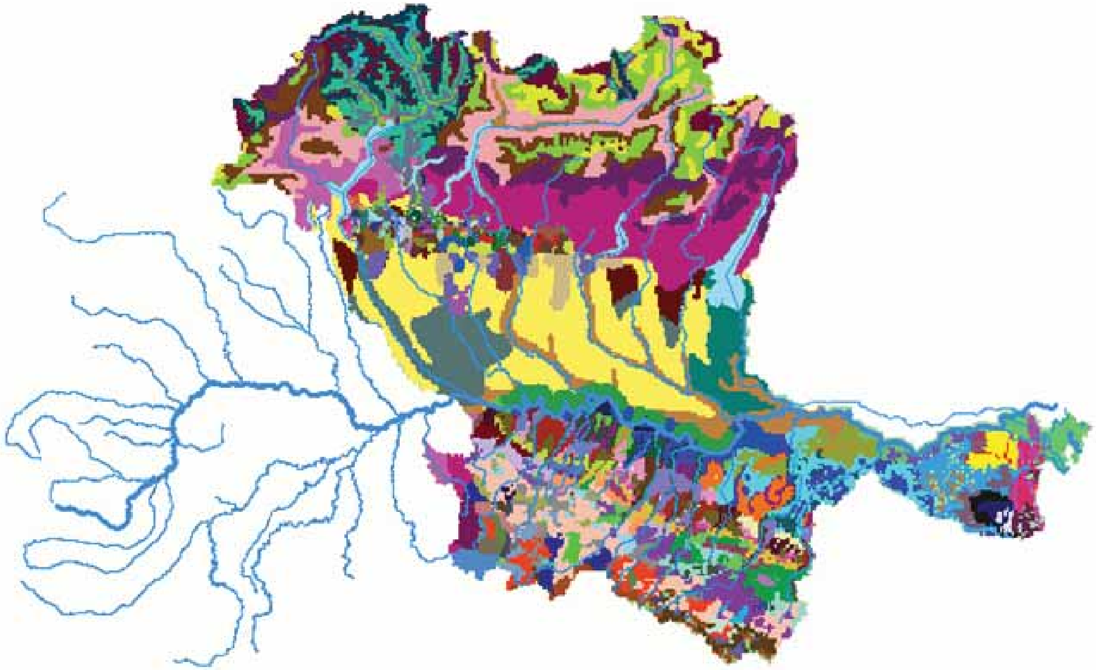
TOPKAPI Basins



Soil types

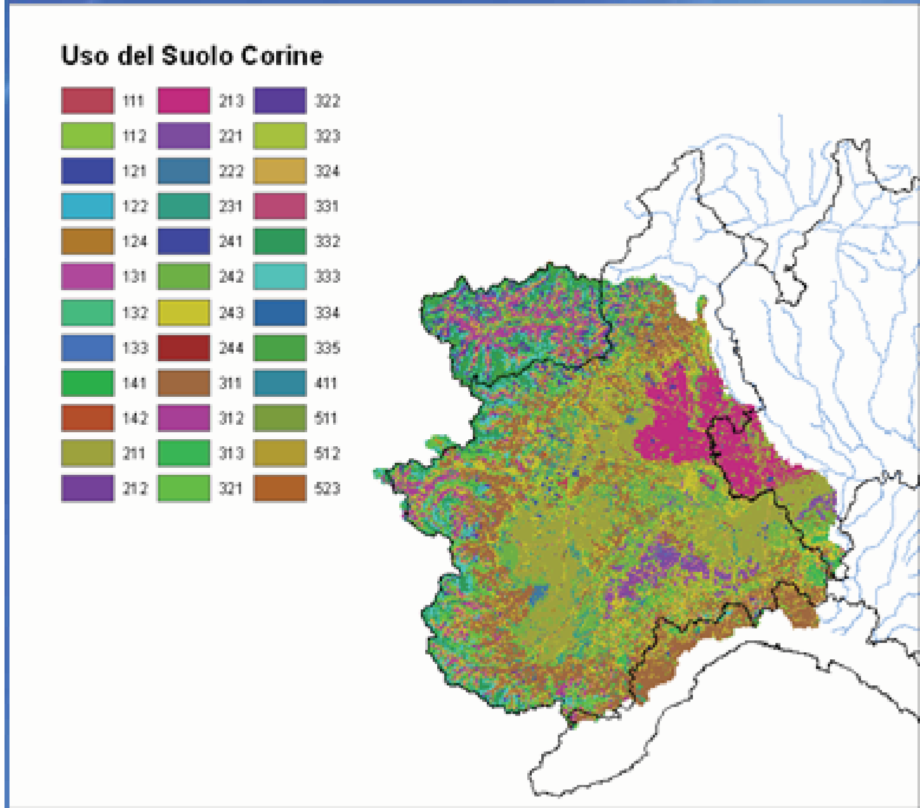
- Emilia Romagna Region pedologic map (1:250000);
- Lombardia Region pedologic map (1:250000);
- Piemonte Region pedologic map (1:250000);
- European soil database (for missing data).



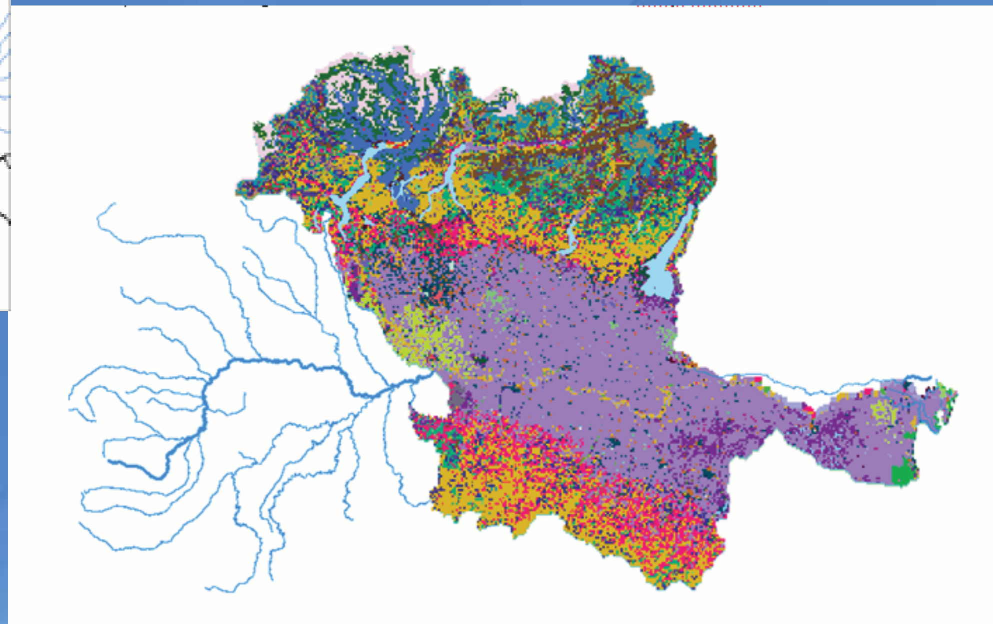


272 soil type classes:
76 Emilia-Romagna
61 Lombardia
82 Piemonte
53 European soil database

Land use



River Po basin land use characteristics have been individuated with "CORINE Program – LAND COVER Project".



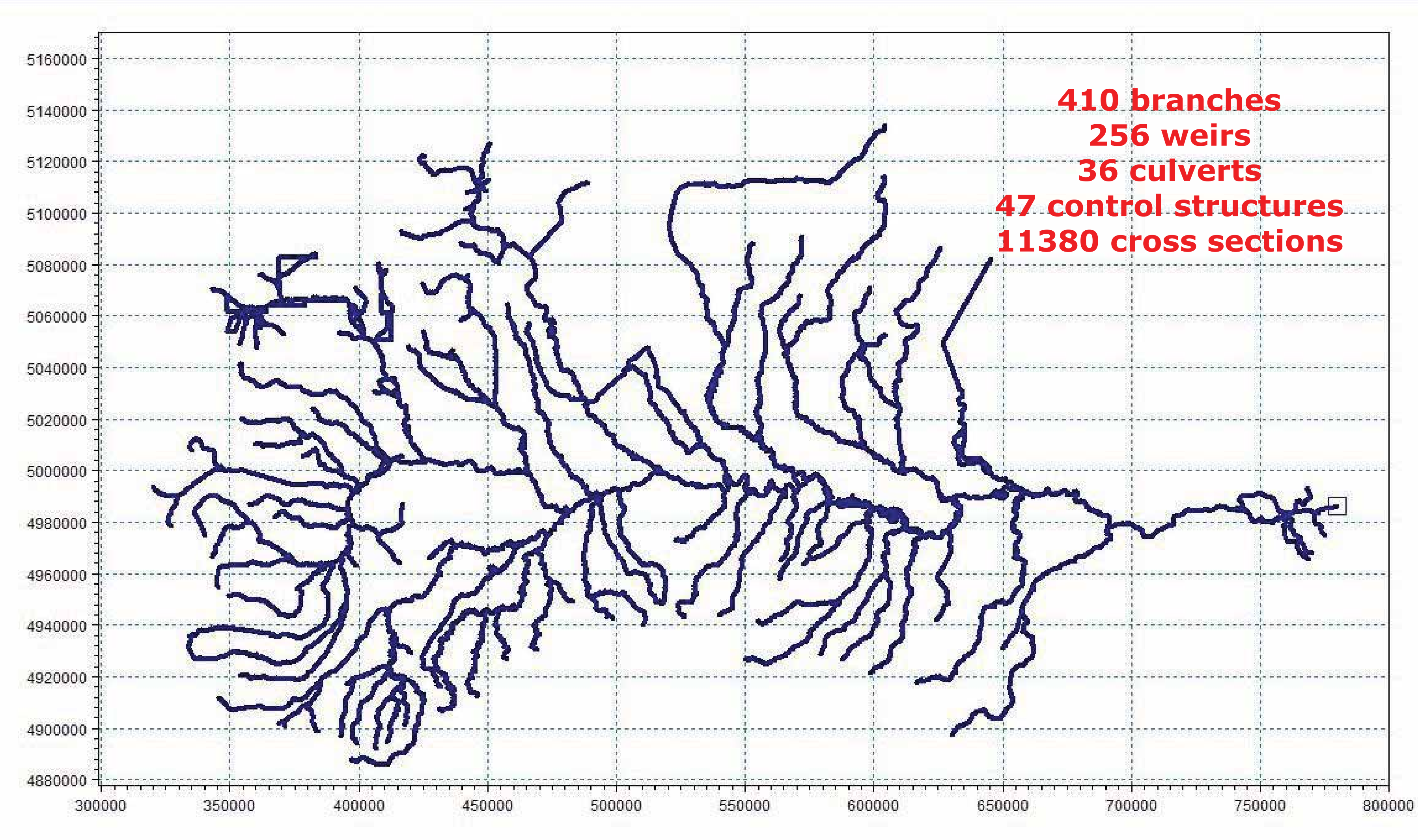
50 DIFFERENT LAND USES

Cell dimensions for each sub-basin: 200 m, 250 m, 500 m, 1000 m

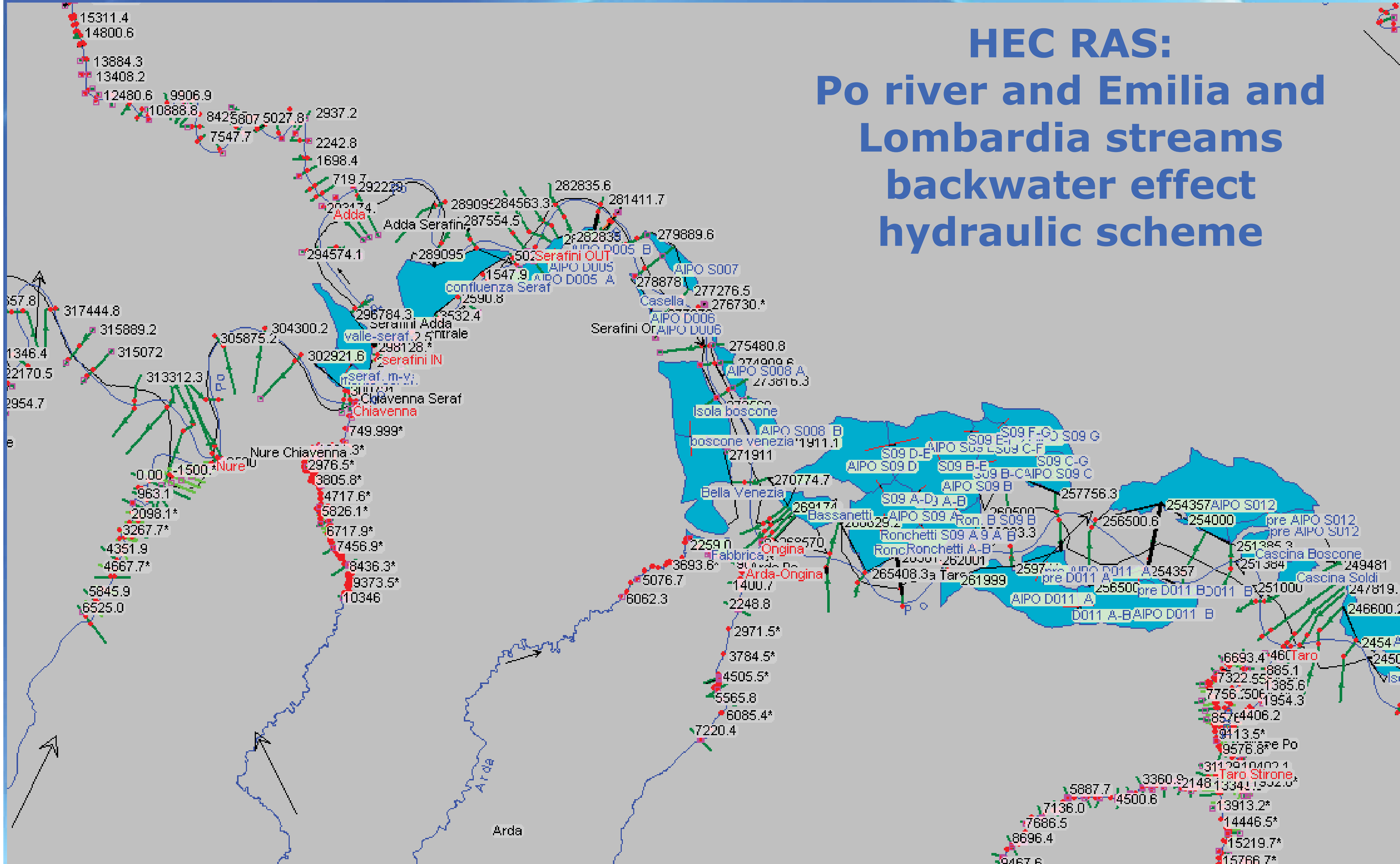
Bacino	**Adda**	**Bacino**	**Trebbia**	**Bacino**	**Scrivia**	**Bacino**	**Orco**
Rows	222	Rows	109	Rows	300	Rows	200
Cols	259	Cols	75	Cols	180	Cols	264
xCellSize	**500**	xCellSize	**500**	xCellSize	**250**	xCellSize	**250**
yCellSize	**500**	yCellSize	**500**	yCellSize	**250**	yCellSize	**250**
Bacino	**Oglio**	**Bacino**	**Ticino**	**Bacino**	**Sesia**	**Bacino**	**Secchia**
Rows	174	Rows	210	Rows	190	Rows	129
Cols	144	Cols	228	Cols	138	Cols	129
xCellSize	**500**	xCellSize	**500**	xCellSize	**500**	xCellSize	**500**
yCellSize	**500**	yCellSize	**500**	yCellSize	**500**	yCellSize	**500**
Bacino	**Mincio**	**Bacino**	**Pianura**	**Bacino**	**Tanaro**	**Bacino**	**Tidone_Staffora**
Rows	195	Rows	150	Rows	244	Rows	170
Cols	88	Cols	327	Cols	330	Cols	174
xCellSize	**500**	xCellSize	**1000**	xCellSize	**500**	xCellSize	**250**
yCellSize	**500**	yCellSize	**1000**	yCellSize	**500**	yCellSize	**250**
Bacino	**Lambro_Olona**	**Bacino**	**Reno**	**Bacino**	**Varaita**	**Bacino**	**Lanzo**
Rows	113	Rows	184	Rows	224	Rows	134
Cols	241	Cols	238	Cols	296	Cols	192
xCellSize	**200**	xCellSize	**500**	xCellSize	**250**	xCellSize	**500**
yCellSize	**200**	yCellSize	**500**	yCellSize	**250**	yCellSize	**500**
Bacino	**Chiavenna-Arda-Nure**	**Bacino**	**Romagna**	**Bacino**	**Pellice**	**Bacino**	**Parma**
Rows	198	Rows	280	Rows	244	Rows	247
Cols	141	Cols	296	Cols	236	Cols	165
xCellSize	**250**	xCellSize	**250**	xCellSize	**250**	xCellSize	**200**
yCellSize	**250**	yCellSize	**250**	yCellSize	**250**	yCellSize	**200**
Bacino	**Enza_Crostolo**	**Bacino**	**Agogna**	**Bacino**	**PianuraPie**	**Bacino**	**Taro**
Rows	302	Rows	372	Rows	160	Rows	252
Cols	231	Cols	256	Cols	302	Cols	259
xCellSize	**200**	xCellSize	**250**	xCellSize	**500**	xCellSize	**250**
yCellSize	**200**	yCellSize	**250**	yCellSize	**500**	yCellSize	**250**
Bacino	**Panaro**	**Bacino**	**DoraBaltea**				
Rows	154	Rows	190				
Cols	99	Cols	212				
xCellSize	**500**	xCellSize	**500**				
yCellSize	**500**	yCellSize	**500**				

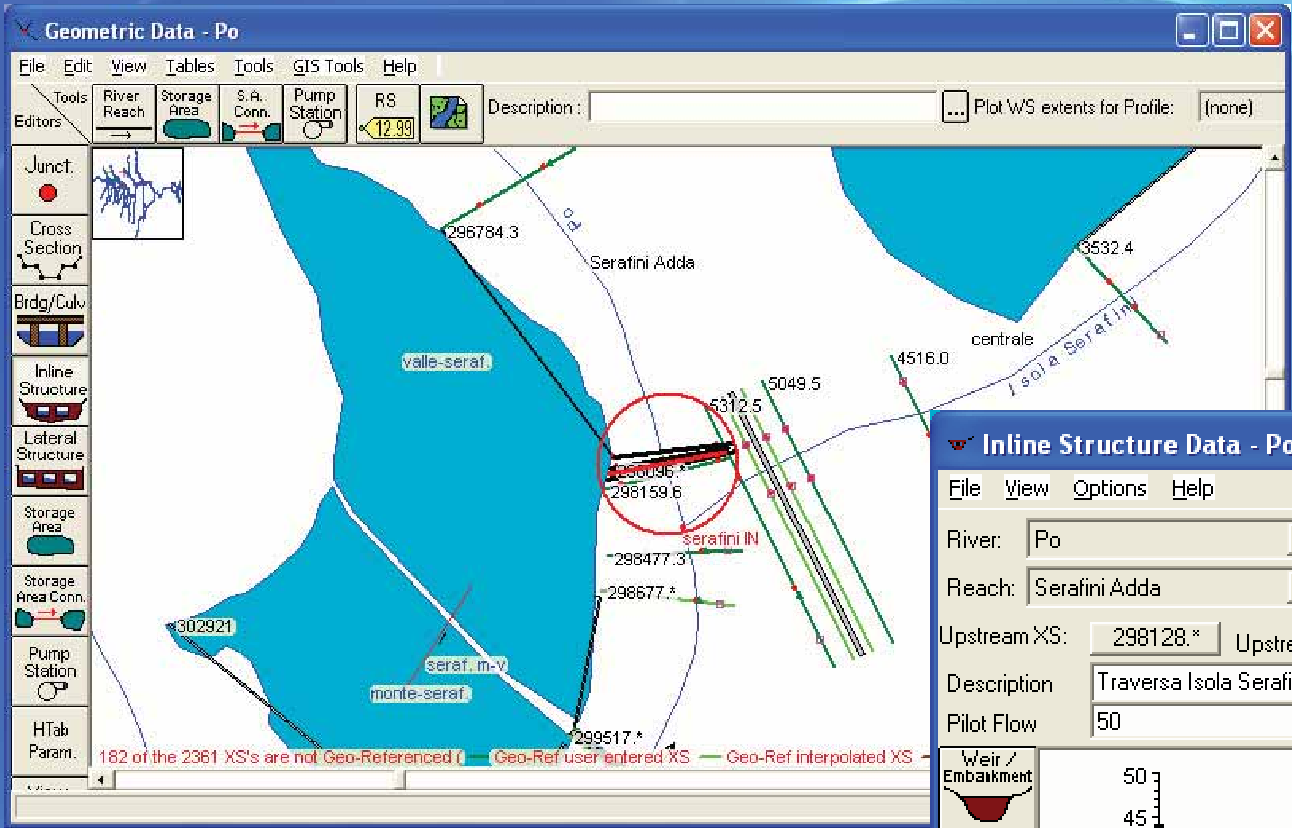
Total number of cells, covering the whole Po basin and Romagna Region: 285.000

