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Hydrological evaluation of merged satellite precipitation product – rain gauge: testing Cellular Automata-based algorithm rainfall assimilation and downscaling on Italian Regions.

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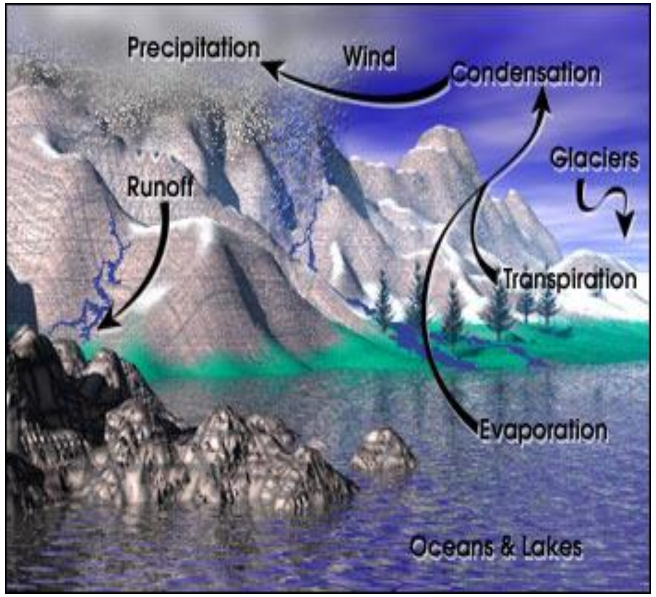
Overview

1. CETEMPS Hydrological Model (CHyM)
2. Precipitation Data Assimilation: Cellular Automata algorithm
3. Hydrological Evaluation
4. Analysis Example: Upper Po River Basin – Tanaro River Basin
5. Preliminary Study : Raingauge Network Analysis
6. Results
7. Conclusion

1. CHyM (Cetemps Hydrological Model)

Distributed grid-based hydrological model. It includes an explicit parameterization of different physical processes contributing to the hydrological cycle.

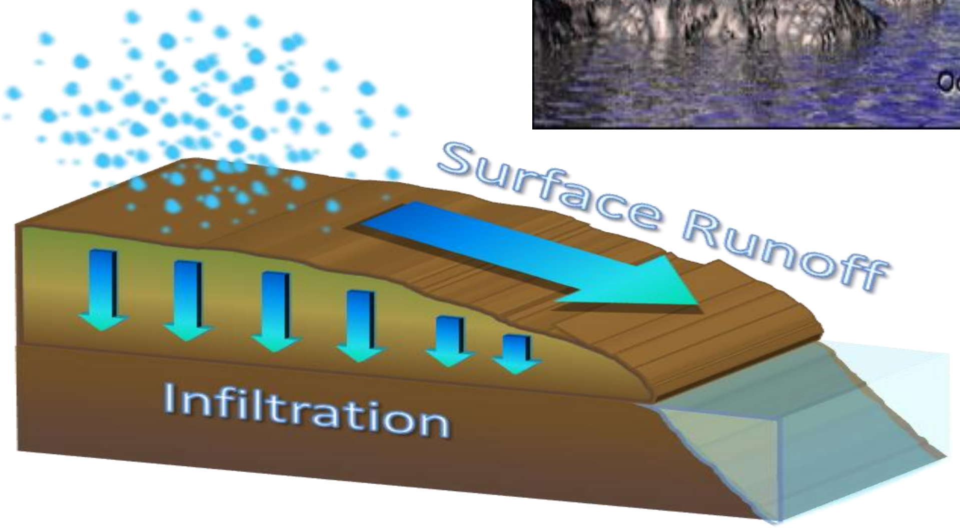


For each cell of the selected domain, the contribution of:

- Runoff
- Melting
- Evapotraspiration
- Interception
- Infiltration
- Rainfall

are explicitly calculated.

Soil moisture storage



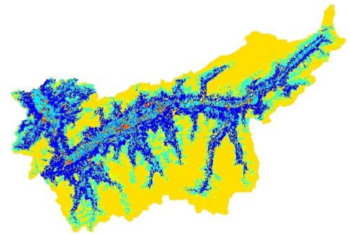
1. CHyM: Cellular Automata (CA) based algorithm has been developed and implemented in the model.

Cellular Automata (CA)

Rhone basin drainage network extranction

- Extract drainage network from every arbitrary DEM matrix and solving the numerical singularities due to the finite horizontal and vertical DEM resolution.

Rhone GIS Map



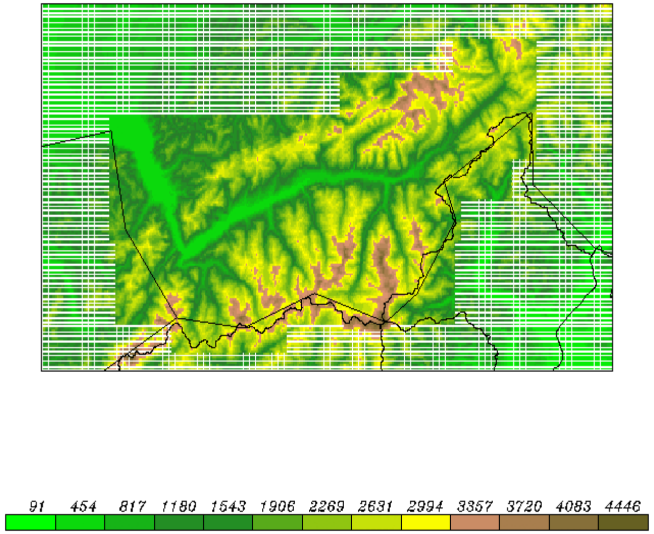
CETEMPS Hydrological Model

CHyM river tracking

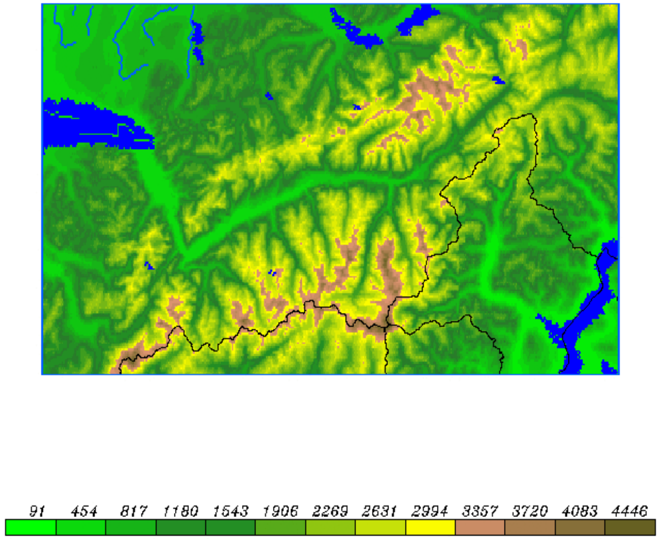
The CA technique allows to fill the singularities

Drainage network extranction

It runs on any geographical domain with any resolution up to the DEM resolution, the drainage network is extracted by a native algorithm implemented in the CHyM code.



DEM smoothing – cycle number 0



tmp001.gif

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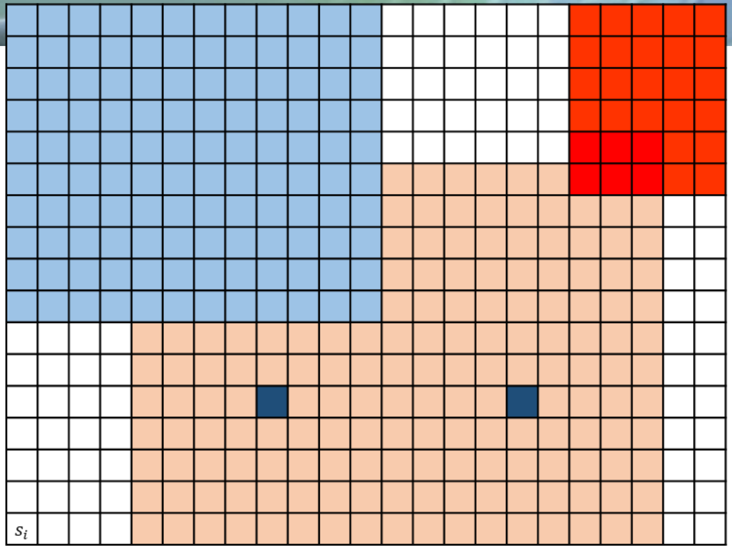
2. Precipitation Data Assimilation: Cellular Automata Technique

	Cellular Automata Rain Data Assimilation
Celluar space:	CHyM NxM 2D grid (hydrological defined spatial resolution).
Cell states:	The status of a cell corresponds to the value of a CHyM field (DEM or precipitation input data).
Initial conditions:	The background rainfall is estimated using the Cressman algorithm.
Neighborhood:	These are the 8 side and corner neighbors, the Moore neighborhood.
State transition function:	$$s_i = s_i + \alpha\left(\sum_{i=1}^{8}\beta_j(s_j - s_i)\right)$$ where s_i is carried out over all 8 surrounding cells. The coefficients β_j allow to consider the different distances between the cells, as an example for a regular equally spaced lattice, they assume the value 1 for the cells in North, East, South and West location, and the value $1/\sqrt{2}$ in the cells located in the North-East, North-West, South-East and South-West direction respect to the cell i-th. The coefficient α assumes a small value (typically from 0.1 to 0.9) in order to ensure a slight smoothing of the original matrix.
Time axis:	All cells are updated synchronously.
Boundary conditions:	The same state is associated to static boundary.

Modular Approch



FX_Previus	Fixed rainfall value (estimated in the previous step or corresponding to current used dataset rain value). The value of the grid points is assigned and is used by the automata cellular algorithm to estimate the other grid points rain value.
FX_GAUGE	
FX_SAT	
NY_FX	No value yet fixed for this grid point.
WB_FX	Precipitation value will be fixed at the current step. The number of grid points involved depends on the background rainfall estimated using the Cressman algorithm (initial condition).
N_FX	No value will be fixed for this grid point: e. g. sea grid points

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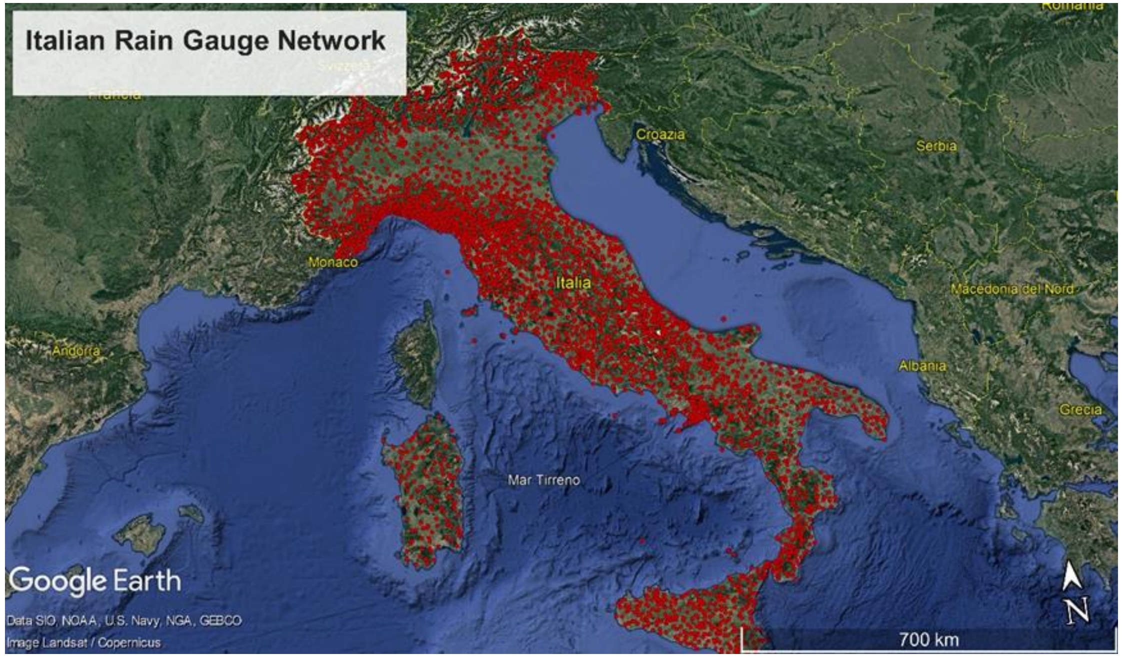
2. Precipitation Data Assimilation

The hydrological model is forced with

- Rain Gauge data, available on DEWETRA platform (every 1h)
- HSAF Product: MW/IR **H03B** product (mm/h at 5 km spatial resolution and 15 min temporal resolution).
- HSAF Product: H SAF MW-only precipitation products **H68** (mm/h at 27.7 km spatial resolution and 30 min temporal resolution).