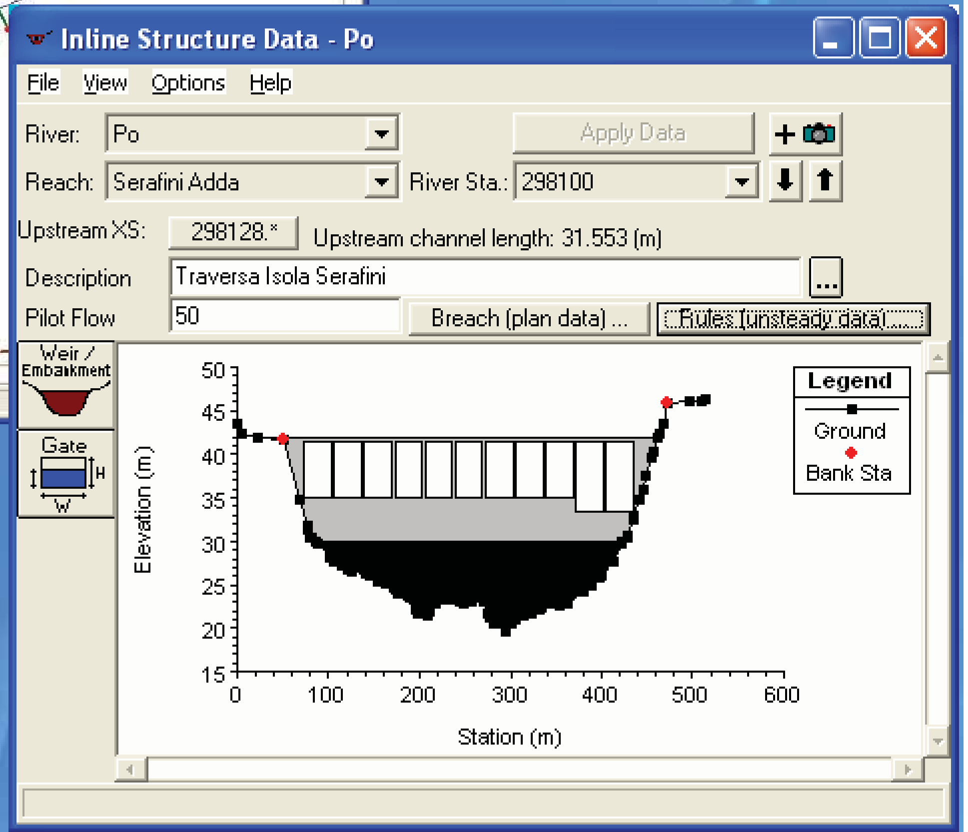
MIKE MODEL
SCHEMATIZATION APPLIED TO THE PO BASIN



HEC RAS: Po river and Emilia and Lombardia streams backwater effect hydraulic scheme

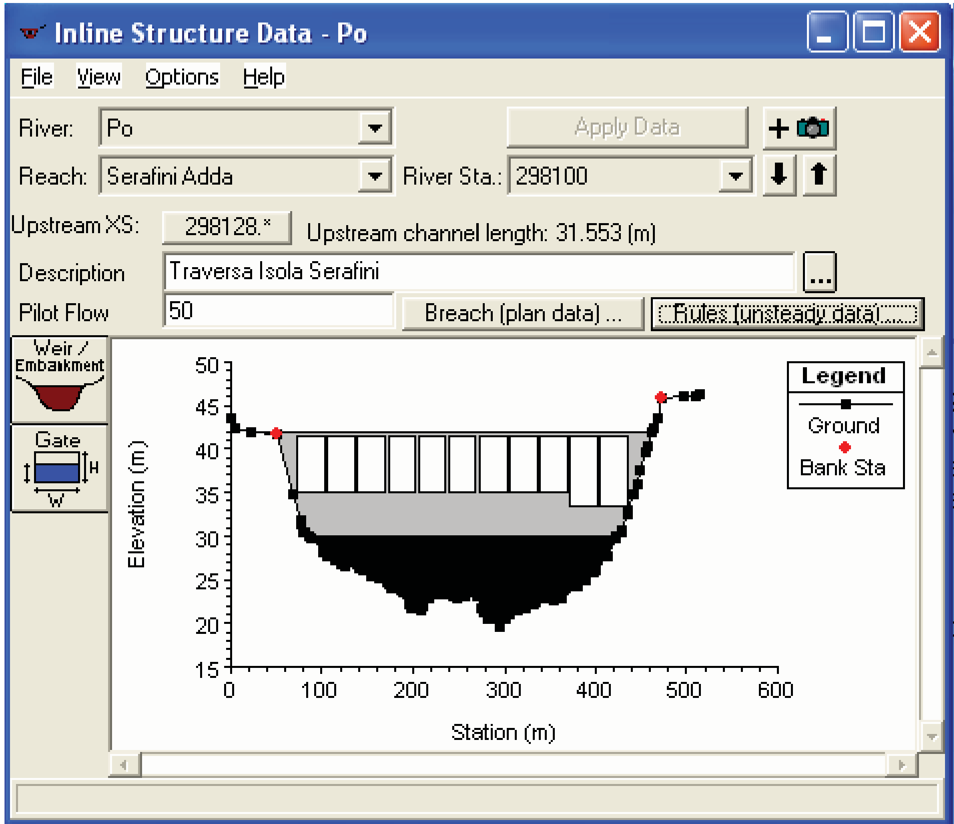






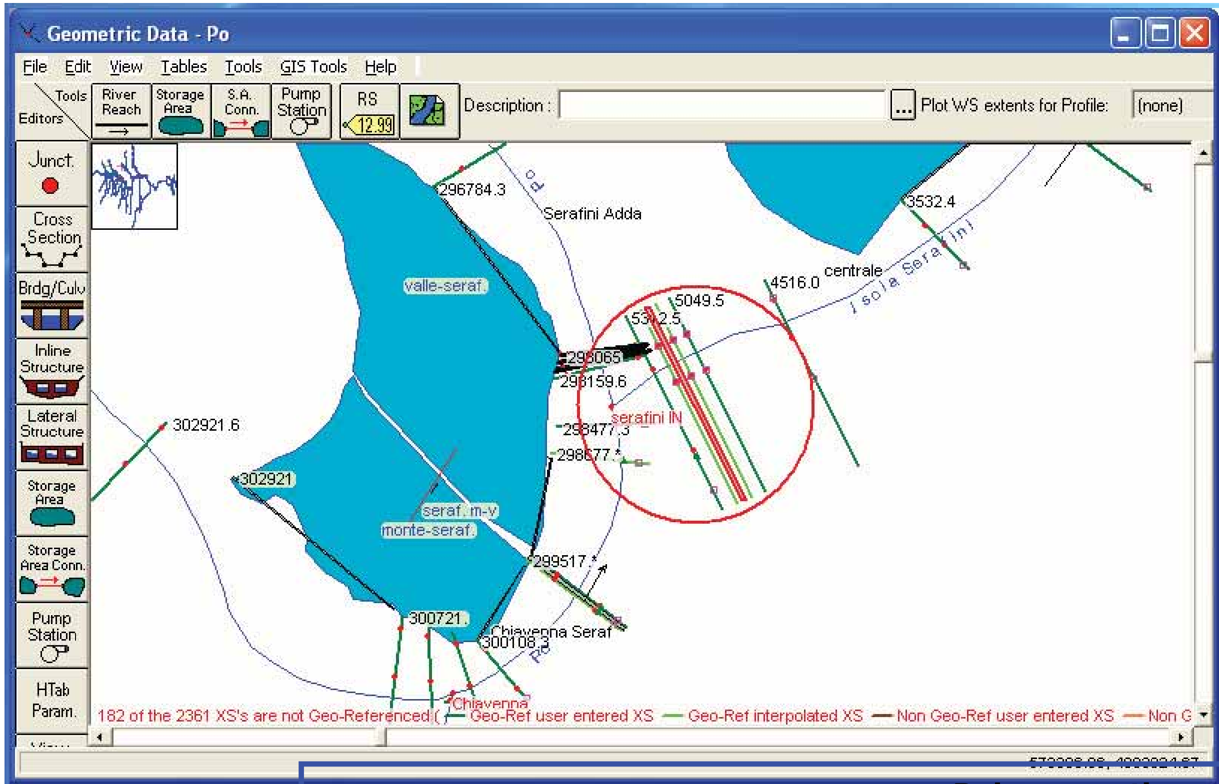
Compound structures analysis in HEC: Isola Serafini hydropower reservoir

Diversion weir in Po river (Isola Serafini)



RULES OPERATION

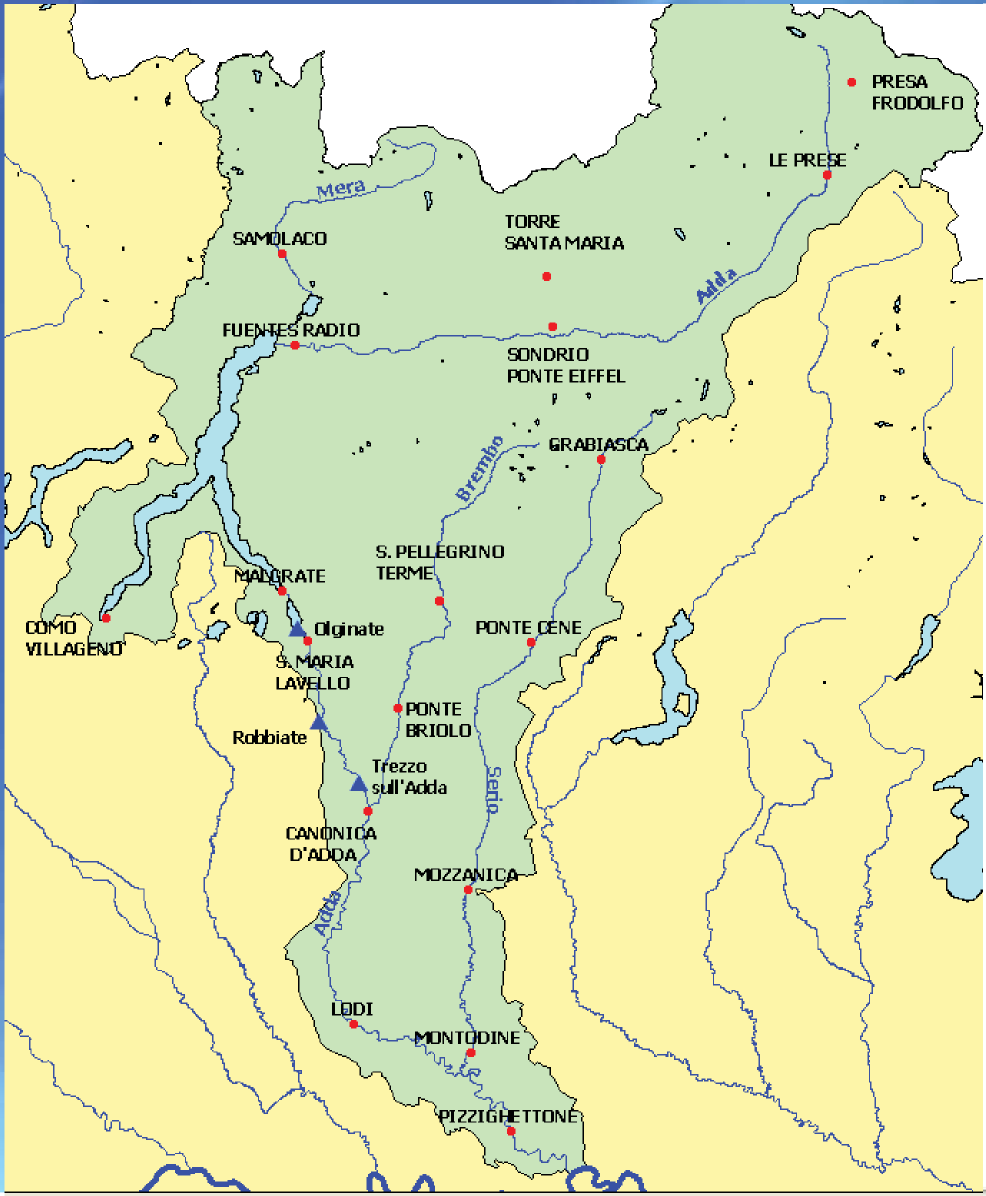
...Elevation(Po,Serafini Adda,298159.6,Value at previous time step)
...s:Flow(Po,Trebbia Nure,327408.5,Value at previous time step)
...ening(Po,Serafini Adda,298100,Gate #1,Value at previous time step)
...ening(Po,Serafini Adda,298100,Gate #2,Value at previous time step)
...e' > 41.05) And ('livello monte' <= 41.1) Then
Gate.Opening = 1.1 * 'gate-1'
Gate.Opening = 1.1 * 'gate-2'
...onte' > 41.1) And ('livello monte' <= 41.2) Then
Gate.Opening = 1.2 * 'gate-1'
Gate.Opening = 1.2 * 'gate-2'
...seIf ('livello monte' > 41.2) Then
Gate.Opening = 1.5 * 'gate-1'
Gate.Opening = 1.5 * 'gate-2'
End If
If ('livello monte' < 40.95) And ('livello monte' >= 40.9) Then
Gate.Opening = 0.9 * 'gate-1'
Gate.Opening = 0.9 * 'gate-2'
ElseIf ('livello monte' < 40.9) And ('livello monte' >= 40.8) Then
Gate.Opening = 0.8 * 'gate-1'
Gate.Opening = 0.8 * 'gate-2'
ElseIf ('livello monte' < 40.8) Then
Gate.Opening = 0.7 * 'gate-1'
Gate.Opening = 0.7 * 'gate-2'
End If
If ('portata monte' > 5500) Then
Gate.Opening = 8
Gate.Opening = 6.5
End If

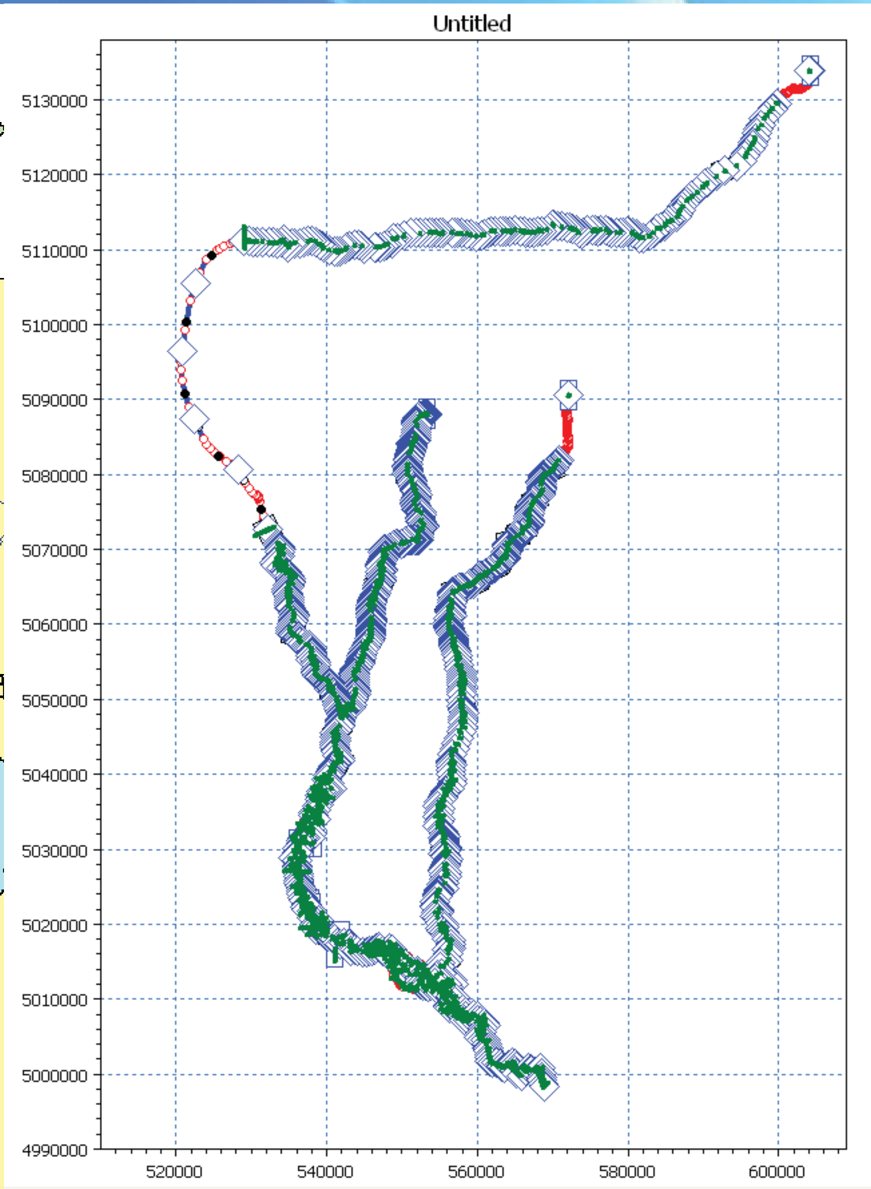


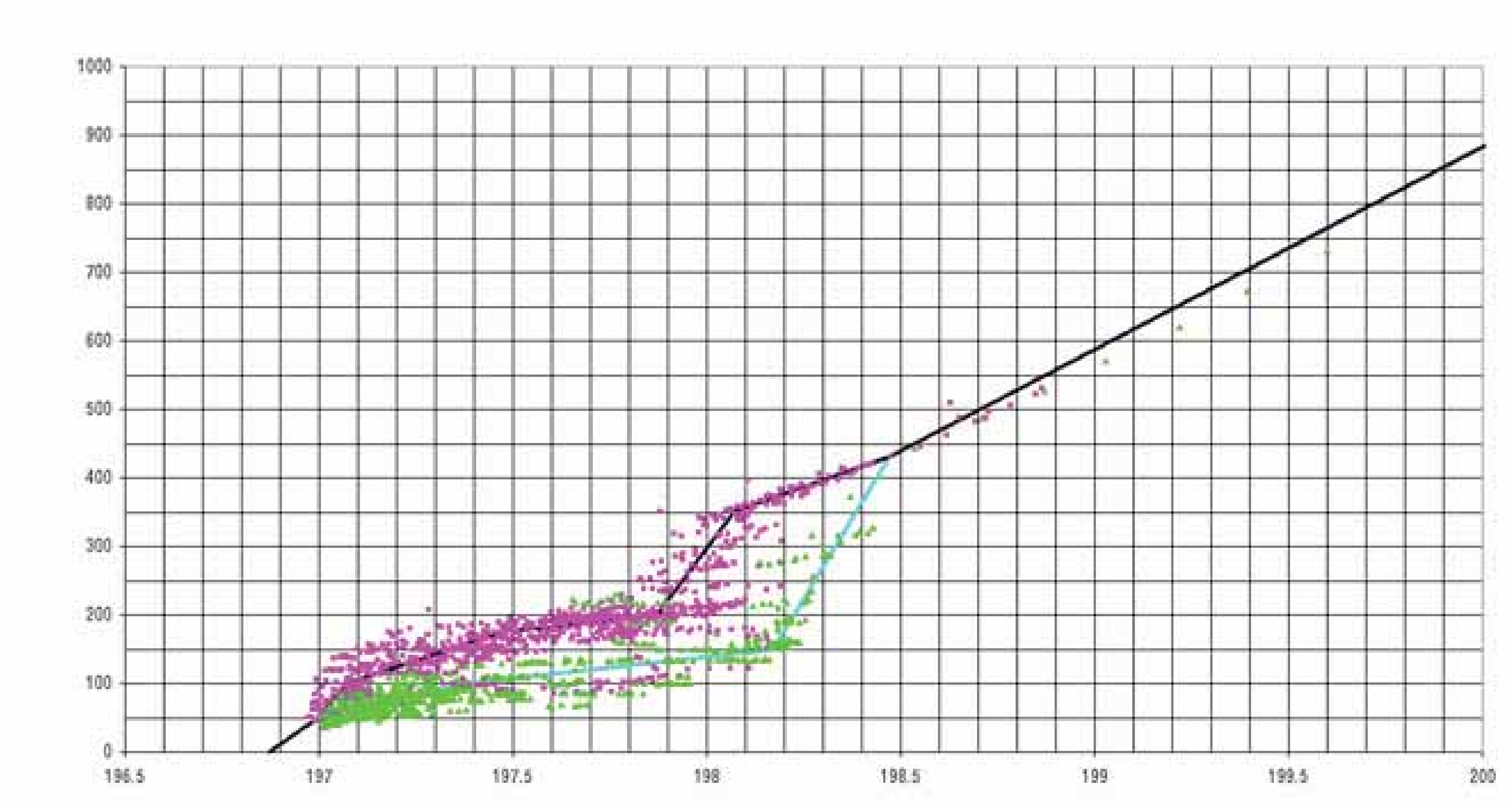
Rules operations

'portata monte' = Cross Sections:Flow(Po,Trebbia Nure,327408.5,Value at current time step)
'struttura old' = Inline Structures:Structure.Total Flow(Isola Serafini,centrale,5200,Value at previous time step)
If ('portata monte' < 1100) Then
Structure.Total Flow (Fixed) = 0.9 * 'portata monte'
Else
Structure.Total Flow (Fixed) = 1000
End If
If ('portata monte' > 3000) And ('portata monte' <= 3400) Then
Structure.Total Flow (Fixed) = 750
ElseIf ('portata monte' > 3400) And ('portata monte' <= 3800) Then
Structure.Total Flow (Fixed) = 500
ElseIf ('portata monte' > 3800) And ('portata monte' <= 4200) Then
Structure.Total Flow (Fixed) = 250
ElseIf ('portata monte' > 4500) Then
Structure.Total Flow (Fixed) = 10
End If1

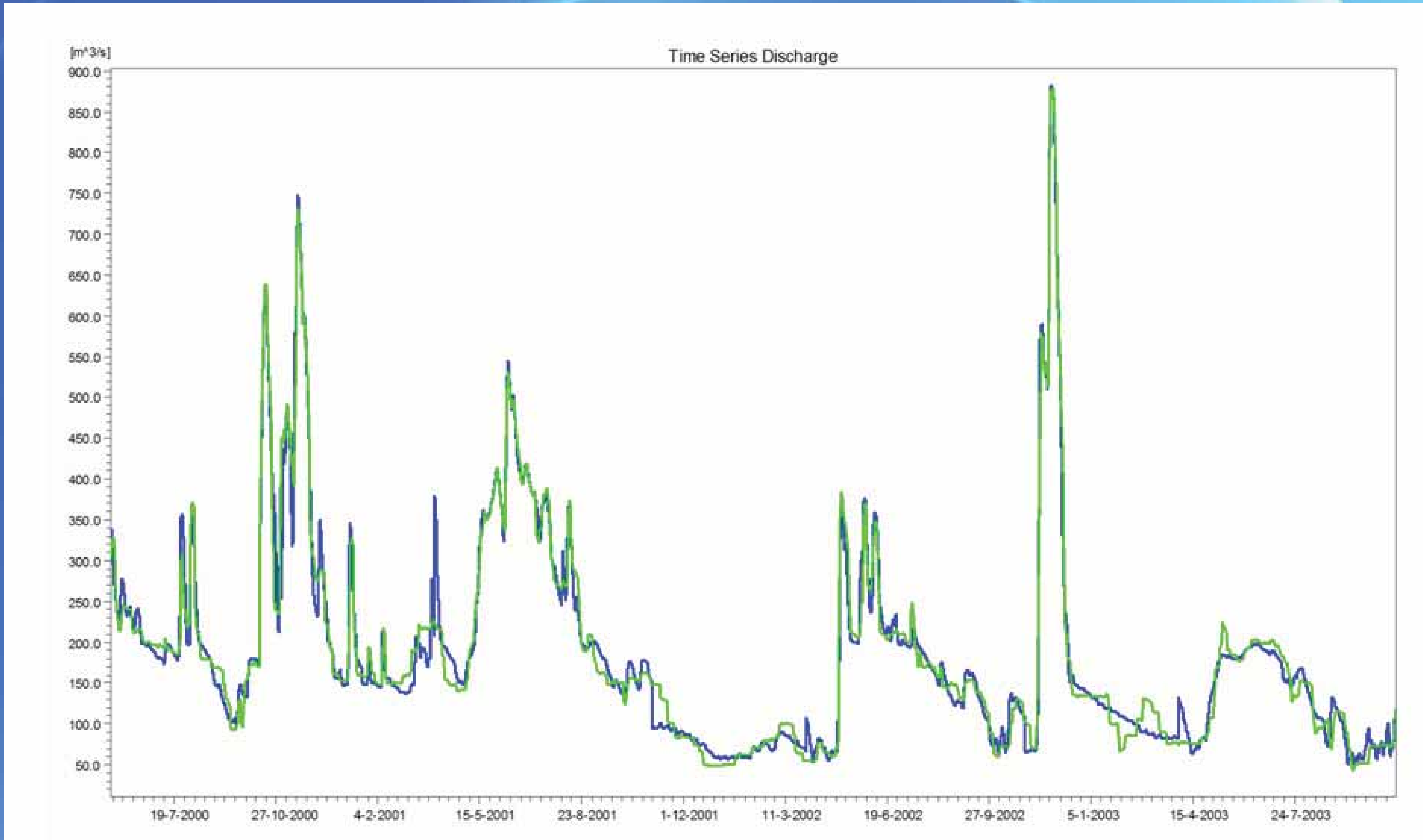
Mike model implemented on Adda and Como Lake







Water level and discharge at the downstream section of Como lake and relations used in the numerical model.