4/5 Hydrological Simulations (5 years)

	DATA	NAME SIMULATION	GAUGE RADIUS (km)	SAT RADIUS (km)
1	Rain Gauge	GAUGE	35	X
2	H03B	SATH03B	X	SAT RES
3	Gauge + H03B	G3SATH03B	3	SAT RES
4	Gauge + H03B	G5SATH03B	5	SAT RES
5	H68	SATH68	X	SAT RES



2500 rain gauges over Italy:

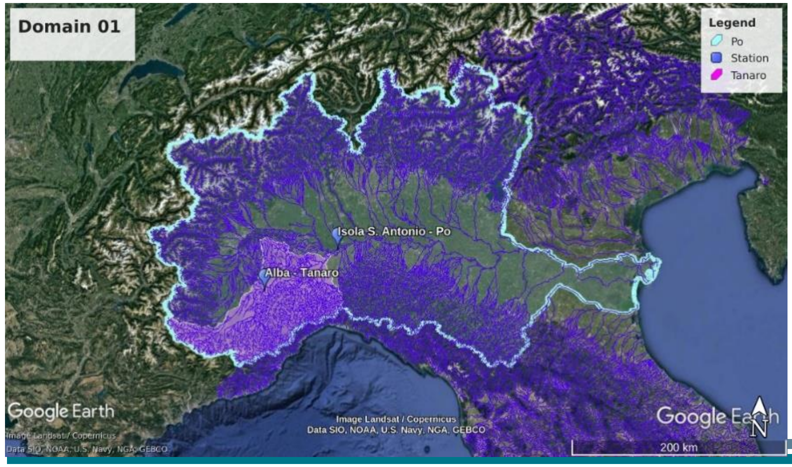
		Network characteristics		
Area	Area size (km2)	Gauge Numbers	Network Density (km² per gauge)	Average Gauge Distance L (km)
Italy	302073	≈2500	≈120	≈ 11

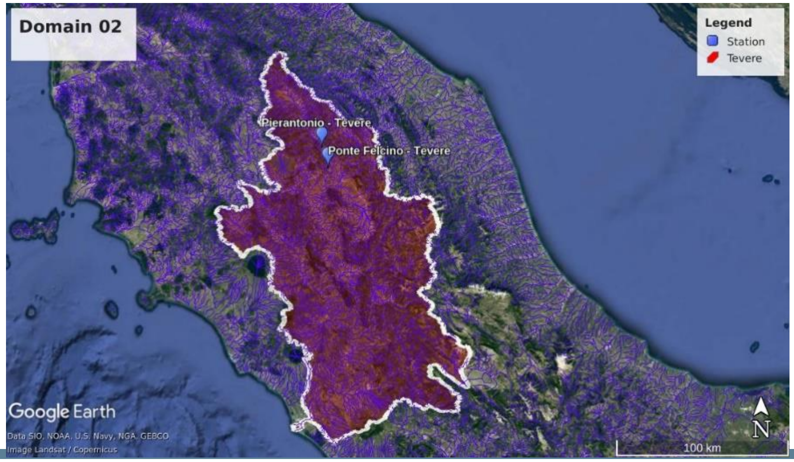
3. Hydrological Evaluation

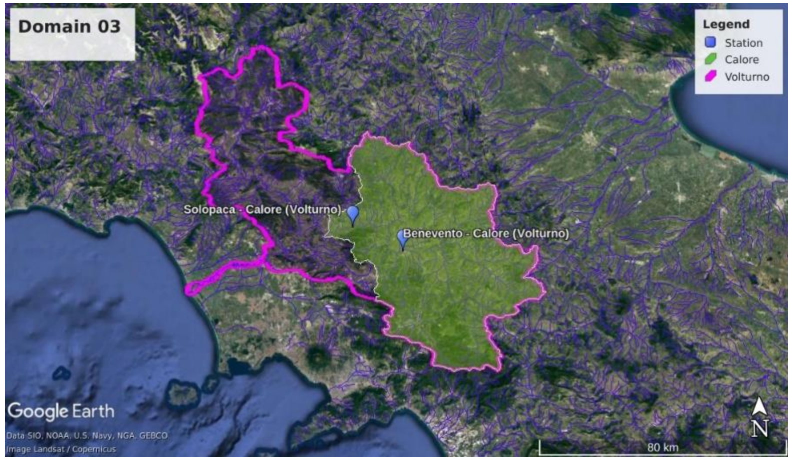
3 selected domains

- ✓ Upper Po River Basin
- ✓ Tevere Basin
- ✓ Volturno Basin

- For the simulations, **neither melting component nor the anthropic impact are considered**, and this condition could affect the baseflow discharge.
- **No calibration** of the hydrological model was done.
- This method does not affect our conclusions as the purpose of our work is not to validate the performance of the hydrological model but to use it as a tool **for assessing the performance of the assimilation technique.**