Data comparison between the observed outflow of the Lake – daily mean (green line) and the modelled outflow (blue line)

ADDA – Sub basins

Subbasins

Presa Frodolfo

Le Prese

Torre Santa Maria

Sondrio

Fuentes

Samolaco

ComoVilla Geno

Santa Maria Lavello

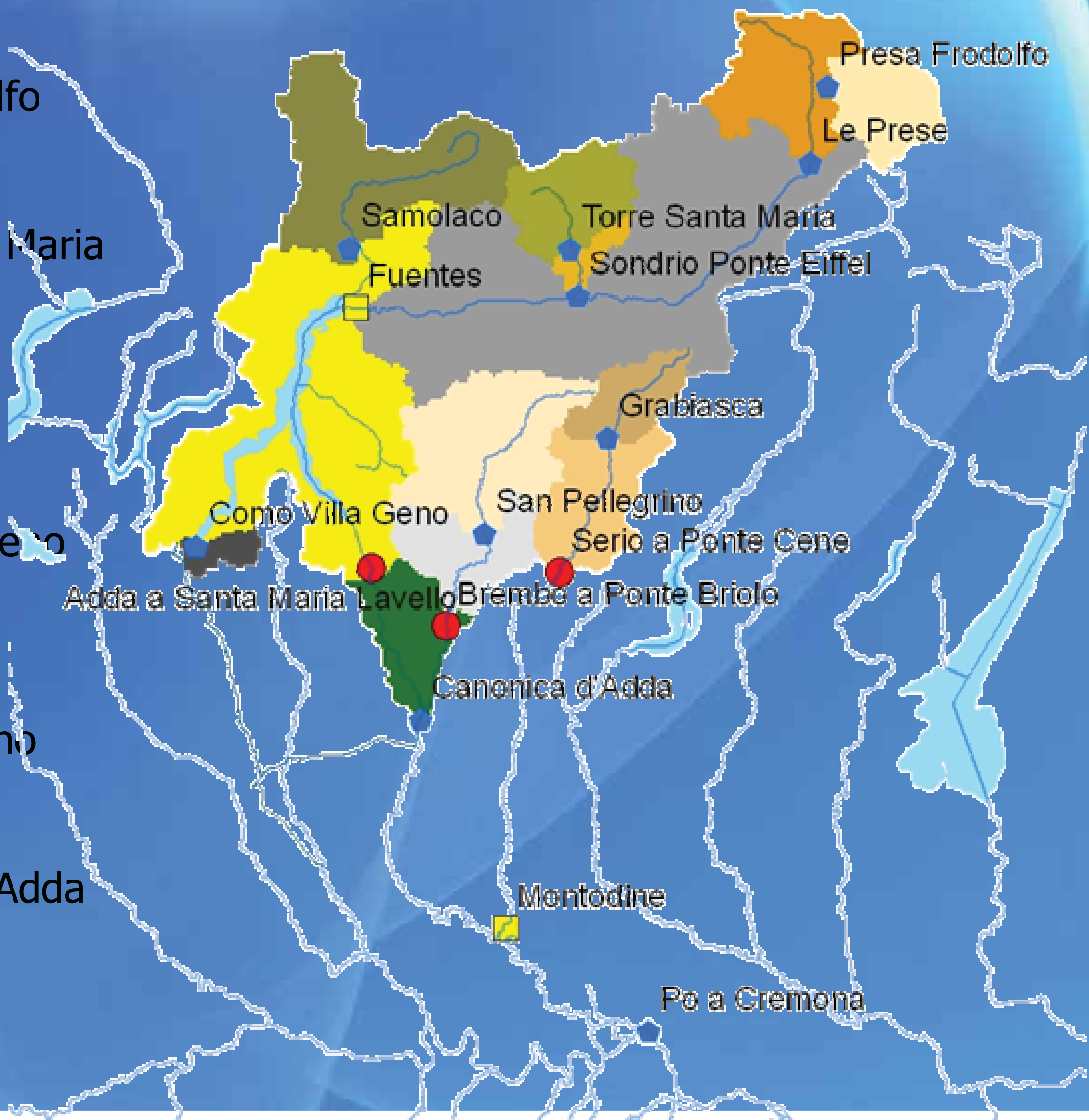
San Pellegrino

Ponte Briolo

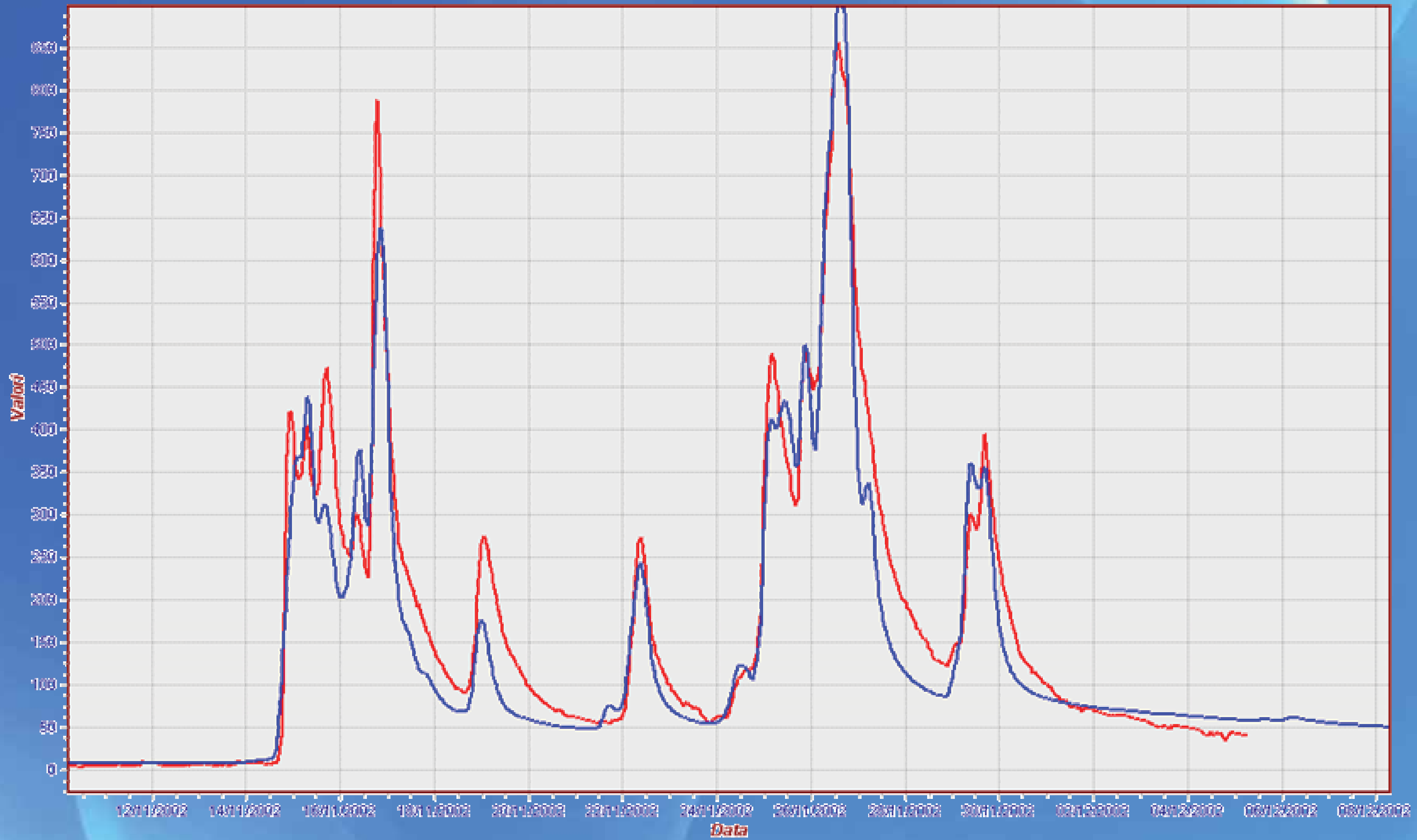
Canonica D'Adda

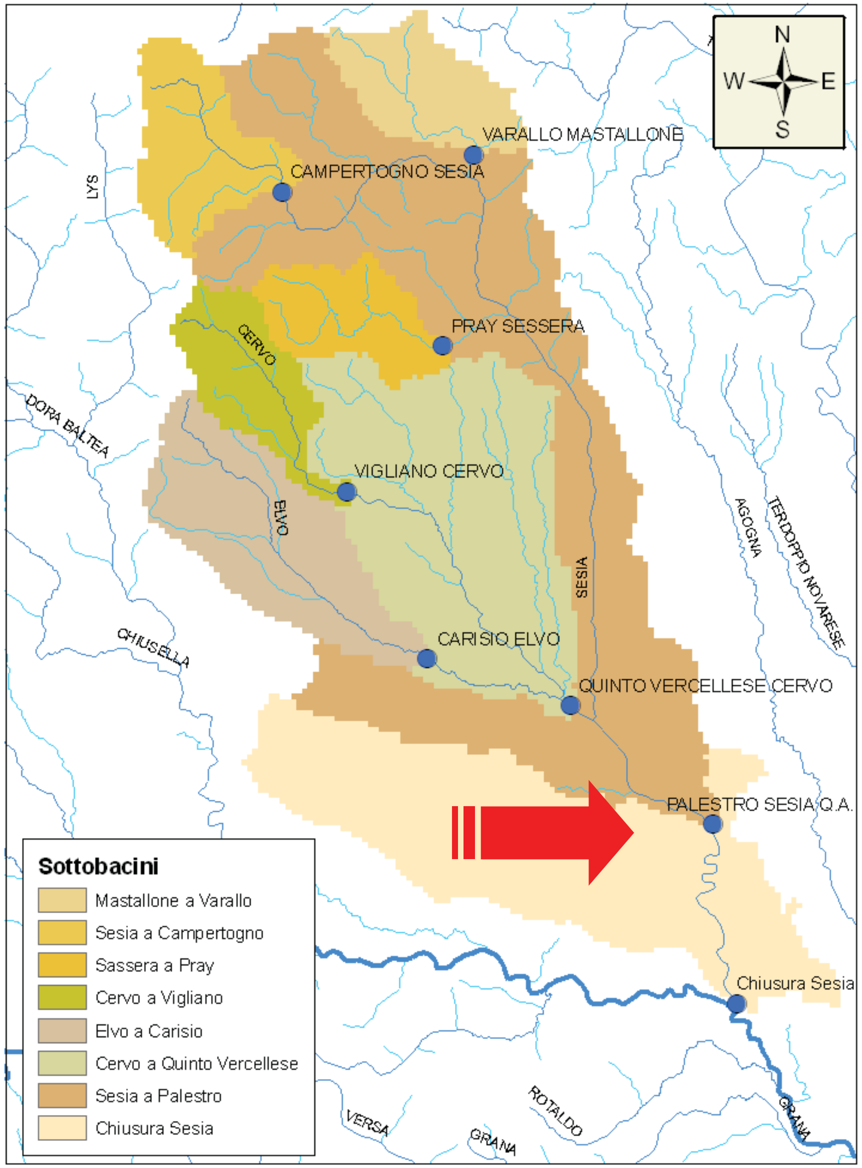
Grabiasca

Ponte Cene

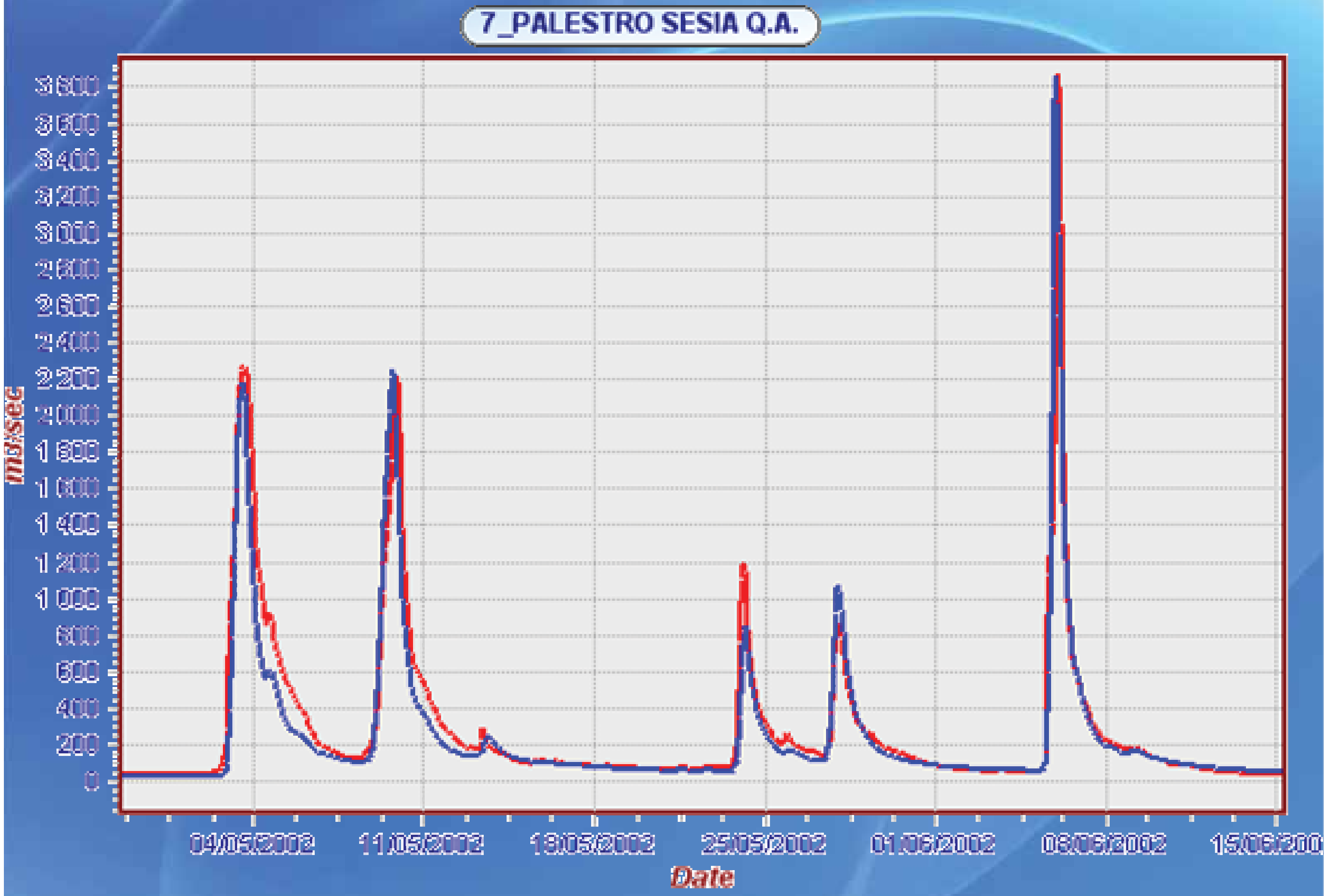


Example of discharge reconstruction at Ponte Briolo



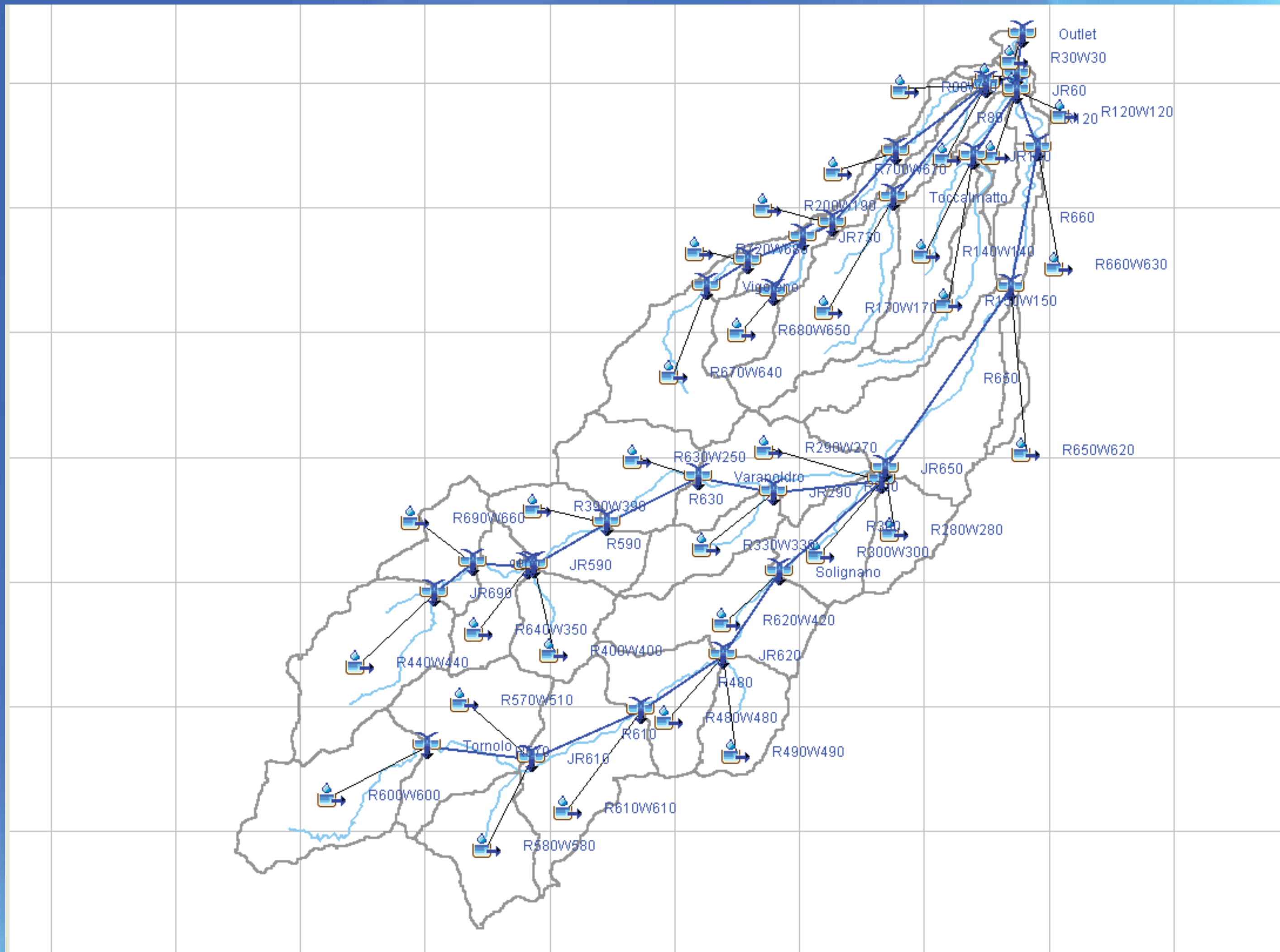


Sesia calibration at Palestro: year 2002

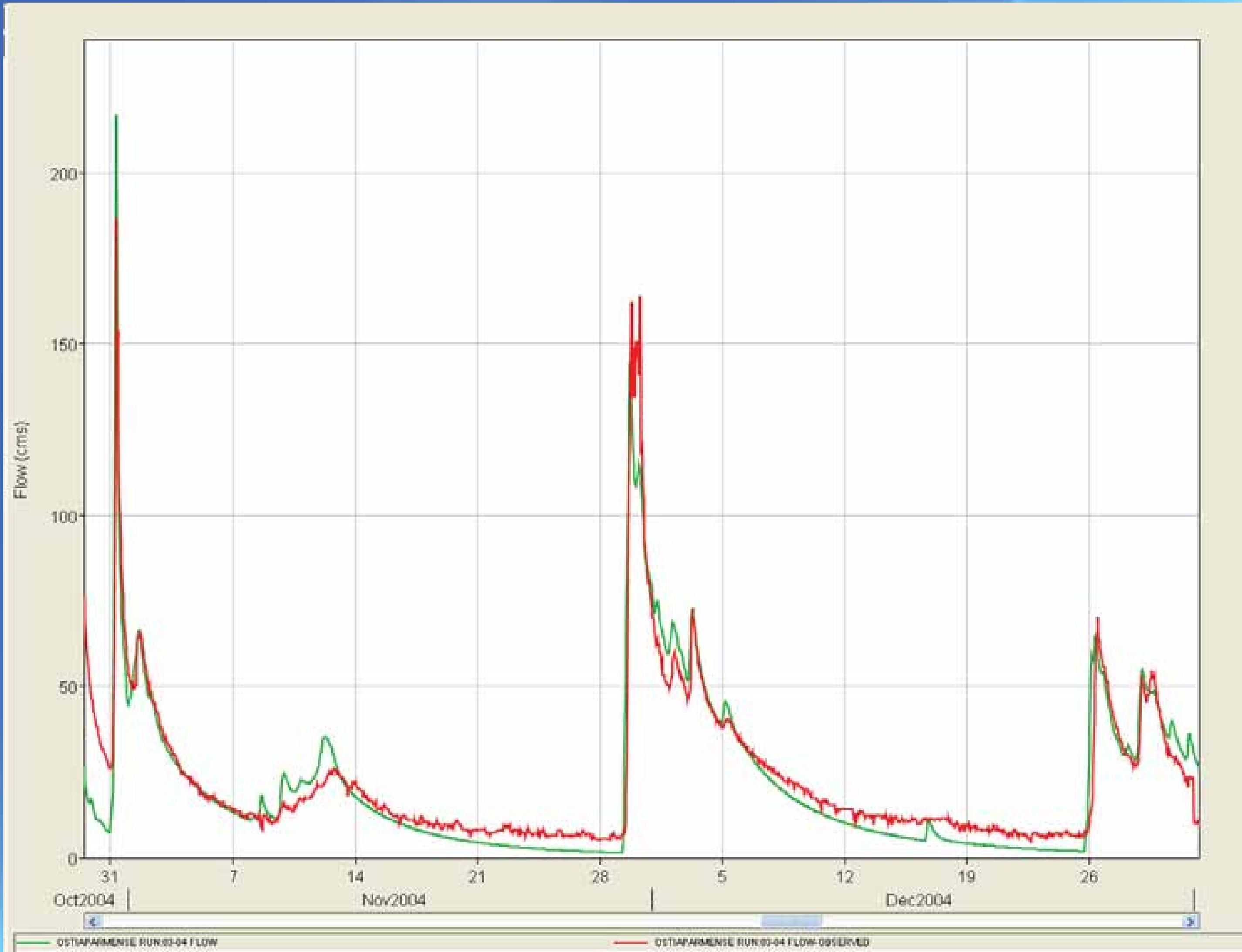


Palestro - E2 01/05/2002 - 17/06/2002	
Q_{max} Osservata [m^3/s]	3865.22
Q_{max} Calcolata [m^3/s]	3854.91
Shift [h]	2
MAE	65.26
RMSE	155.78
R2	0.95
EV	0.89
E	0.89
VC	0.75
CMM	0.94
d	0.97
N.Dati	1151

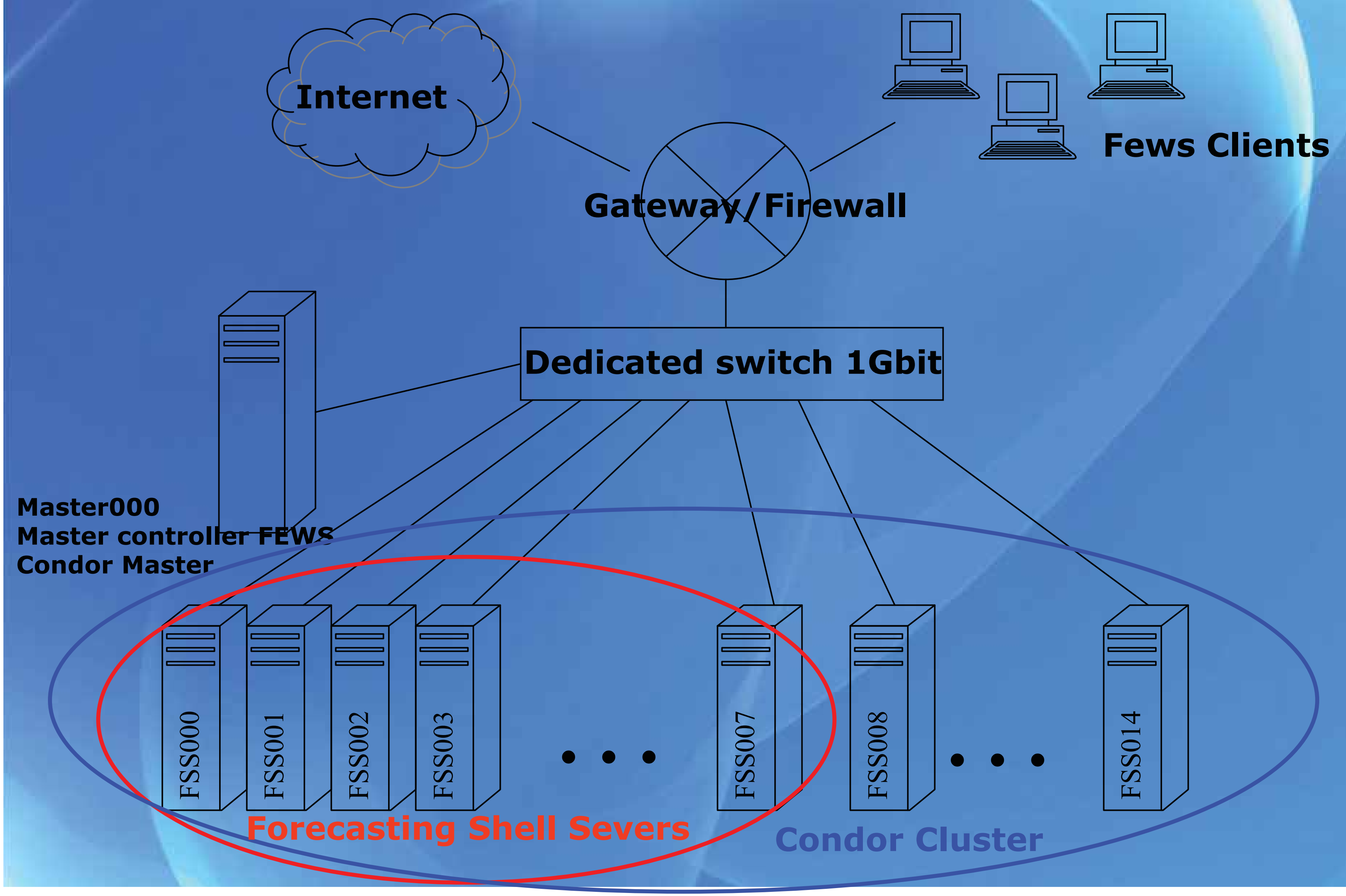
HEC model – Taro basin



HEC Calibration - Taro at Ostia Parmense



The FEWSPo System

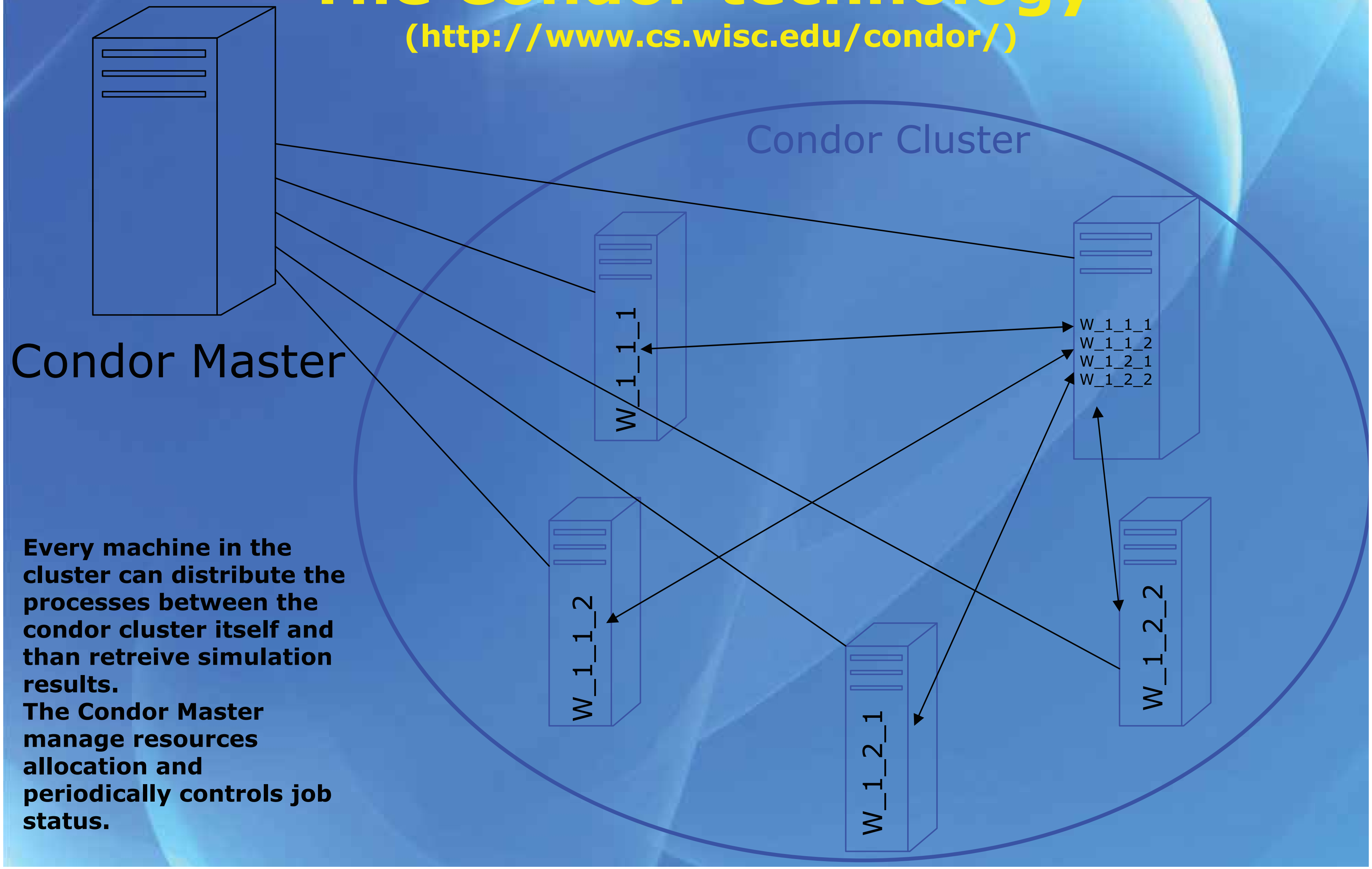


The FEWSPo System: HARDWARE

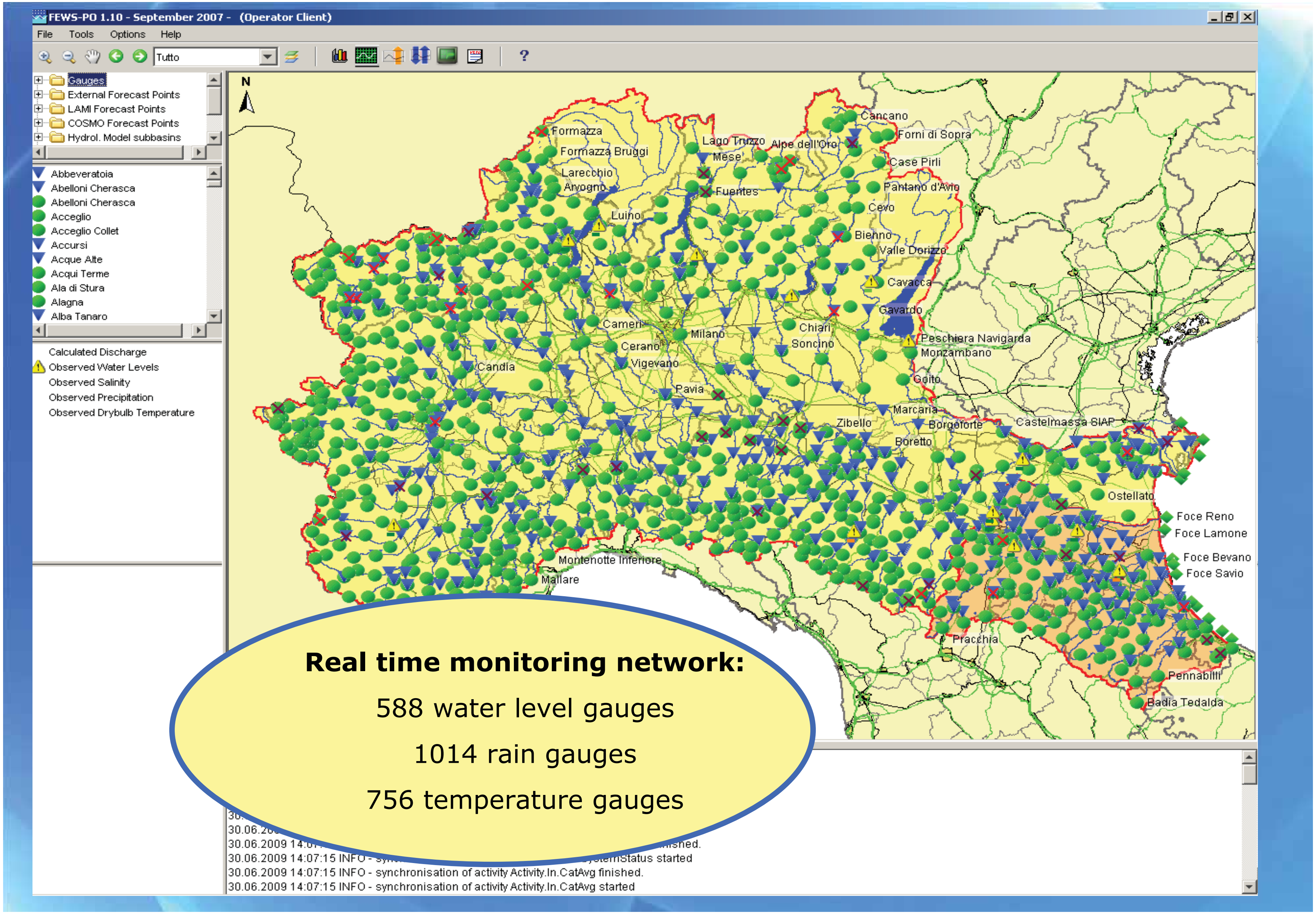
16 Servers (multi processor – 4 GB ram each)

A total of more than 140 CPU cores
3 TB Storage (> 10 yrs)

The Condor technology
(http://www.cs.wisc.edu/condor/)



Every machine in the cluster can distribute the processes between the condor cluster itself and than retreive simulation results.
The Condor Master manage resources allocation and periodically controls job status.



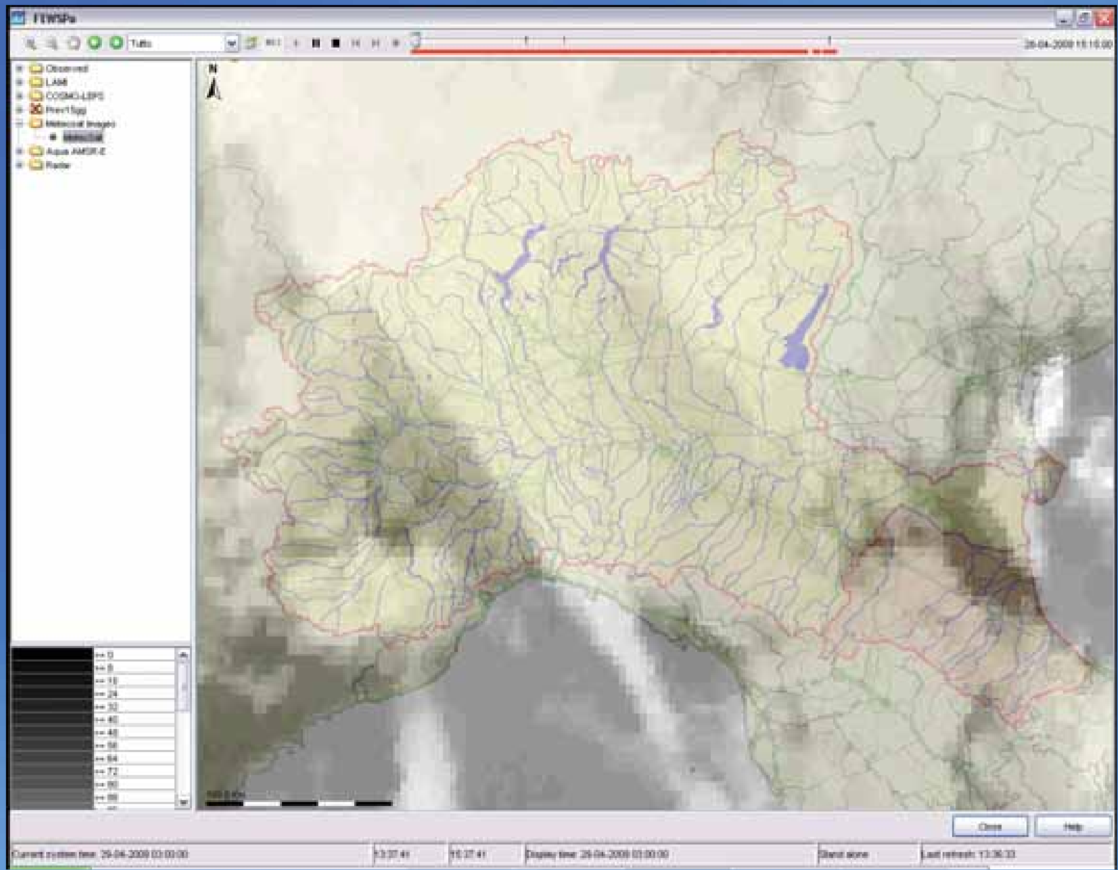
Real time monitoring network:

588 water level gauges

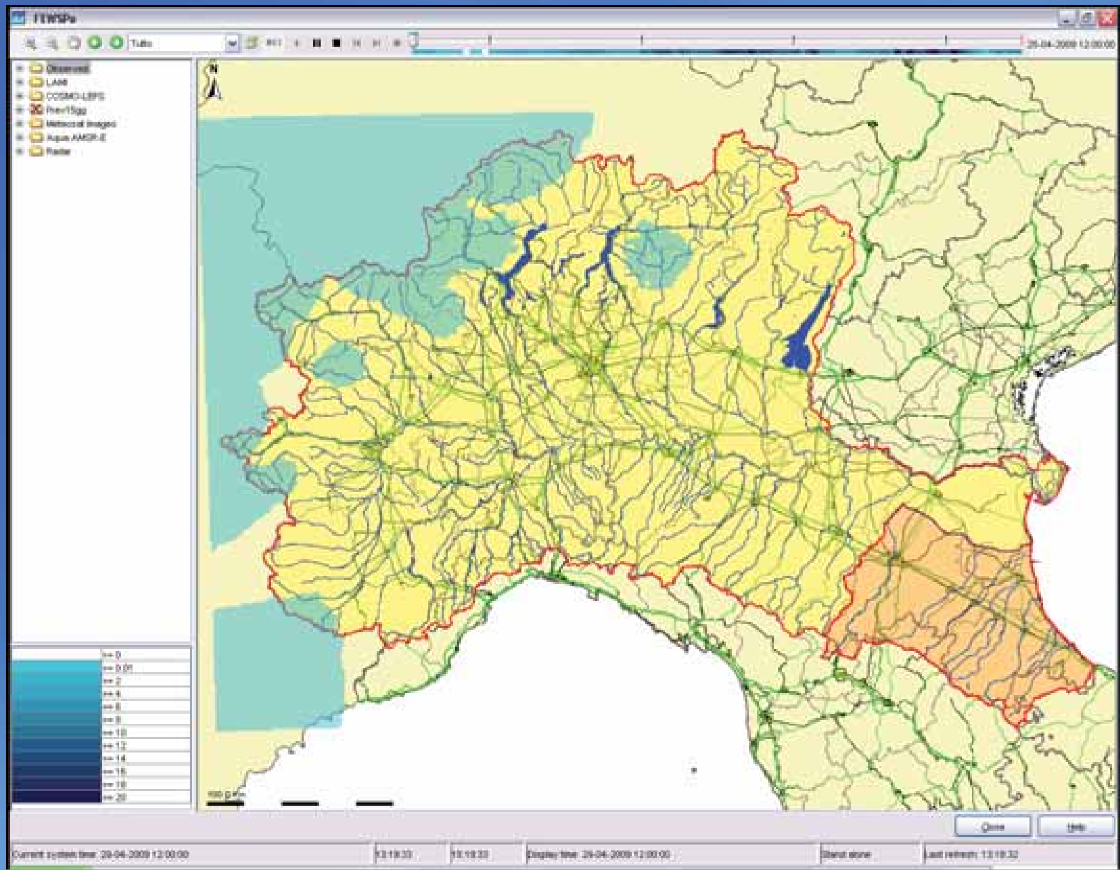
1014 rain gauges

756 temperature gauges

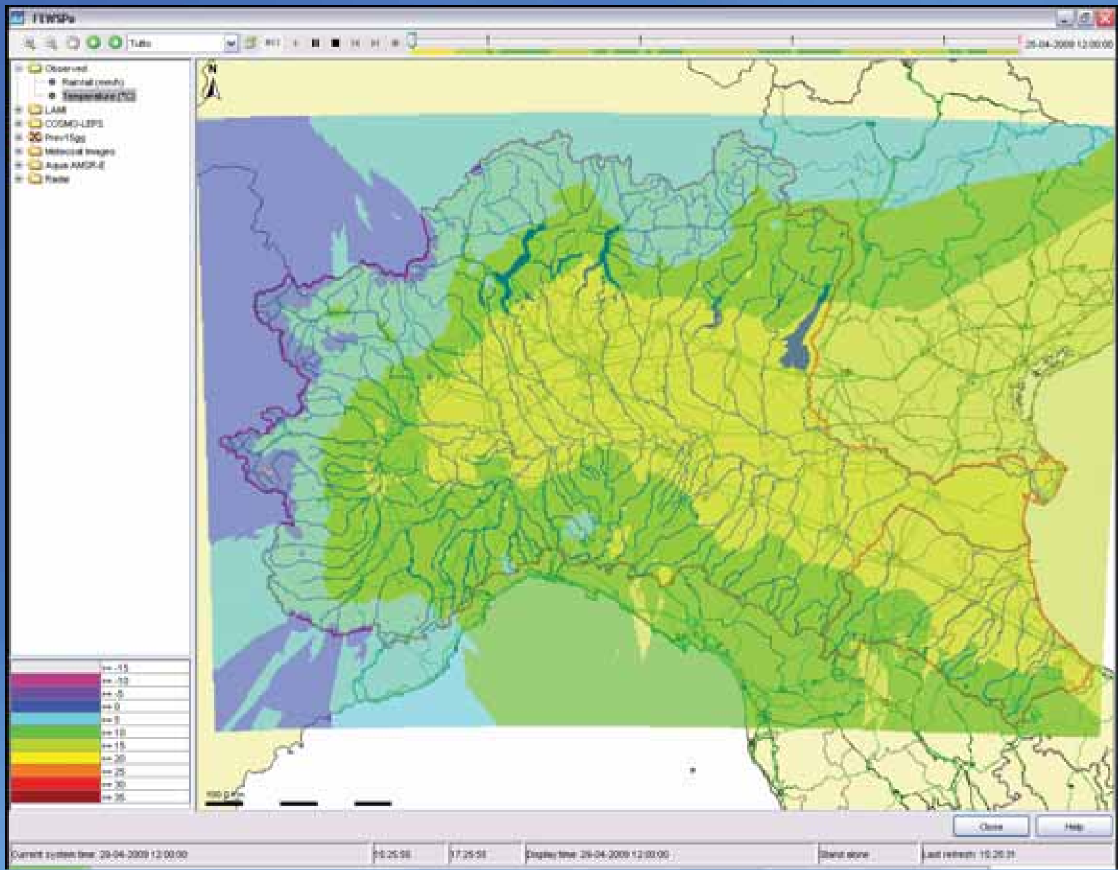
PO RIVER FLOOD EVENT IN APRIL 2009



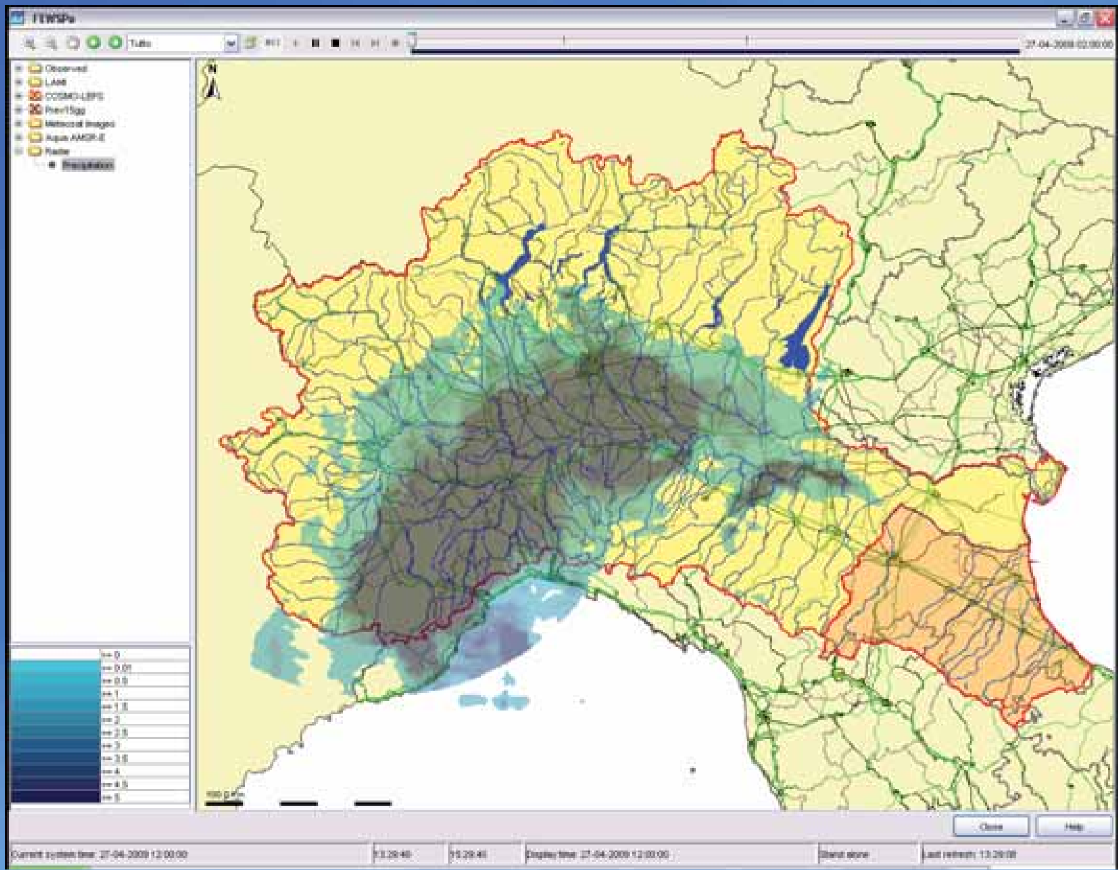
Observed precipitation



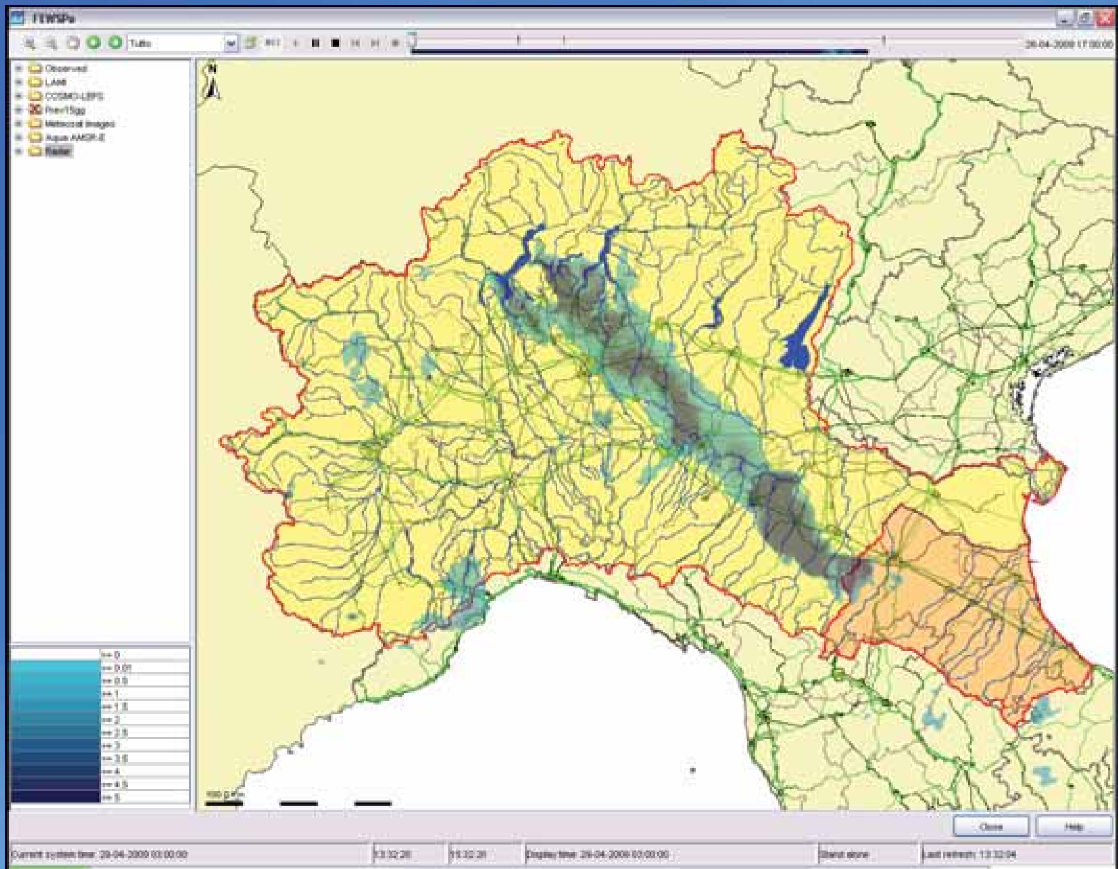
Observed temperature



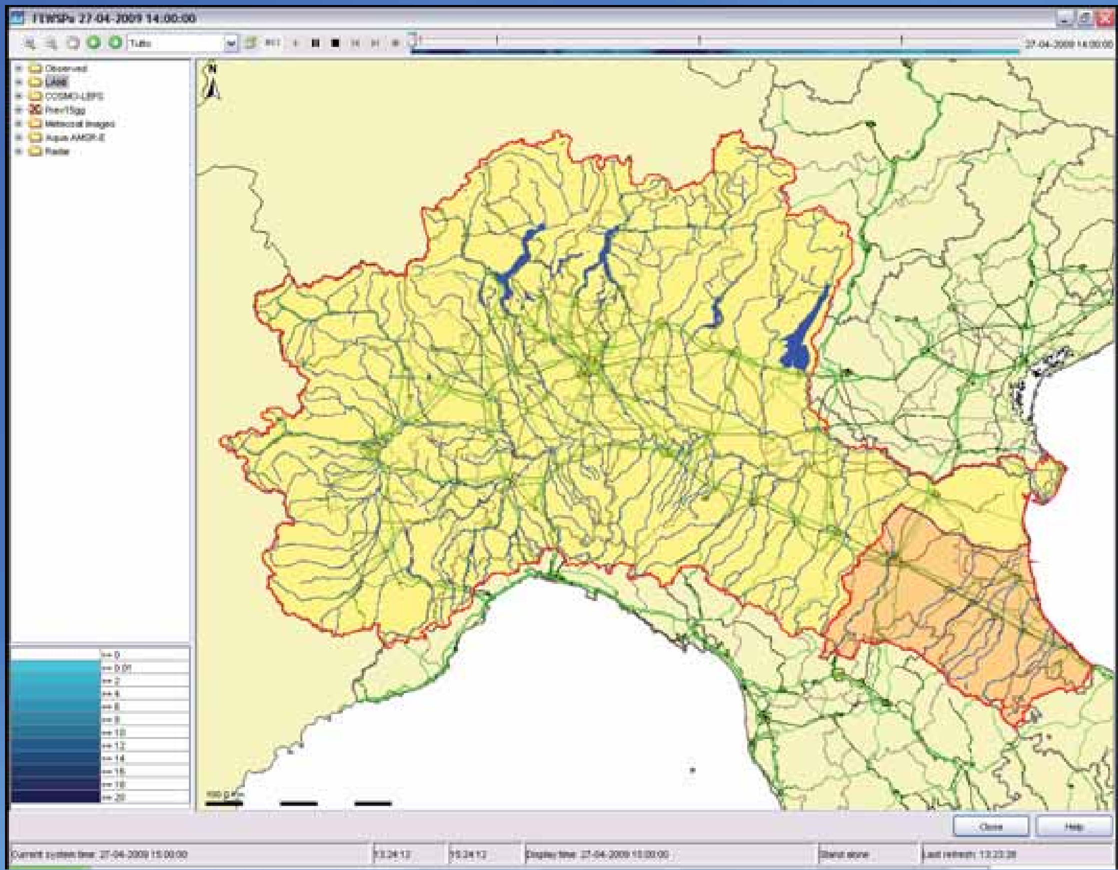
Radar precipitation 1/2



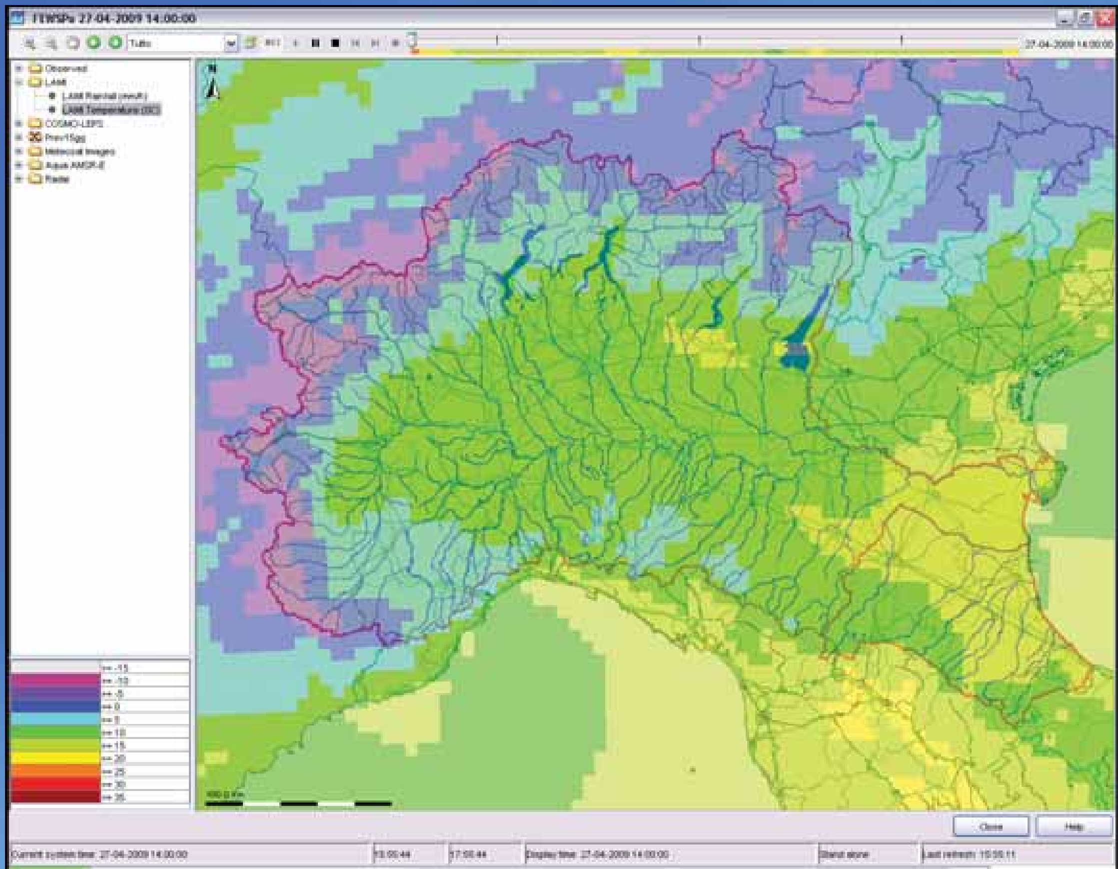
Radar precipitation 2/2



LAMI rainfall forecast

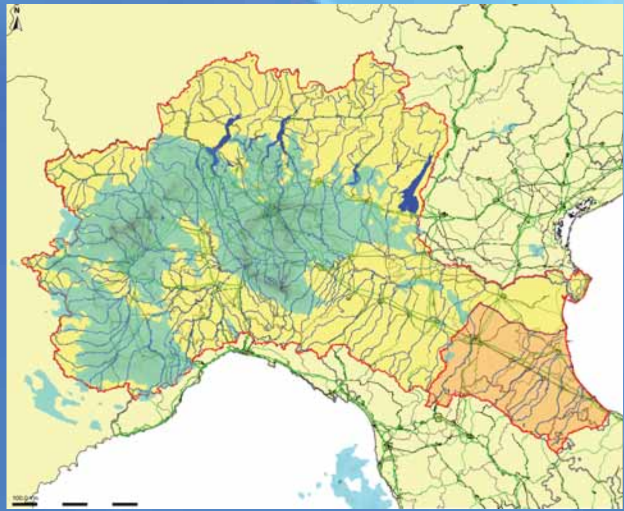


LAMI temperature forecast

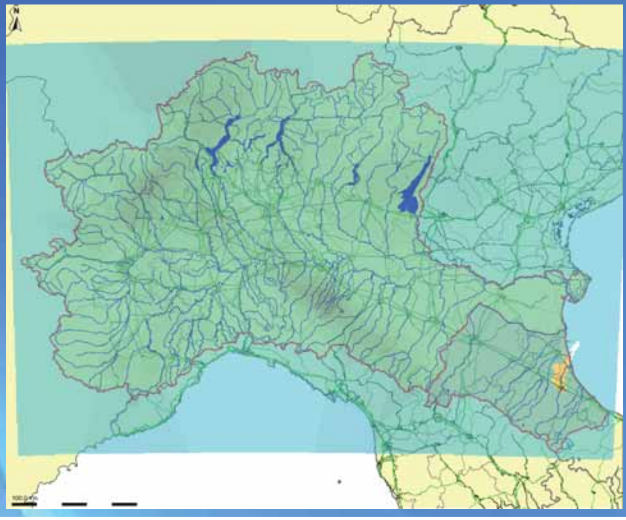


LAMI FORECAST 27 apr h20

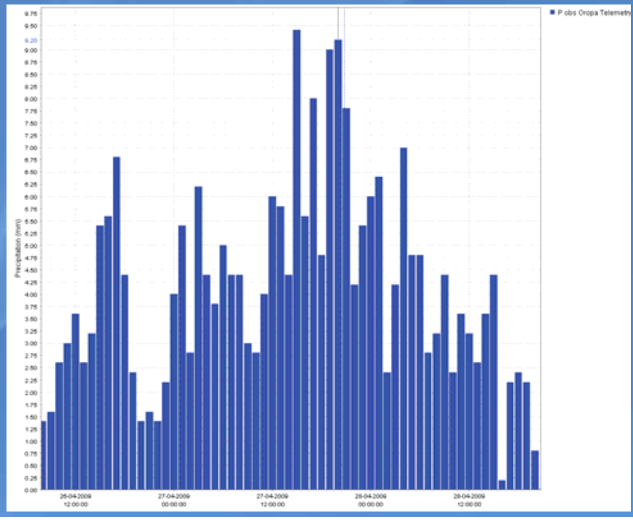
RADAR COMPOSITE MAP 27 apr h20



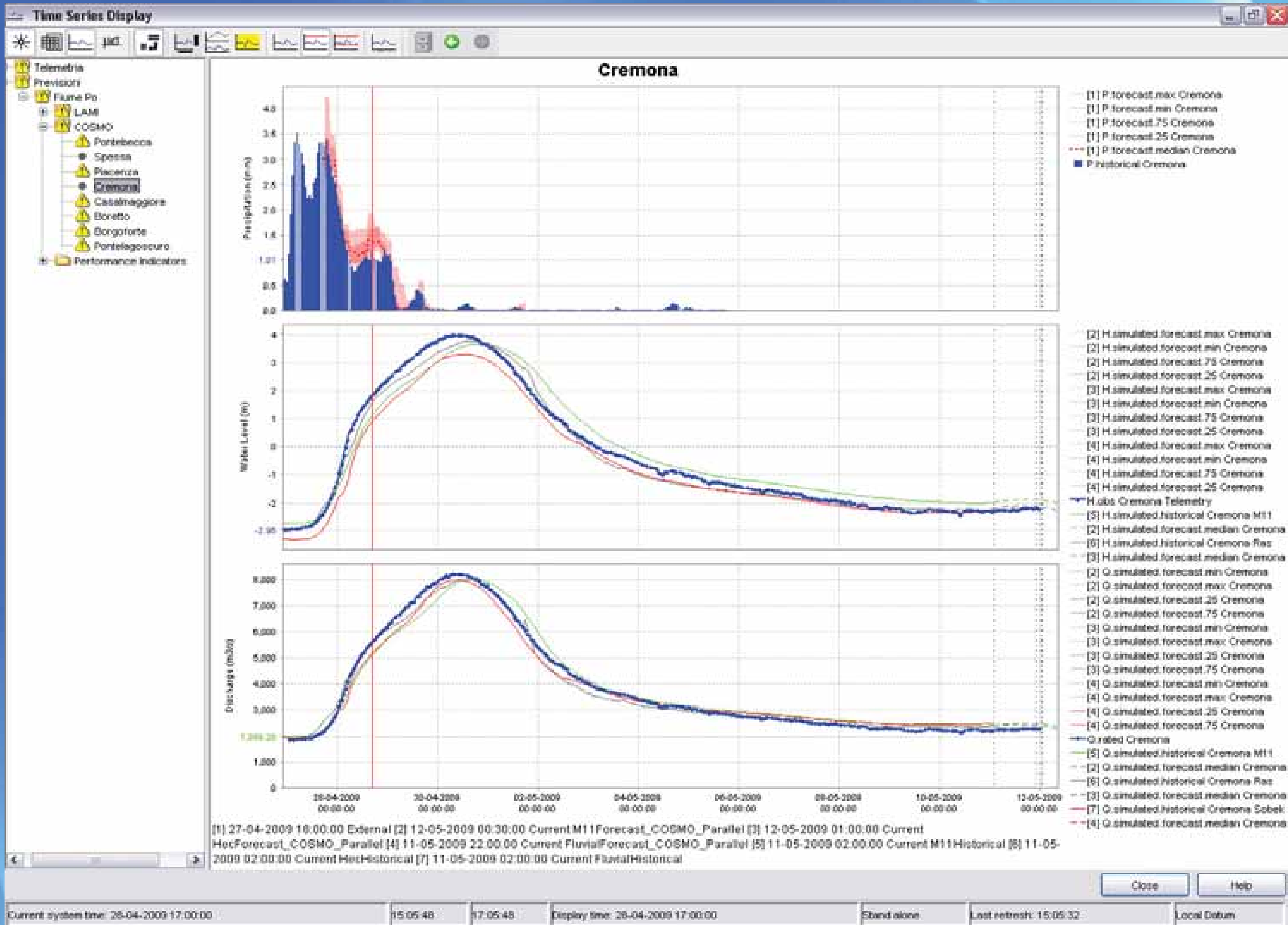
SPATIAL INTERPOLATION BASED ON OBSERVATIONS 27 apr h20