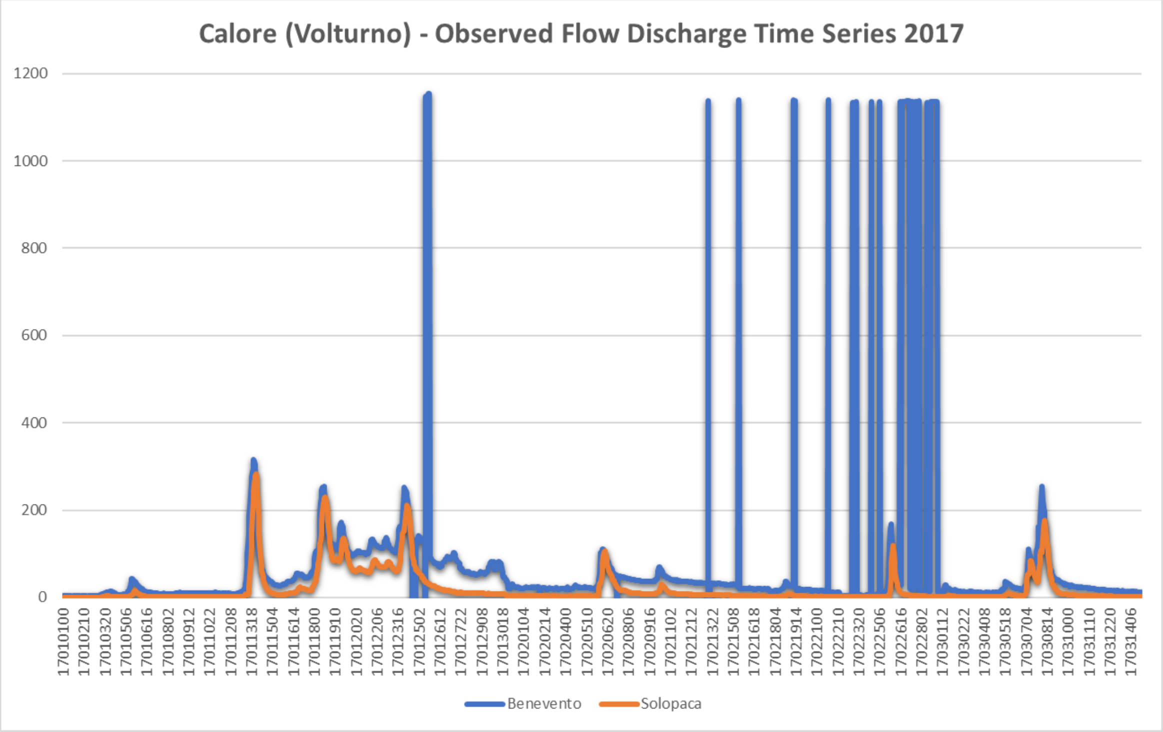






3. Hydrological Evaluation

The observed data quality



Observed flow discharge time series in the Calore basin (Volturno) relating to two consecutive measurement stations for the year 2017

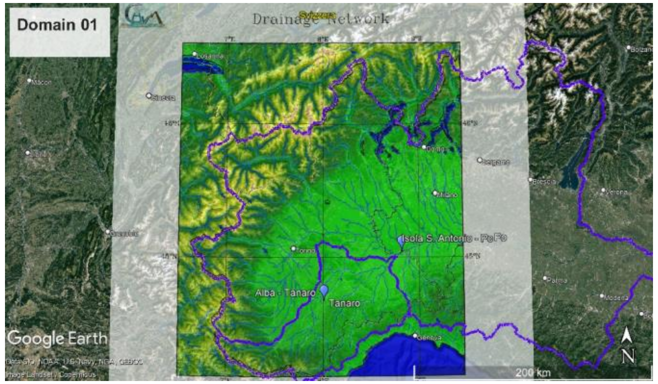
3. Hydrological Evaluation

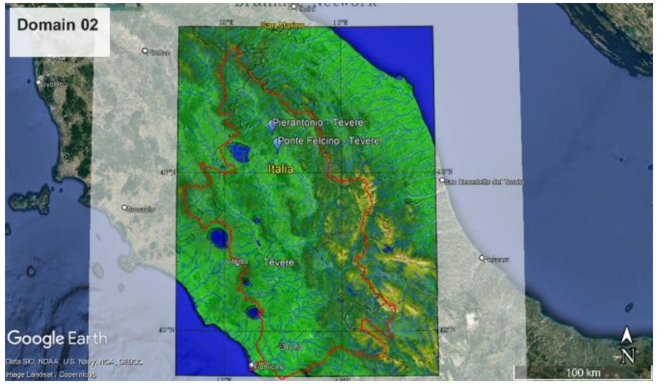
To overcome these limitations

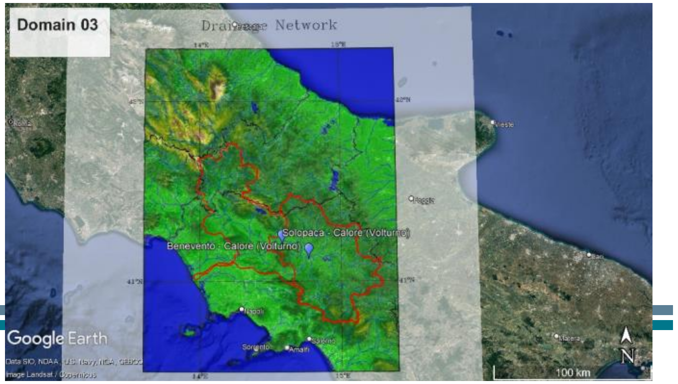
2 two long observed time series on the same basin to reduce the error associated with the observed data

- ✓ **Tanaro – Alba ; Po – Isola S. Antonio**
- ✓ **Tevere – Ponte Felcino; Tevere – Pierantonio**
- ✓ **Calore (Volturno) – Benevento; Calore (Volturno) - Solopaca**

17 Quality Scores, simulated flow discharge VS observed flow discharge, have been selected to make the analysis more objective