RAINFALL OROPA (PIEMONTE) 27 apr h20

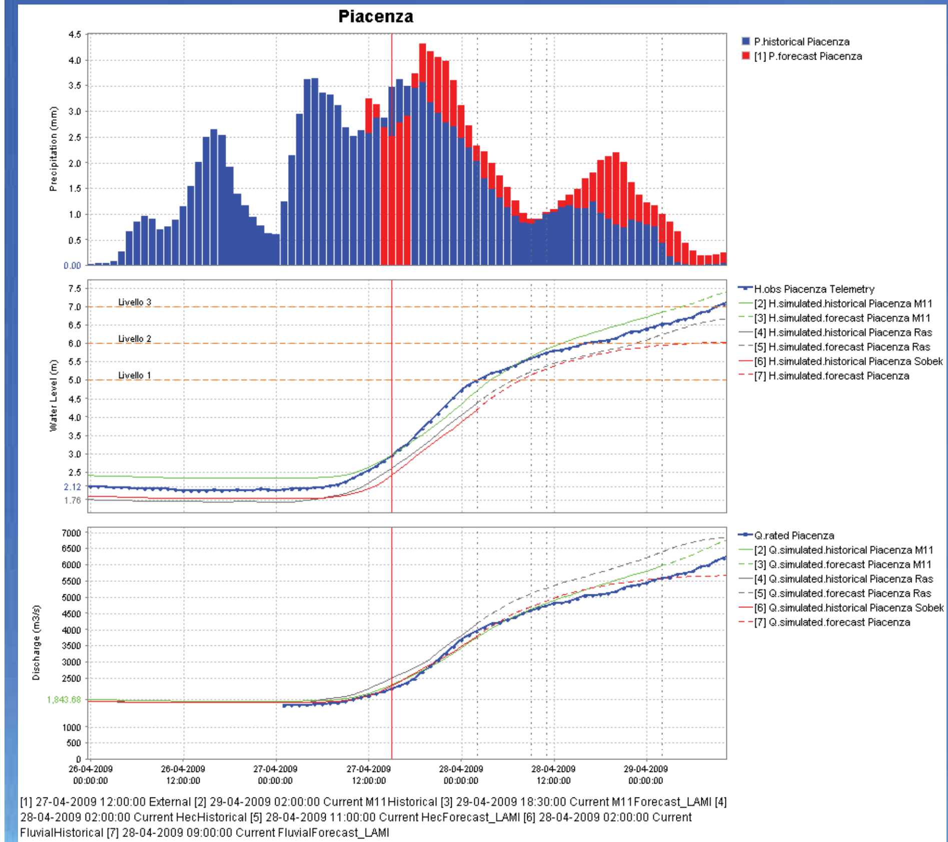


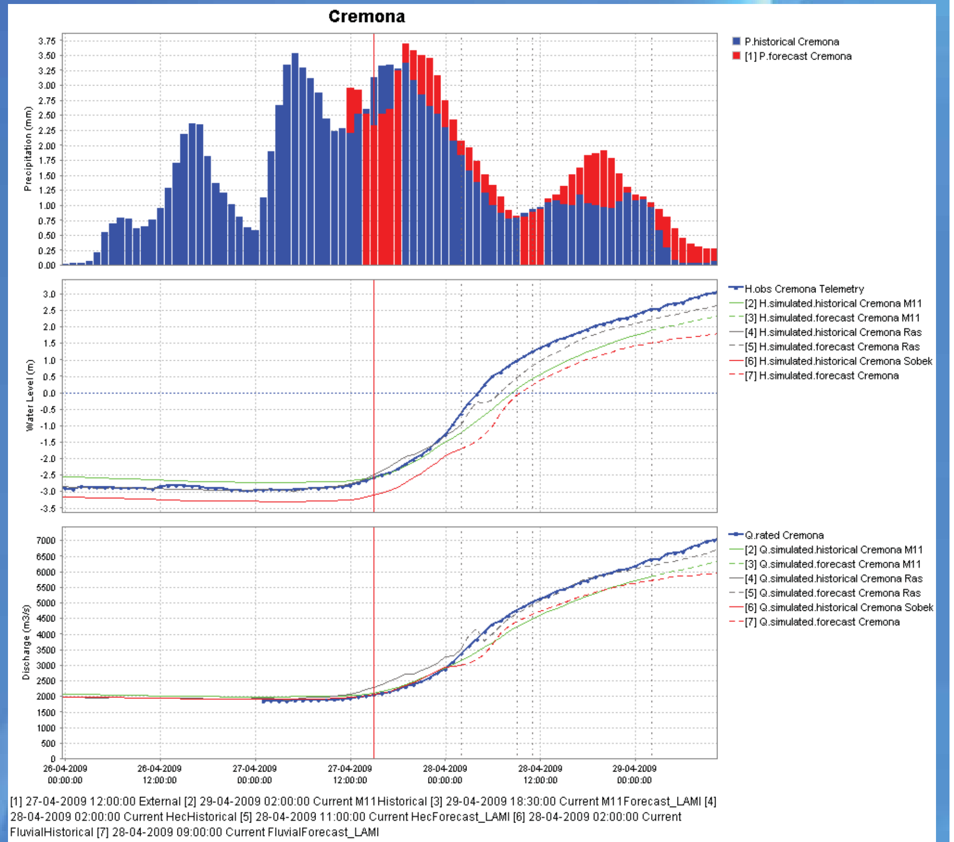
Shortcuts



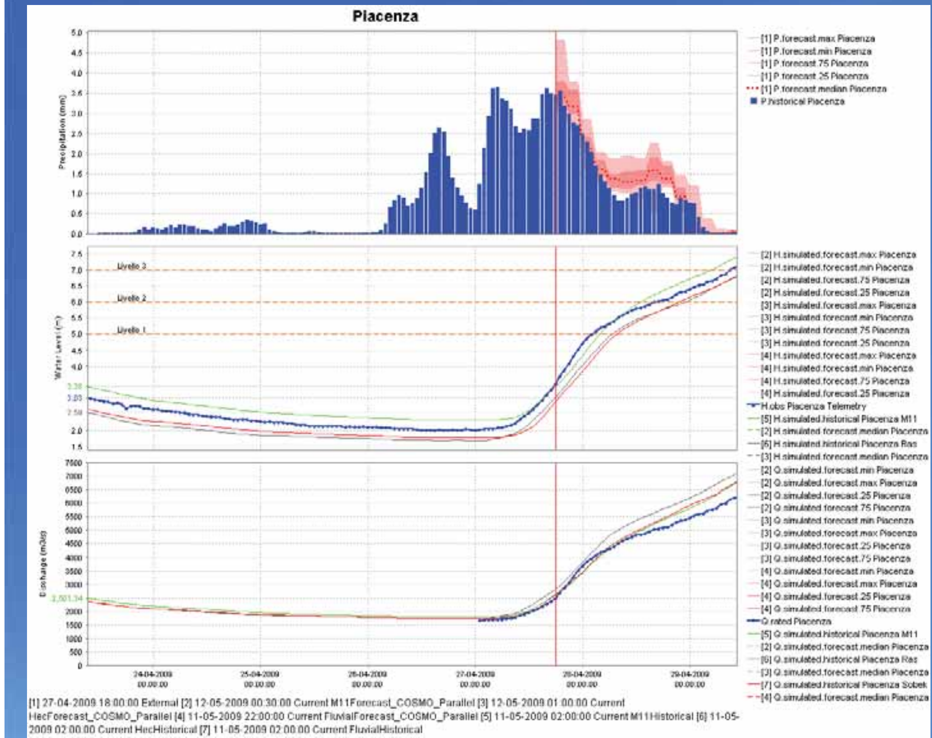
Time Series Display
Telemetria
Previsioni
Fiume Po
LAMI
COSMO
Pontebecca
Spessa
Piacenza
Cremona
Casalmaggiore
Boretto
Borgoforte
Pontelagoscuro
Performance indicators
Cremona
[1] P.forecast.max Cremona
[1] P.forecast.min Cremona
[1] P.forecast.75 Cremona
[1] P.forecast.25 Cremona
[1] P.forecast.median Cremona
P.historical Cremona
H.obs Cremona Telemetry
Q.rated Cremona
[1] 27-04-2009 18:00:00 External [2] 12-05-2009 00:30:00 Current M11Forecast_COSMO_Parallel [3] 12-05-2009 01:00:00 Current HecForecast_COSMO_Parallel [4] 11-05-2009 22:00:00 Current FluvialForecast_COSMO_Parallel [5] 11-05-2009 02:00:00 Current M11Historical [6] 11-05-2009 02:00:00 Current HecHistorical [7] 11-05-2009 02:00:00 Current FluvialHistorical
Close
Help
Current system time: 28-04-2009 17:00:00
Display time: 28-04-2009 17:00:00
Stand alone
Last refresh: 15:05:32
Local Datum

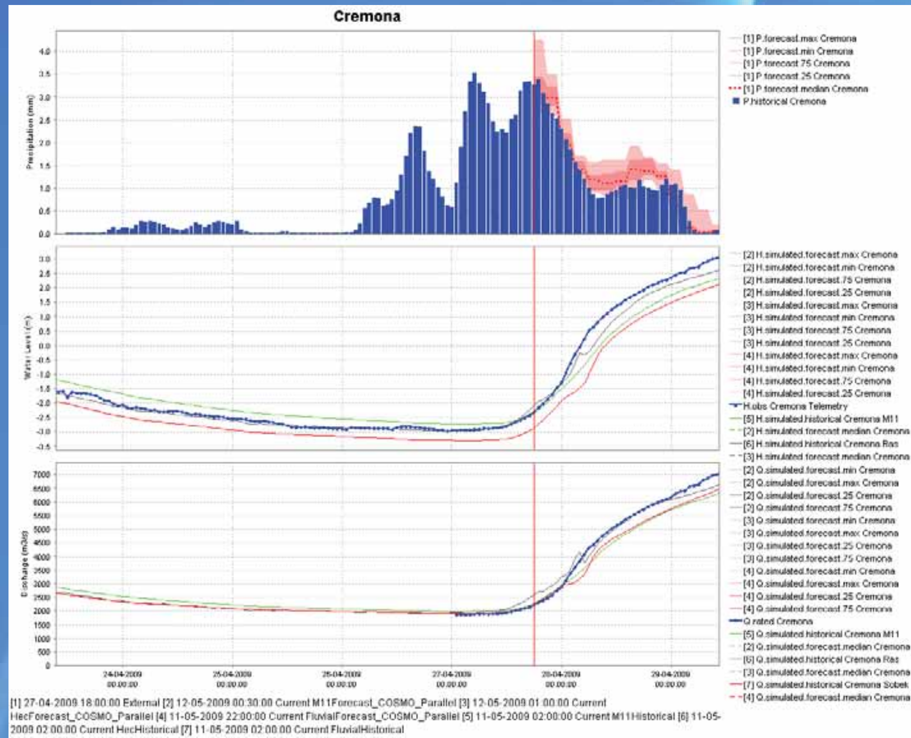
LAMI mean areal rainfall





COSMO mean areal rainfall





POST-ELABORATION:

PREDICTIVE UNCERTAINTY

How to use in the best way measures and models to improve reliability and efficiency of operational decisions

DECISION MAKING UNDER UNCERTAINTY

In many operational problems, such as

- Flood warning;
- Flood emergency management;
- Reservoir management;
- Etc.

decision makers must take important decisions under the uncertainty of future events.

THE DEFINITION OF PREDICTIVE UNCERTAINTY

Predictive Uncertainty can be defined as the probability of occurrence of a future value of a predictand (such as water level, discharge or water volume) conditional on :

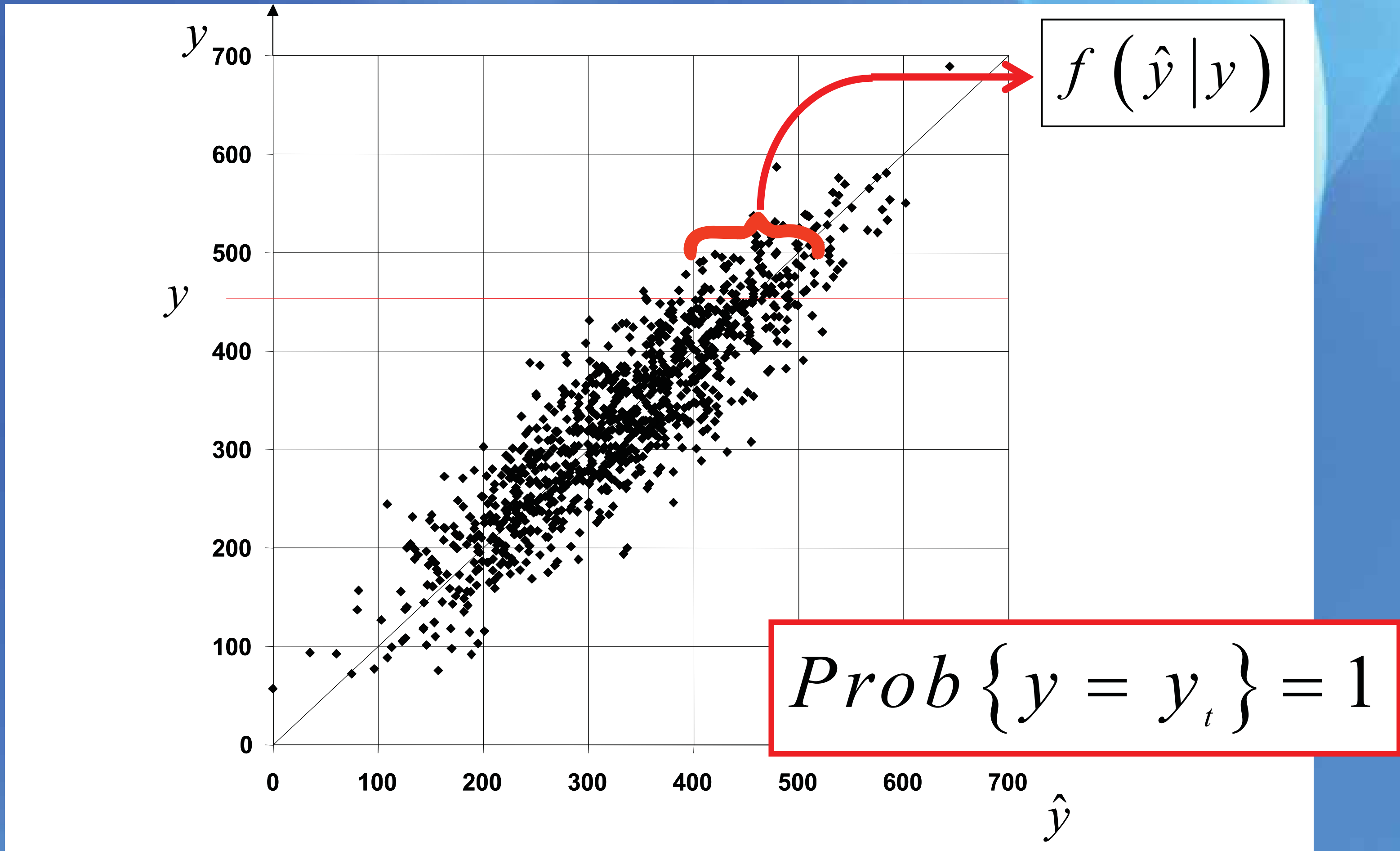
1) prior observations and knowledge
2) all the information that can be obtained on the future value, which is typically embodied in one or more meteorological, hydrological and hydraulic model forecasts.

THE DEFINITION OF PREDICTIVE UNCERTAINTY

PU is obviously the uncertainty that we have on the occurrence of a real future value, as for instance the water level in 12 hours from now.

This must not be confused with "Emulation Uncertainty".

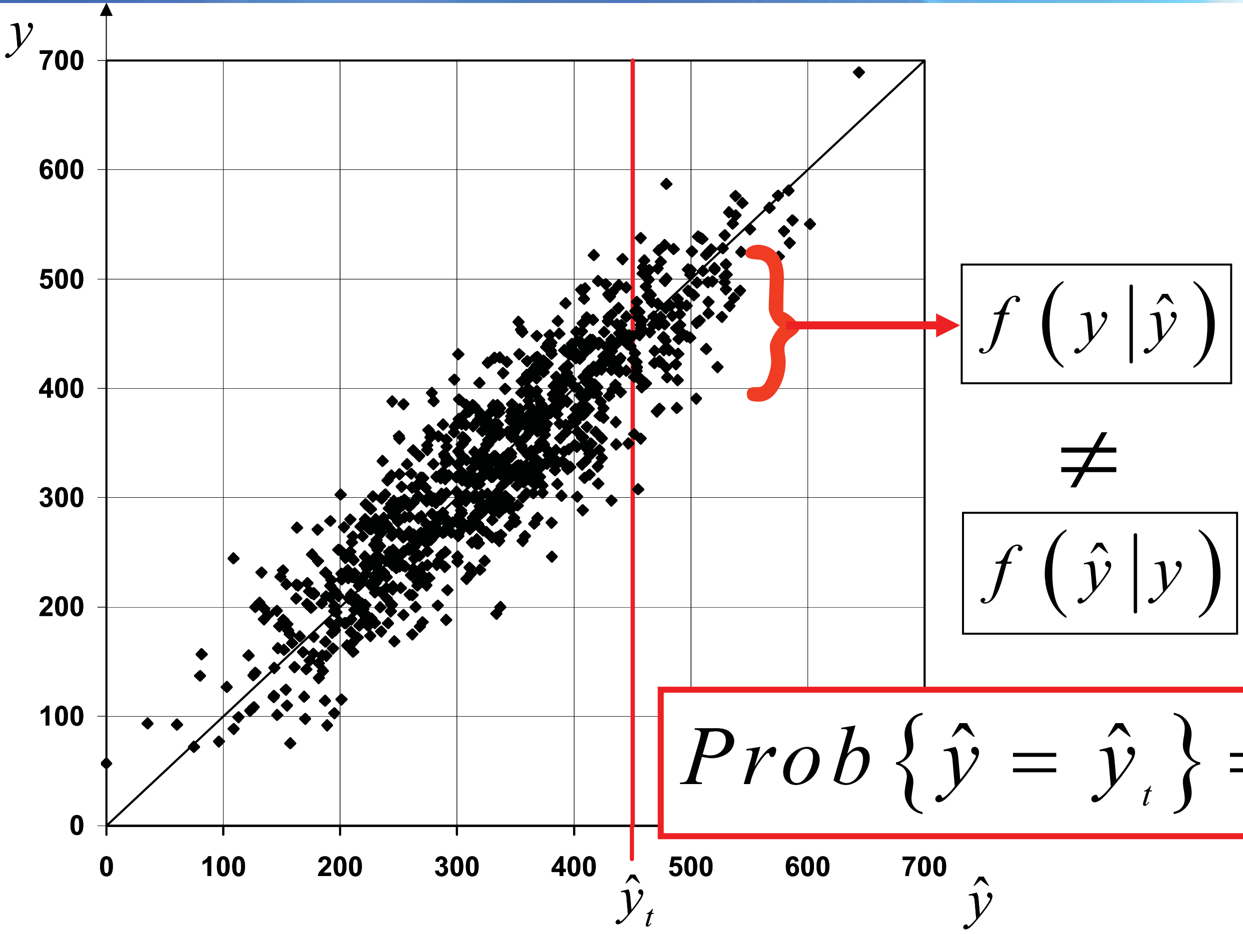
Representation of Emulation Uncertainty



y Predictand

$\hat{y}$ Model

Representation of Predictive Uncertainty



$$Prob\{\hat{y} = \hat{y}_t\} = 1$$

y Predictand

$\hat{y}$ Model

MODEL AND PARAMETER UNCERTAINTY

Anyway, presently available experiences show that marginalising parameters uncertainty, although statistically correct, does not produce substantial differences from using a best fit parameter set.

This is mostly due to the fact that the nearly best parameters produce predictions that are closely related among them, while the posterior probability, of the worst parameter sests is obviously very low.

MODEL AND PARAMETER UNCERTAINTY

This is why it is more interesting to approach the problem in terms of

few alternative models

of widely different nature.

I.e. a physically based model, a conceptual model and a data driven model.

This has given rise to the development of several multi-model

Predictive Uncertainty Processors.

Available Single or Multi-model Predictive Uncertainty Processors

Hydrological Uncertainty Processor

Krzysztofowicz, 1999; Krzysztofowicz and Kelly, 2000

Bayesian Model Averaging

Raftery et al., 2003;

Model Conditional Processor

Todini, 2008.

………………………

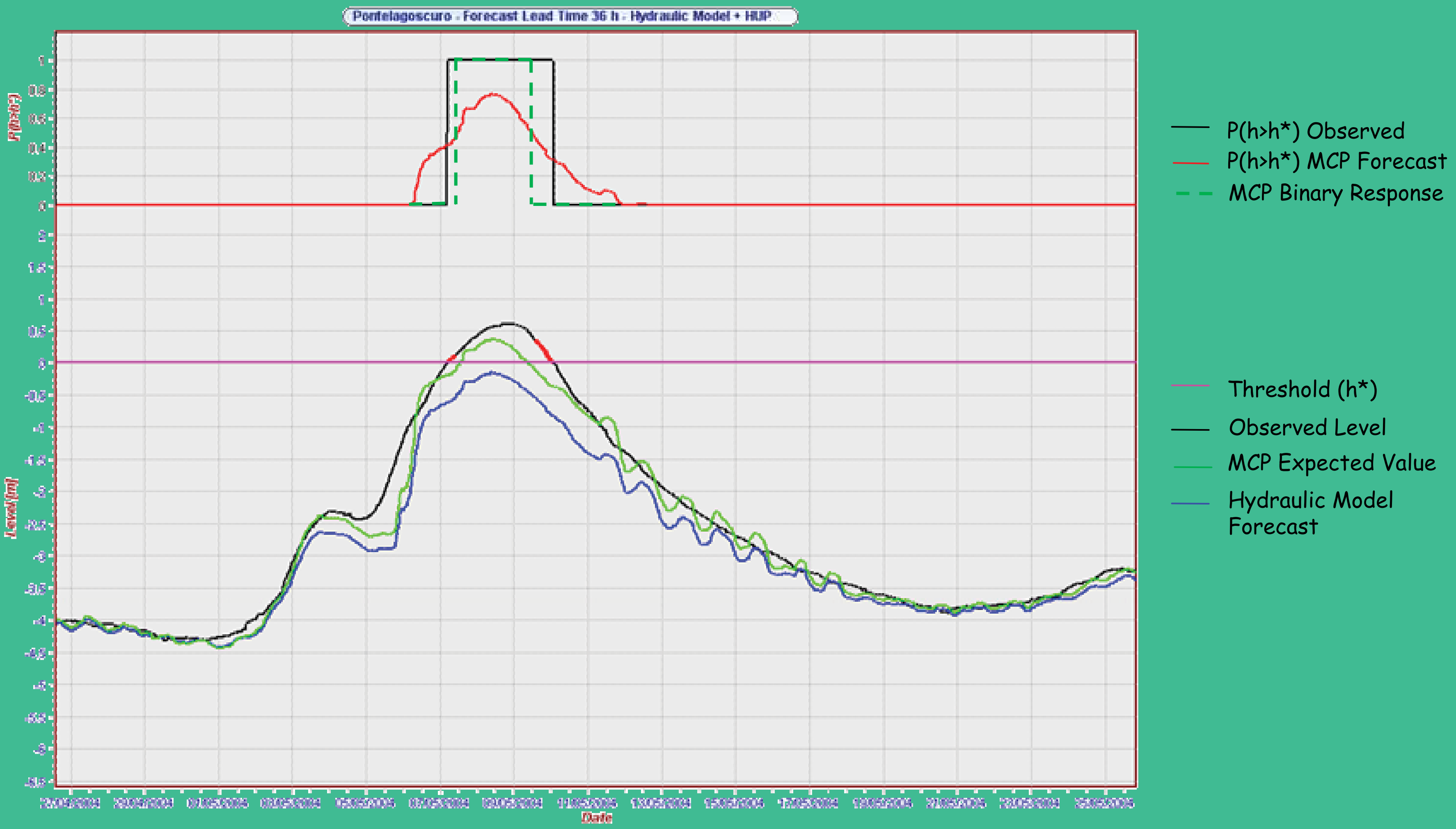
*Krzysztofowicz, R., 1999. Bayesian theory of probabilistic forecasting via deterministic hydrologic model. Water Resour. Res., **35**, 2739–2750.*

Raftery, A. E., F. Balabdaoui, T. Gneiting, and M. Polakowski, 2003. Using Bayesian model averaging to calibrate forecast ensembles, Tech. Rep. 440, Dep. of Stat., Univ. of Wash., Seattle.

*Todini, E., 2008. A model conditional processor to assess predictive uncertainty in flood forecasting. Intl. J. River Basin Management. Vol. **6** (2), 123-137.*

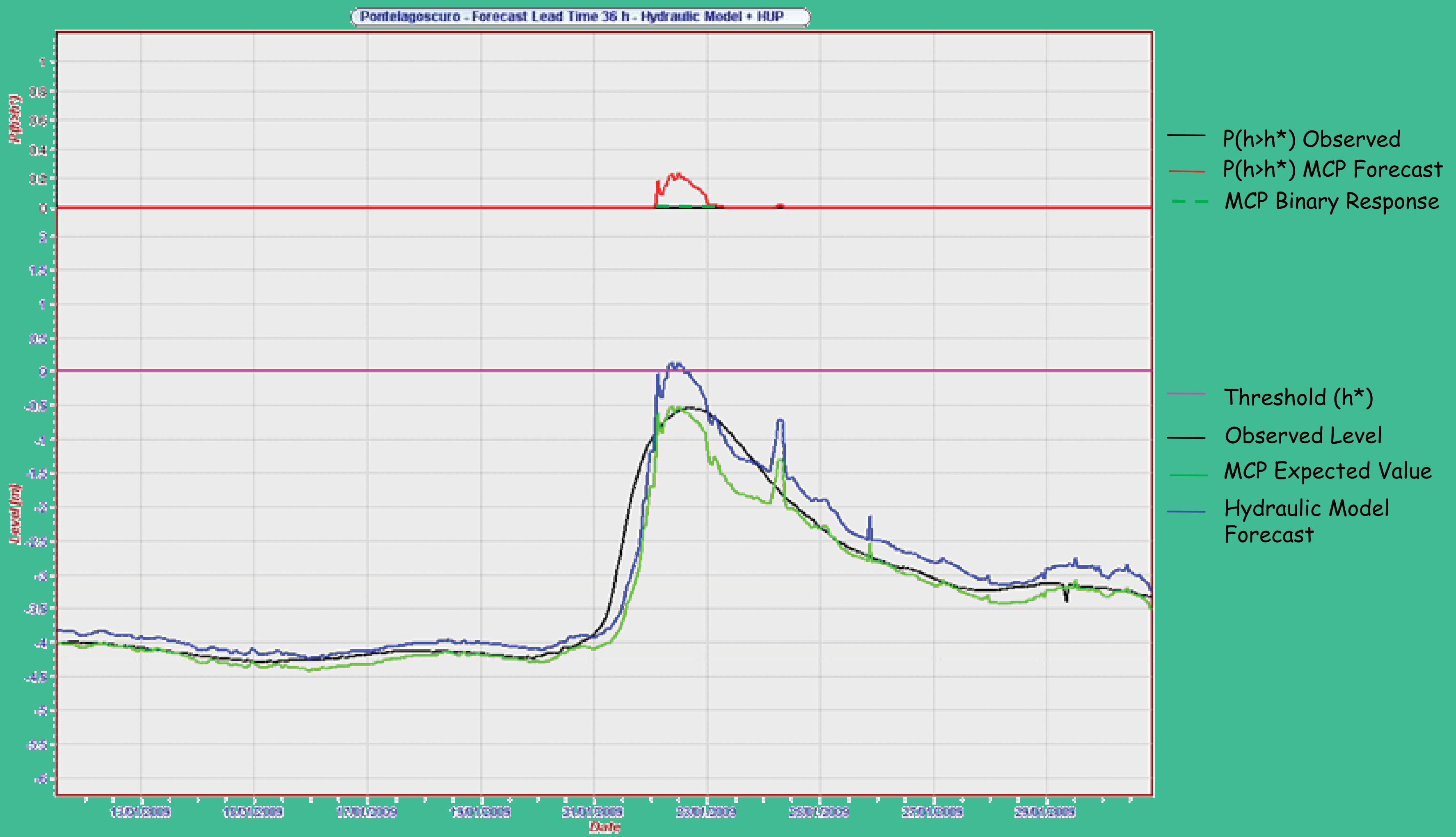
Po at Pontelagoscuro: 36 h forecast
Mike11 and MCP processed PU

MISSED ALARMS CORRECTED BY THE MCP



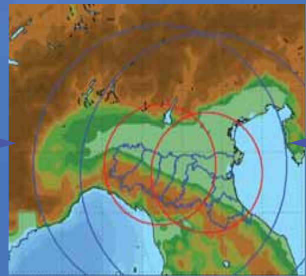
Po at Pontelagoscuro: 36 h forecast
Mike11 and MCP processed PU

FALSE ALARM CORRECTED BY THE MCP

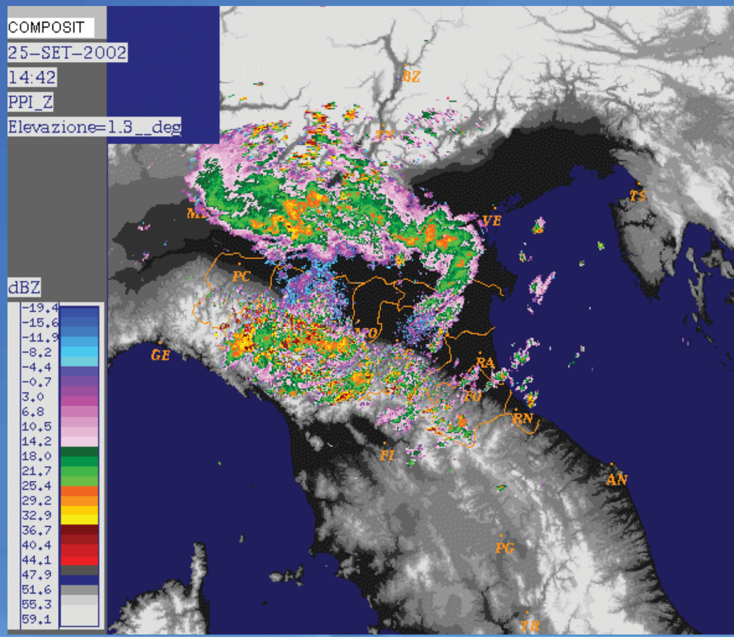


Composite radar

Gattatico



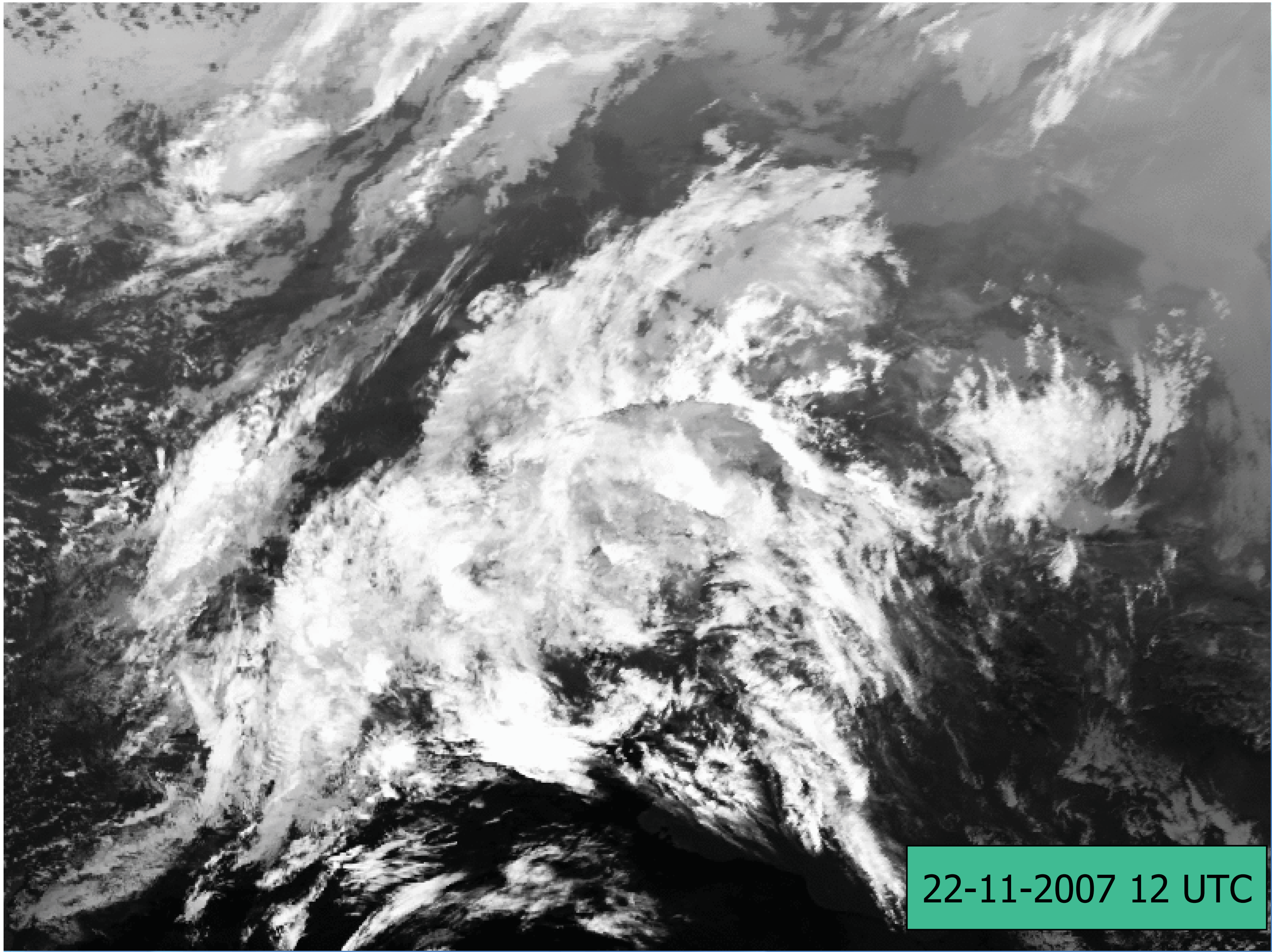
San Pietro Capofiume

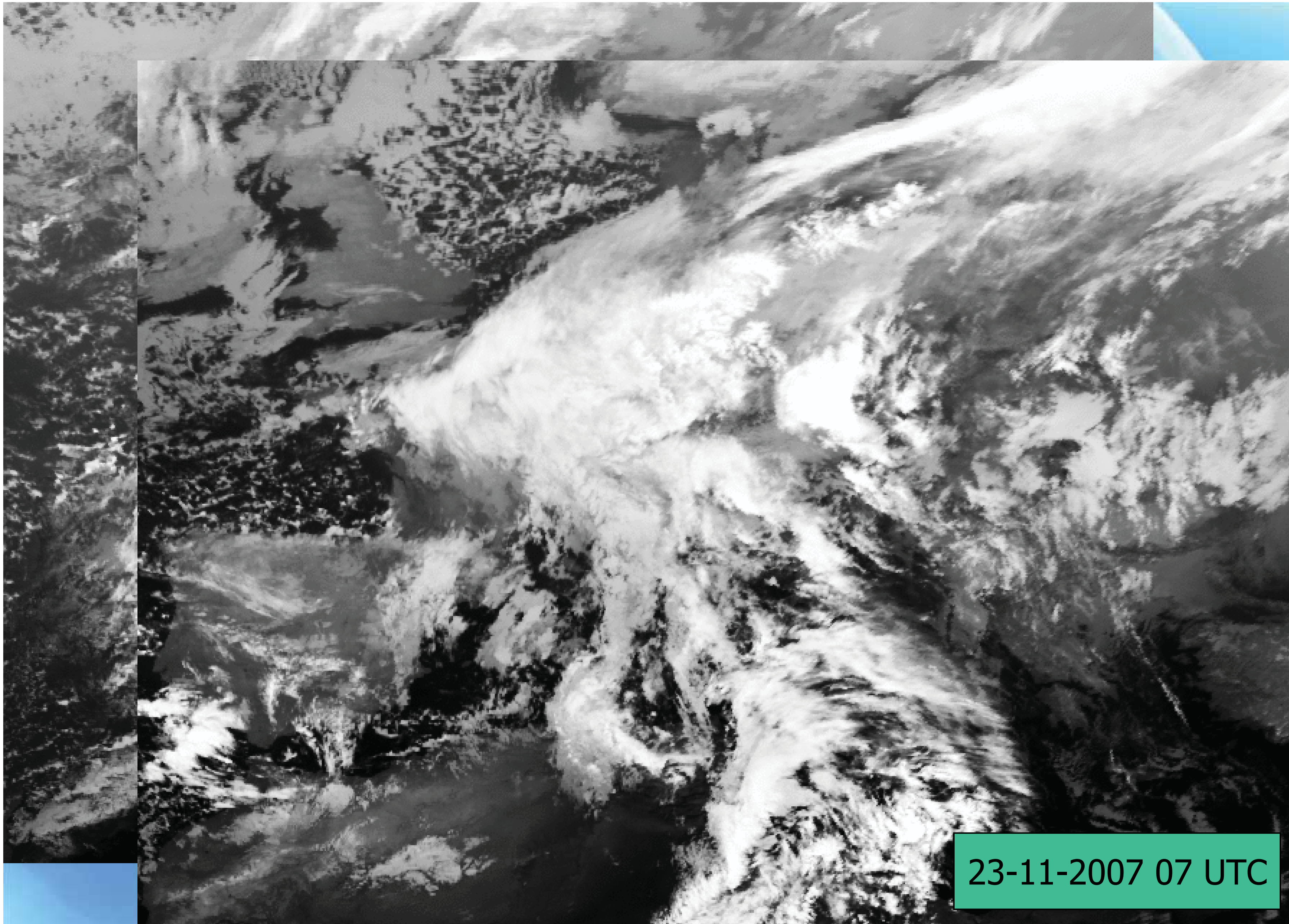


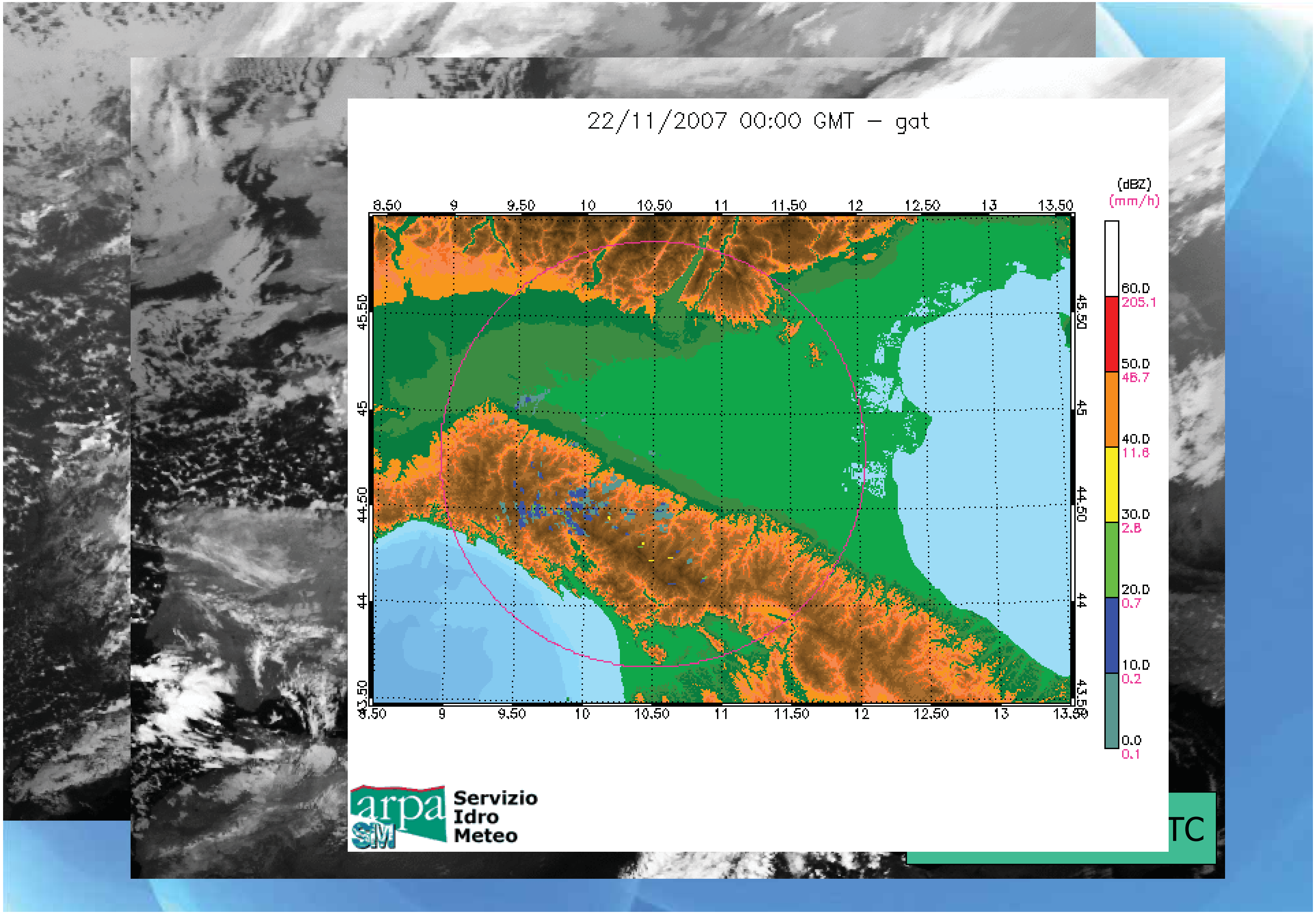
The radar network

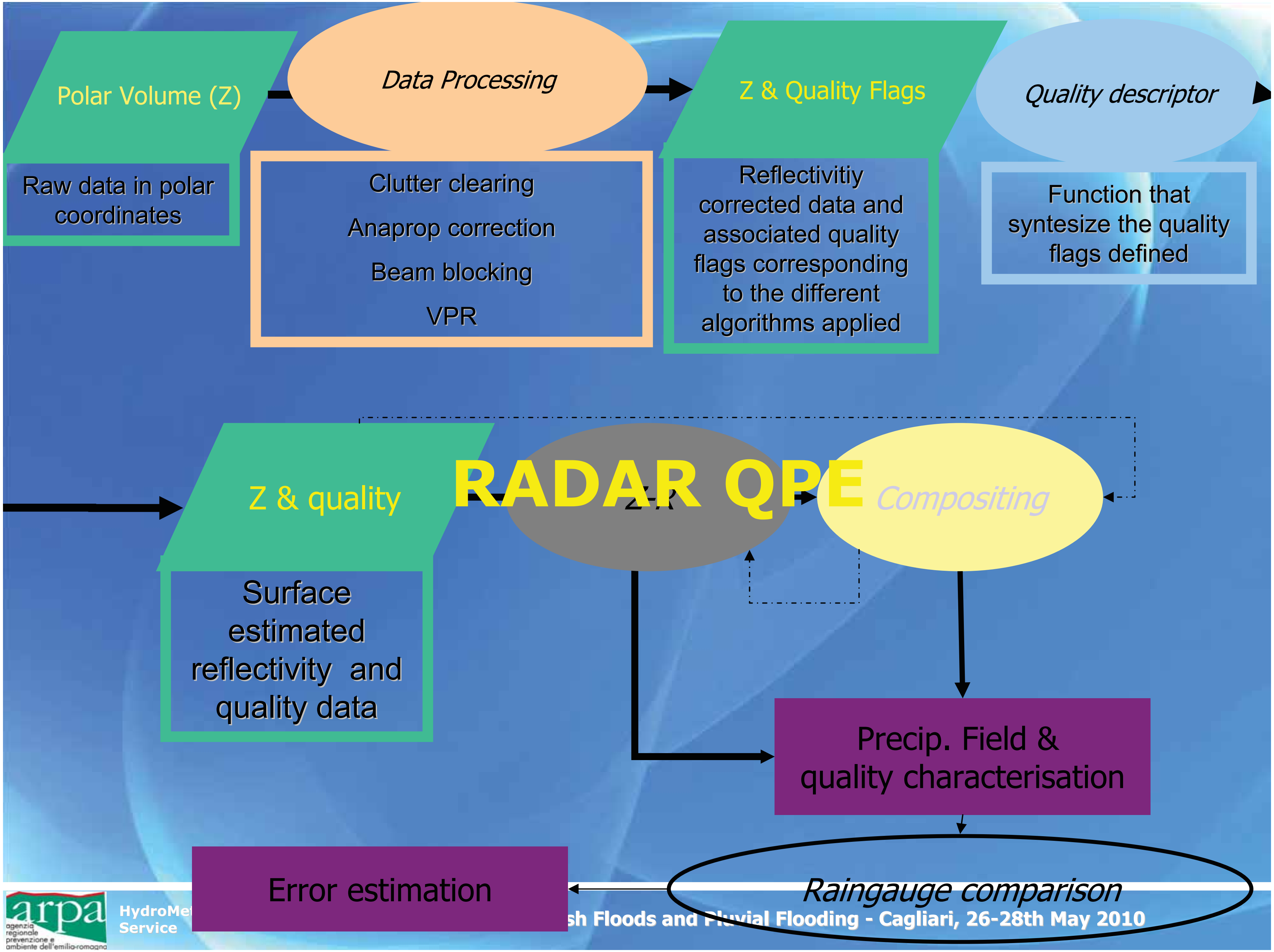
Event description

- A mesoscale system pass over Italy between 22-23 November 2007.
- Severe rain developed on the Apennine
- Maximum of precipitation in the study area was around 300 mm in 3 day