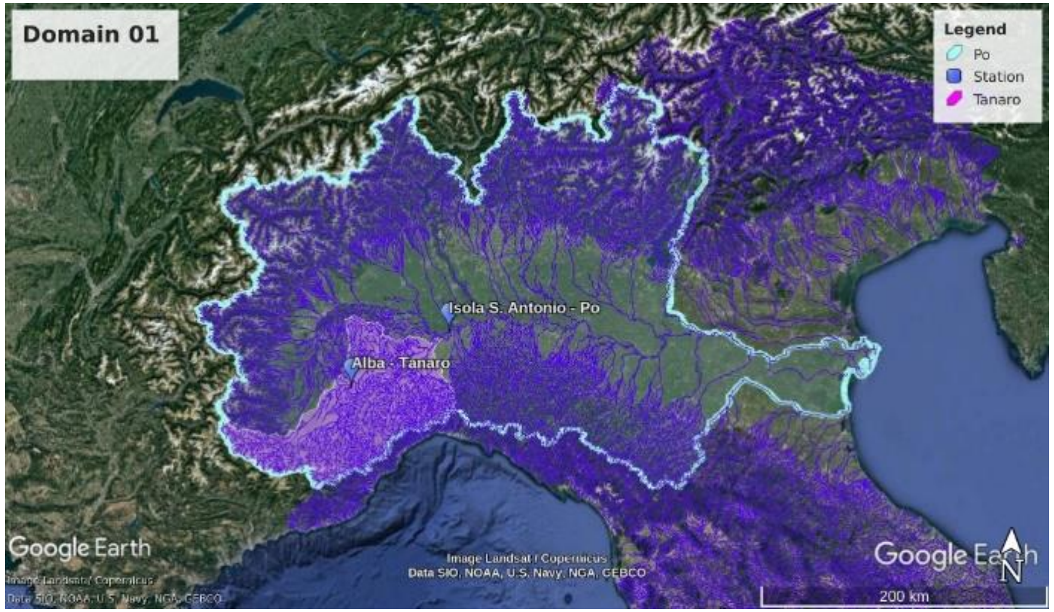


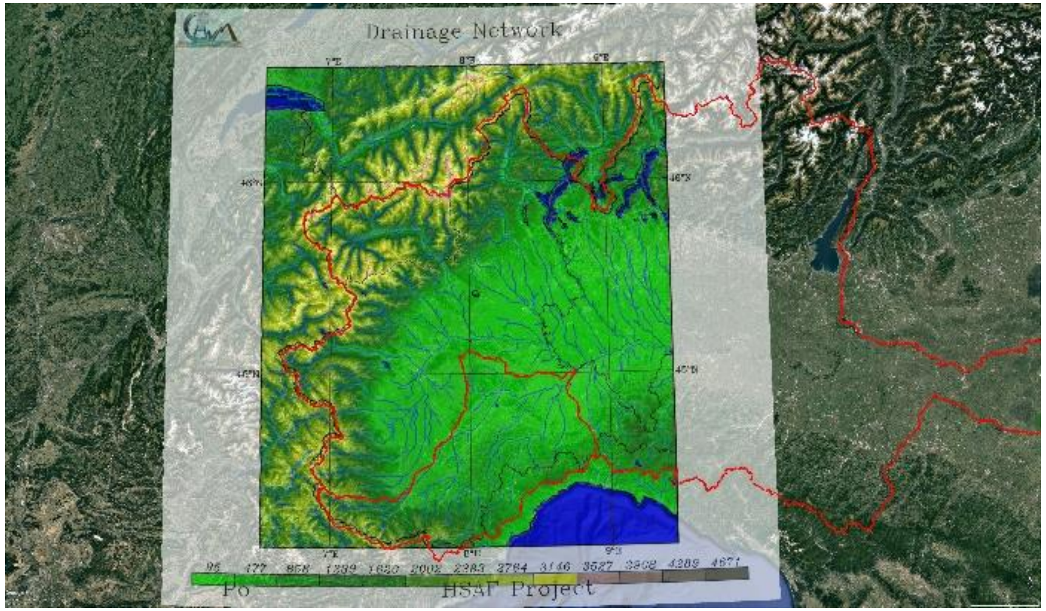




4. Analysis EXAMPLE: the UPPER Po River BASIN

Domain	01
Station	✓ Isola S. Antonio ✓ Alba Tanaro
Basin Drainage Area (km2)	✓ Po: 25640 ✓ Tanaro: 8175
Estimated Basin Drainage Area	✓ Po: 25641 ✓ Tanaro: 8411
SLON SLAT	✓ 6.50 ✓ 44.10
NLON NLAT	✓ 330 ✓ 280
Spatial resolution	860 m





5. Preliminary Study: Raingauge Network Analysis

$$L = \sqrt{\frac{S}{N}}$$

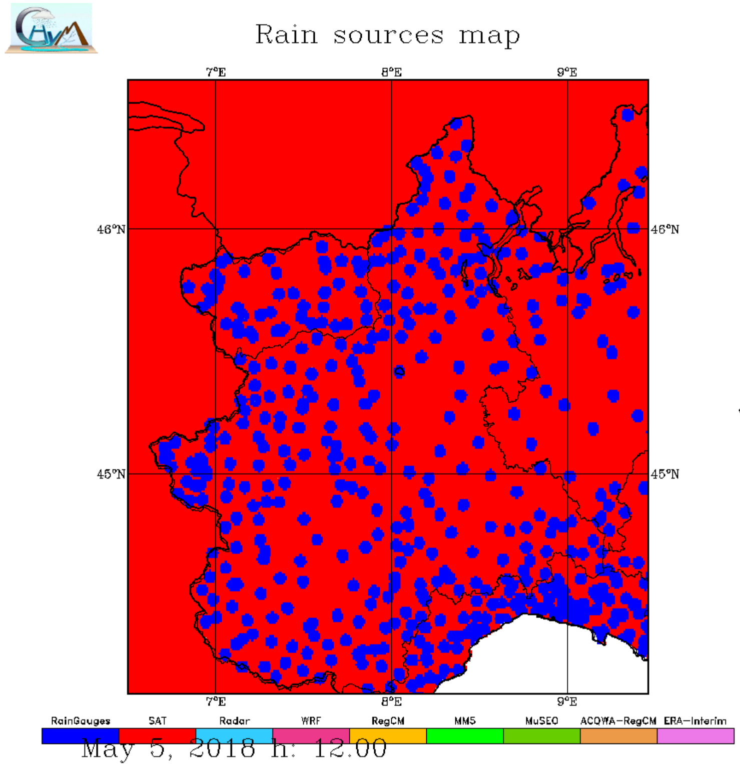
where L is the mean distance between stations; S is the considered area and N is the number of rain gauges.