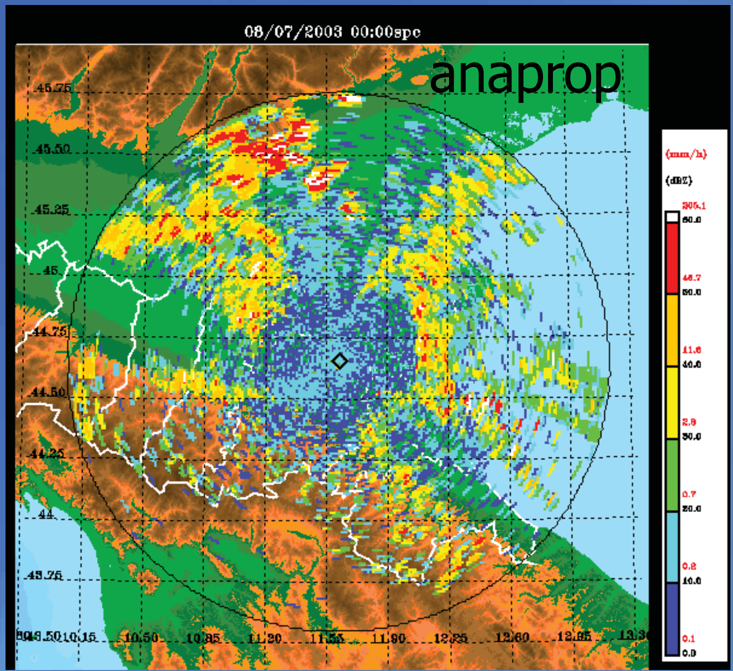

22-11-2007 12 UTC

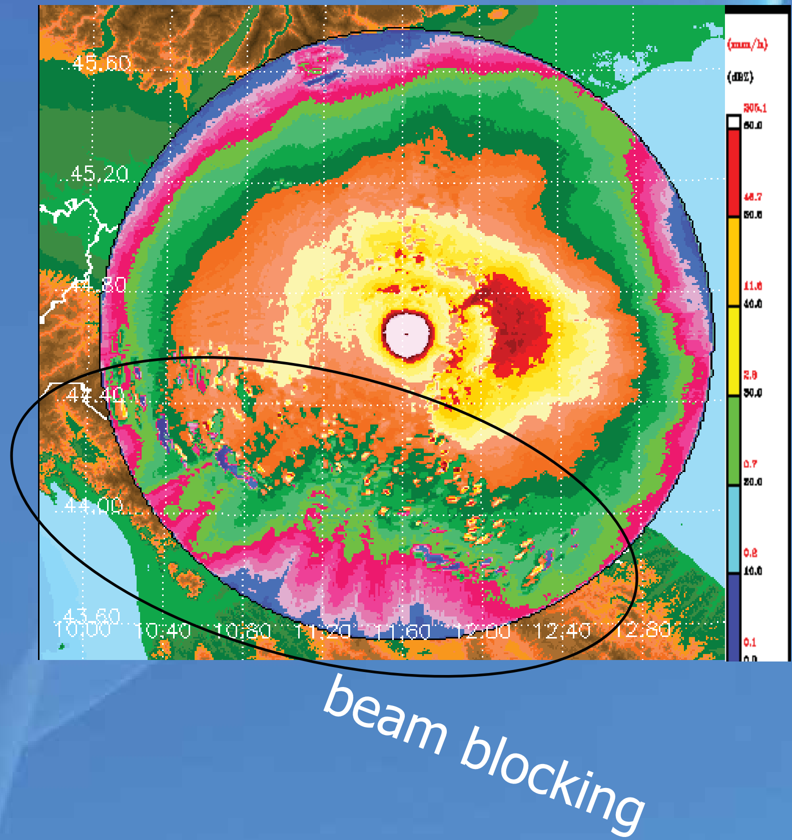

23-11-2007 07 UTC


22/11/2007 00:00 GMT – gat
8.50 9 9.50 10 10.50 11 11.50 12 12.50 13 13.50
45.50 45 44.50 44 43.50
(dBZ)
(mm/h)
60.0 205.1
50.0 48.7
40.0 11.6
30.0 2.8
20.0 0.7
10.0 0.2
0.0 0.1
Servizio
Idro
Meteo
TC

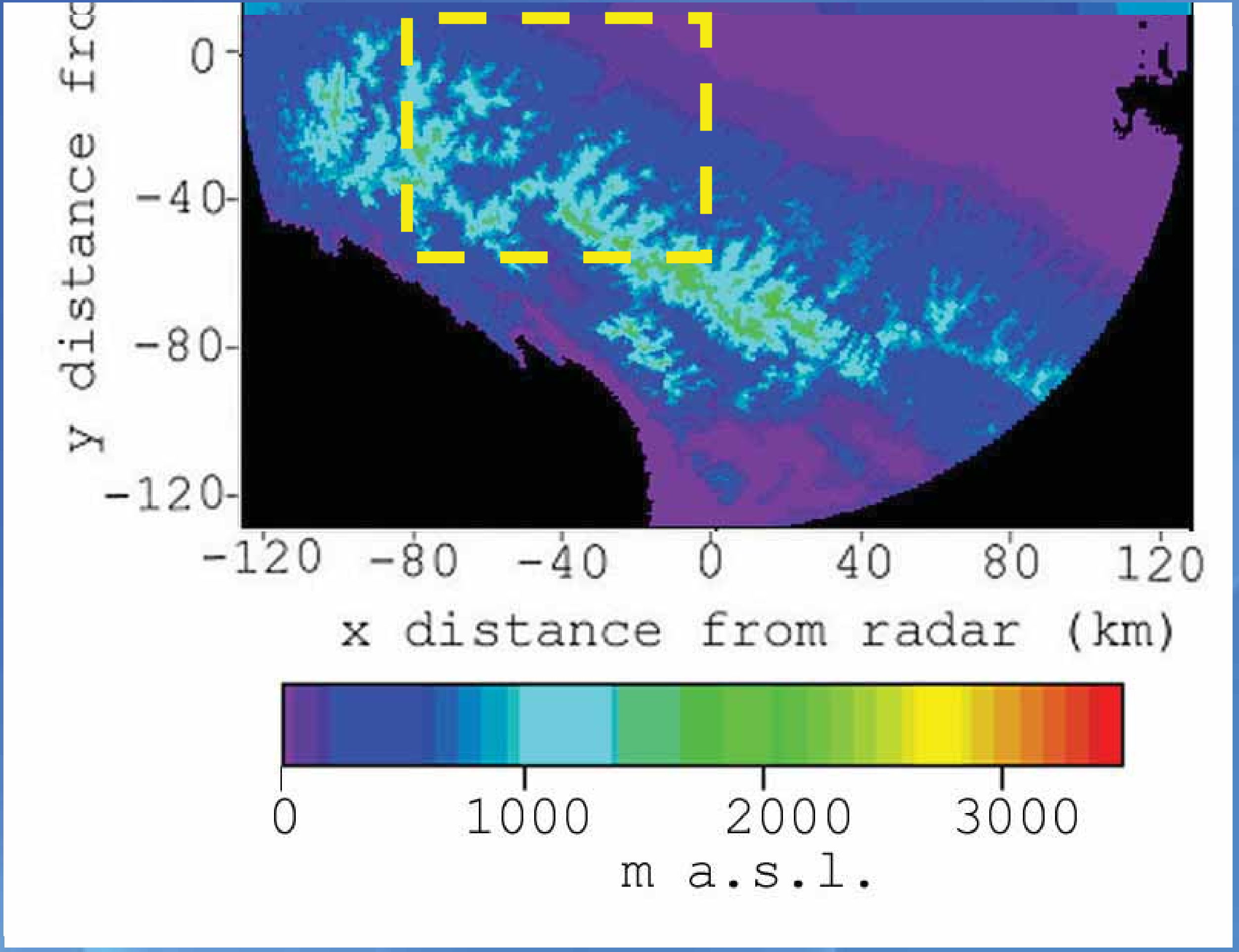

Polar Volume (Z)
Raw data in polar coordinates
Data Processing
Clutter clearing
Anaprop correction
Beam blocking
VPR
Z & Quality Flags
Reflectivitiy corrected data and associated quality flags corresponding to the different algorithms applied
Quality descriptor
Function that syntesize the quality flags defined
RADAR QPE
Z & quality
Surface estimated reflectivity and quality data
Z-R
Compositing
Precip. Field & quality characterisation
Raingauge comparison
Error estimation
HydroMet
Service
Cagliari, 26-28th May 2010

Just few samples



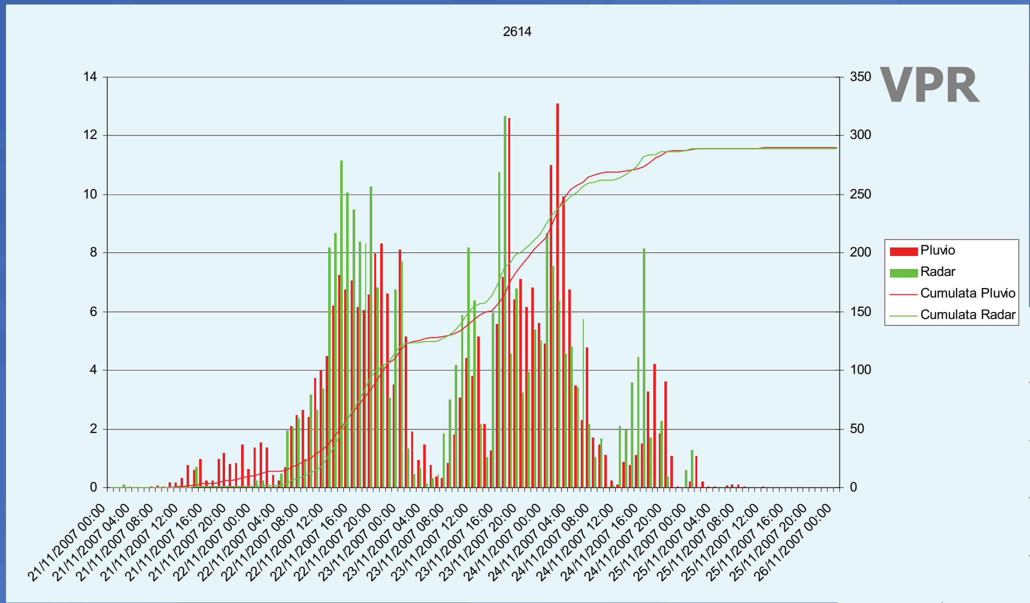


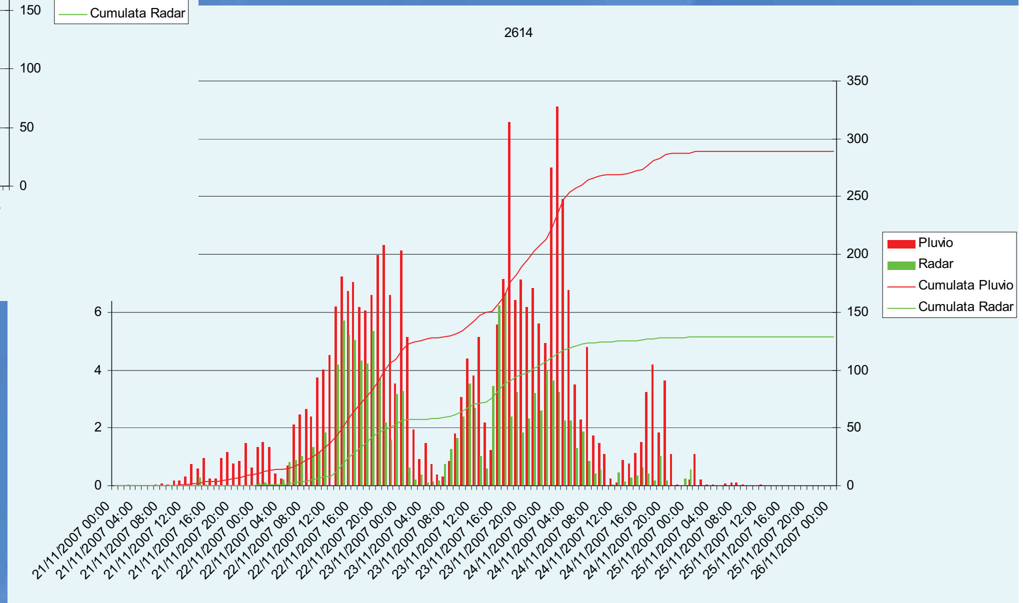
Radar visibility of the Taro Catchment

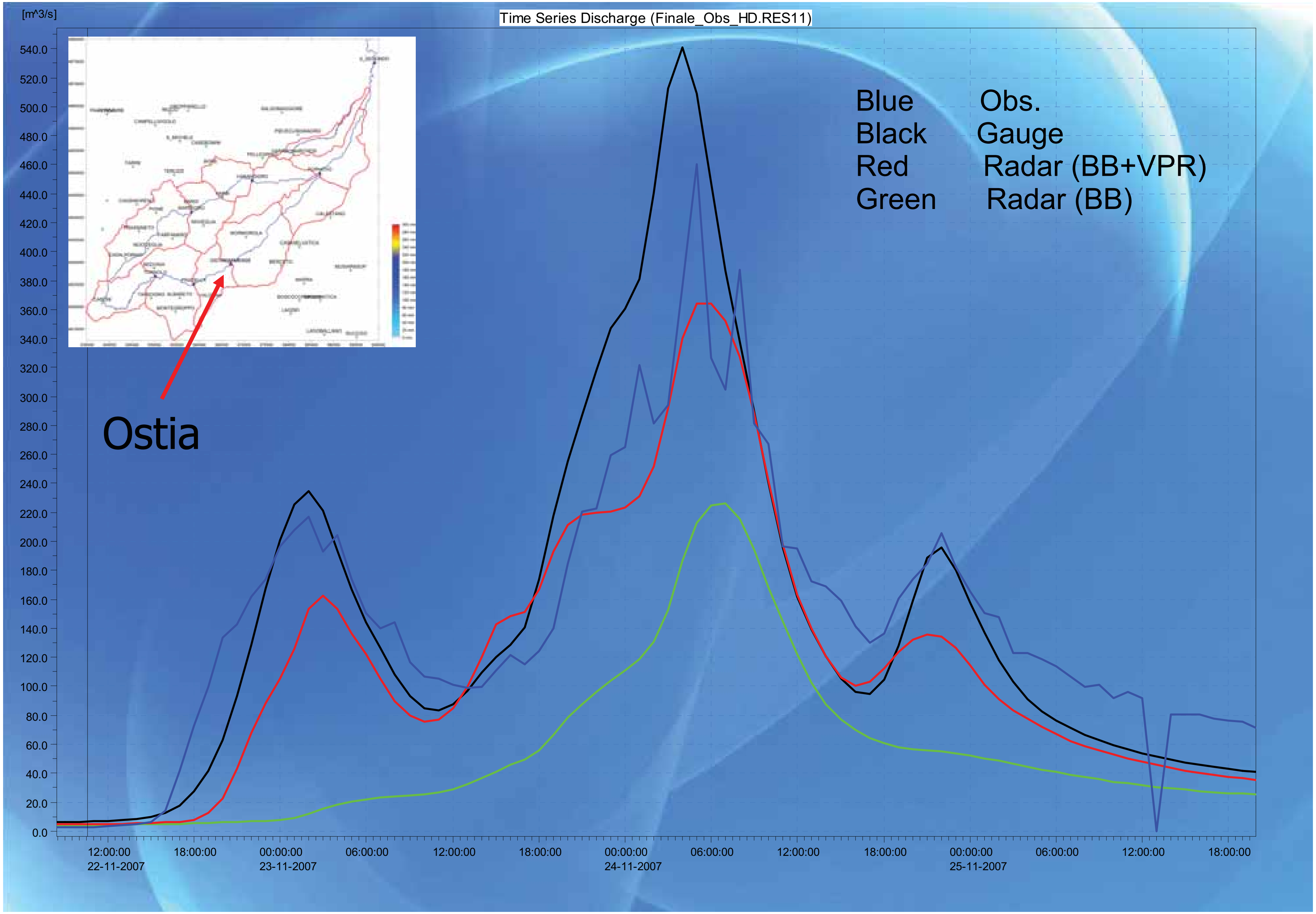


- DTM
- BB
- Elev. Selection
- Residual BB
- Height of beam center above dtm

Areal averaged precipitation timeseries






[m^3/s]
Time Series Discharge (Finale_Obs_HD.RES11)
540.0
520.0
500.0
480.0
460.0
440.0
420.0
400.0
380.0
360.0
340.0
320.0
300.0
280.0
260.0
240.0
220.0
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Blue Obs.
Black Gauge
Red Radar (BB+VPR)
Green Radar (BB)
Ostia
12:00:00
22-11-2007
18:00:00
00:00:00
23-11-2007
06:00:00
12:00:00
18:00:00
00:00:00
24-11-2007
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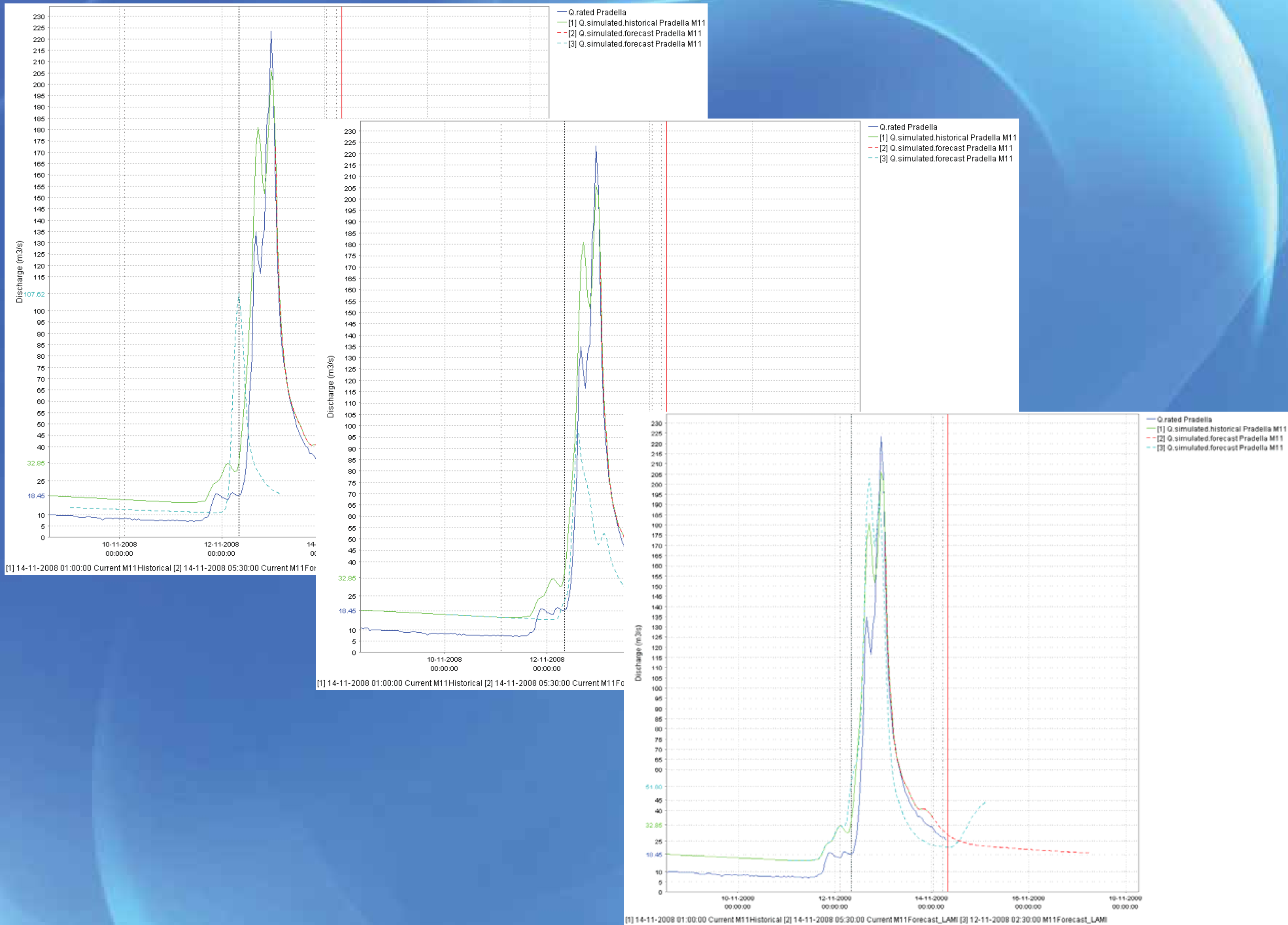
25-11-2007
06:00:00
12:00:00
18:00:00



Q.rated Pradella
[1] Q.simulated.historical Pradella M11
[2] Q.simulated.forecast Pradella M11
[3] Q.simulated.forecast Pradella M11
Discharge (m3/s)
10-11-2008 00:00:00
12-11-2008 00:00:00
14-11-2008 00:00:00
[1] 14-11-2008 01:00:00 Current M11Historical [2] 14-11-2008 05:30:00 Current M11Forecast_LAMI [3] 12-11-2008 02:30:00 M11Forecast_LAMI

Thank you for your attention