Area	Area size (km2)	Network characteristics: Gauge Numbers	Network characteristics: Basin Network Density (km^2 per gauge)	Network characteristics: Average Gauge Distance L (km)	Gauge Covered Area % (R=3km)**	Gauge Covered Area % (R=5km)**
Upper Po River Basin	25640	273	94	9.7	0.15	0.56
Montain (>700 MSL)	11157 (44%)	152	73	8.5	0.19	0.69
Hill (700 ≤ H ≤ 300)	5798 (23%)	68	85	9.2	0.19	0.67
Flat (< 300)	8414 (33%)	53	158	12.6	0.09	0.38

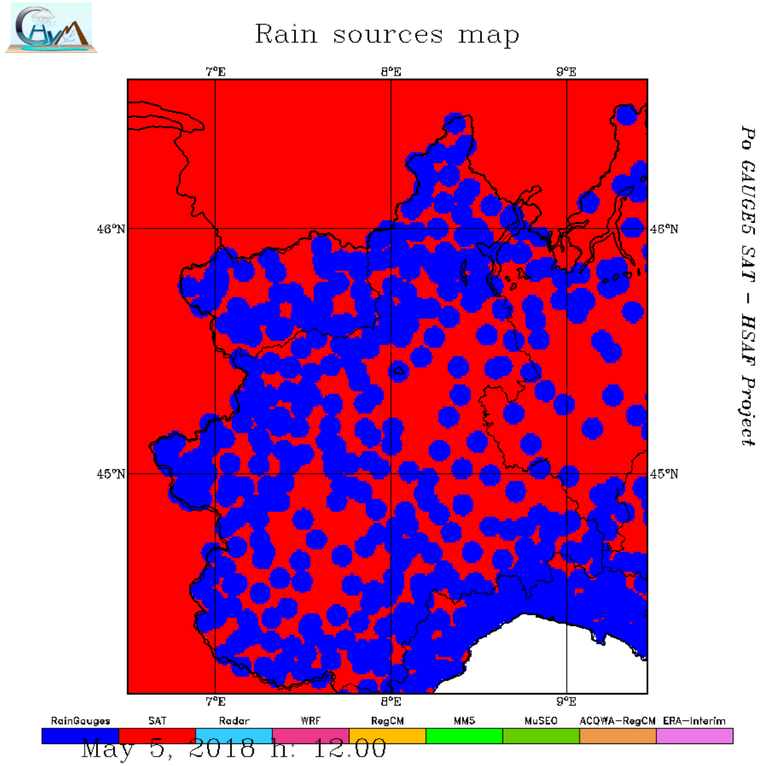
Up to 460 rain gauges over domain 01
From Dewetra Platform december 2019

5. Preliminary Study: Domain 01 Upper Po River Basin

RainGAUGE RADIUS of Influence = 3km



RainGAUGE RADIUS of Influence = 5 km

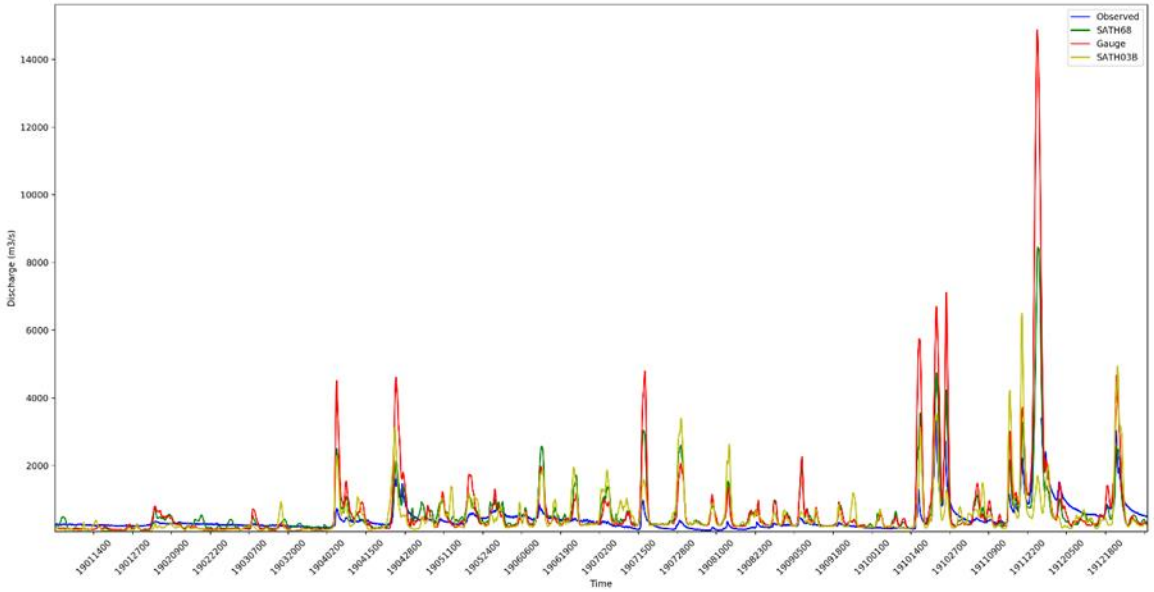


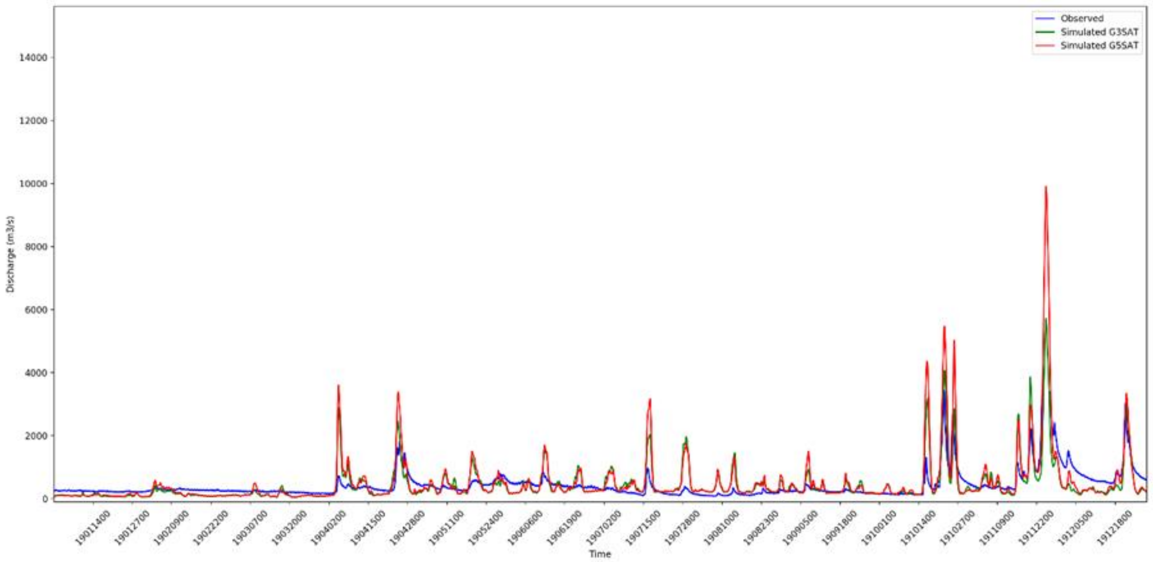
6. Results

Domain 01 Upper Po River BasinFlow

Discharge Annual Comparisons - observedVSsimulated - 2019

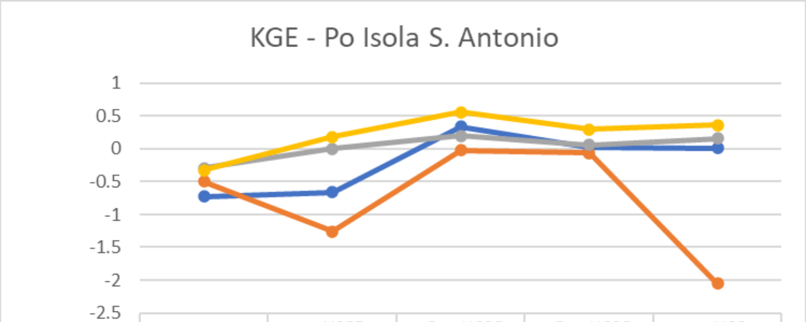
	DATA	NAME SIMULATION	GAUGE RADIUS (km)	SAT RADIUS (km)
1	Rain Gauge	GAUGE	35	X
2	MW/IR H03B	SATH03B	X	5
3	Gauge + MW/IR H03B	G3SATH03B	3	5
4	Gauge + MW/IR H03B	G5SATH03B	5	5
5	MW-only precipitation products H68	SATH68	X	28



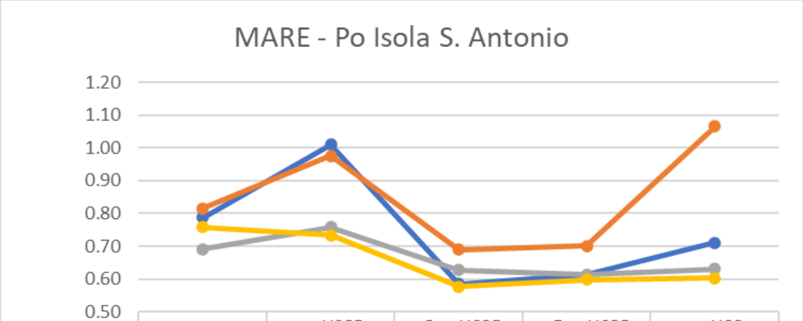


6. Results: Flow Discharge Annual Comparisons

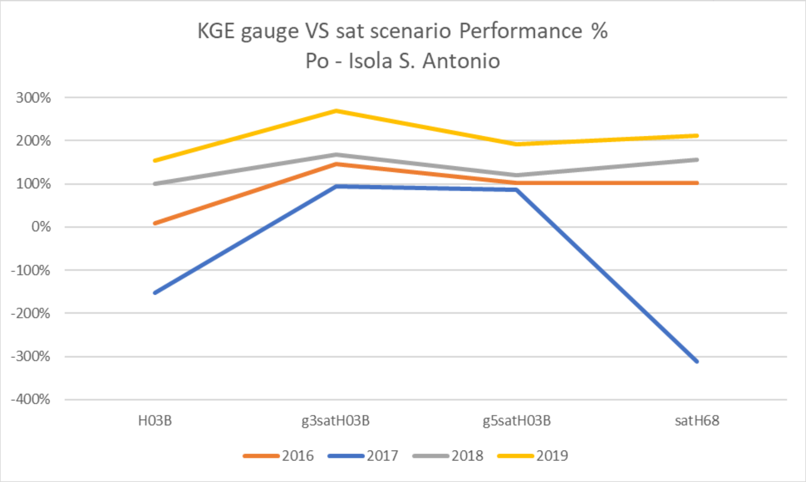
observedVSsimulated

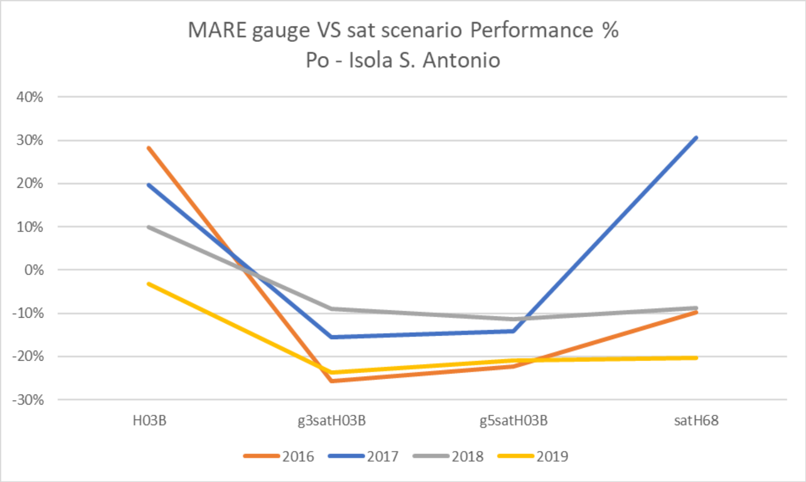


	gauge	satH03B	g3satH03B	g5satH03B	satH68
2016	-0.724	-0.659	0.3371	0.023	0.0107
2017	-0.497	-1.259	-0.024	-0.063	-2.051
2018	-0.289	-0.002	0.1984	0.0591	0.1599
2019	-0.329	0.1798	0.556	0.2999	0.3652



	gauge	satH03B	g3satH03B	g5satH03B	satH68
2016	0.79	1.01	0.59	0.61	0.71
2017	0.82	0.98	0.69	0.70	1.07
2018	0.69	0.76	0.63	0.61	0.63
2019	0.76	0.73	0.58	0.60	0.60





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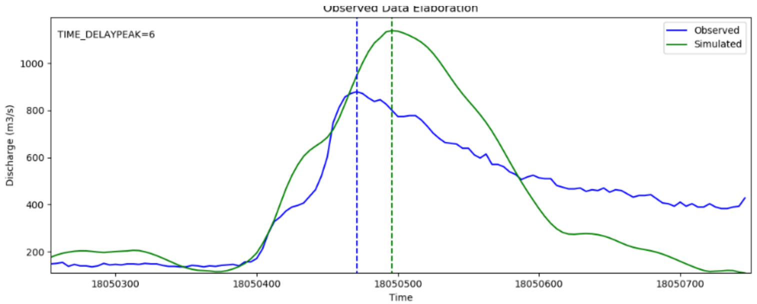
CS 02

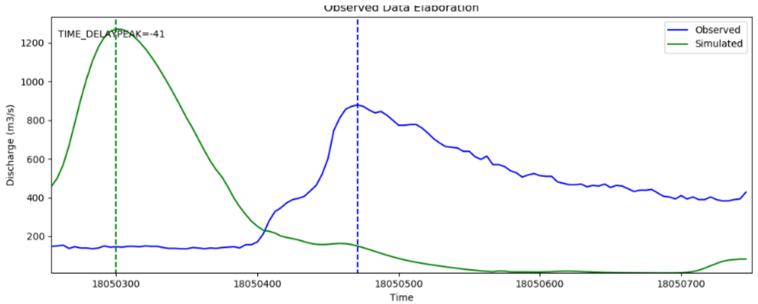
6. Results: TANARO BASIN Case Studies

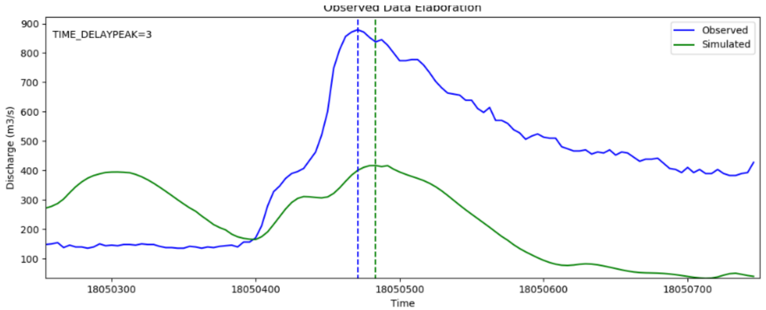
Case Study	Period
01	23/11/16 12 - 27/11/16 12
02	02/05/18 12 - 06/05/18 12
03	31/10/18 12 - 04/11/18 12
04	25/11/19 14 - 29/11/19 14



GAUGE

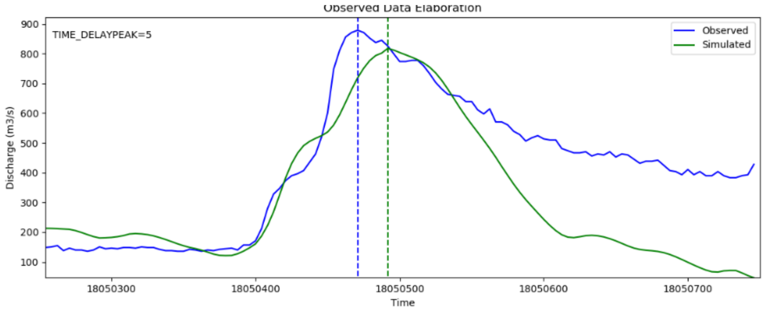
SAT





G3SAT

G5SAT



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CS	SIMULATION	nse	Nse c2m	kge	Kge c2m	kgeprime	kgeprimec 2m	kgenp	Kgenp c2m
01	GAUGE	-1.93	-0.49	-0.43	-0.18	0.07	0.04	0.09	0.05
	SAT	0.49	0.33	0.47	0.31	0.41	0.26	0.47	0.31
	G3SAT	0.50	0.33	0.72	0.57	0.66	0.49	0.79	0.66
	G5SAT	-0.14	-0.07	0.32	0.19	0.56	0.38	0.63	0.46
02	GAUGE	0.37	0.23	0.52	0.35	0.52	0.36	0.78	0.64
	SAT	-5.66	-0.74	-0.87	-0.30	-1.24	-0.38	-0.66	-0.25
	G3SAT	-0.96	-0.32	-0.11	-0.05	-0.02	-0.01	-0.03	-0.01
	G5SAT	0.37	0.23	0.68	0.51	0.51	0.35	0.56	0.38
03	GAUGE	-9.15	-0.82	-0.93	-0.32	-0.06	-0.03	0.08	0.04
	SAT	-0.85	-0.30	0.24	0.13	0.18	0.10	0.30	0.18
	G3SAT	-0.24	-0.11	0.47	0.31	0.41	0.26	0.60	0.43
	G5SAT	-1.92	-0.49	0.02	0.01	0.29	0.17	0.55	0.38
04	GAUGE	-2.24	-0.53	-0.70	-0.26	-0.05	-0.02	0.59	0.42
	SAT	-0.96	-0.32	-0.13	-0.06	-0.10	-0.05	0.21	0.12
	G3SAT	0.42	0.27	0.54	0.37	0.55	0.38	0.59	0.41
	G5SAT	0.37	0.22	0.26	0.15	0.15	0.08	0.79	0.65

CS	SIMULATION	rmse	mare	pbias	MC	CT DELAY	DTW	DDTW	TP DELAY	E%
01	GAUGE	1214.30	1.02	-90.40	1.9	-8	12.99	0.08	6	0.78
	SAT	505.47	0.51	44.57	0.55	-6	2.18	0.06	4	-0.39
	G3SAT	504.21	0.50	14.74	0.85	-9	0.4	0.07	5	-0.13
	G5SAT	759.20	0.63	-35.06	1.35	-9	2.36	0.07	6	0.31
02	GAUGE	180.86	0.34	-0.56	1.01	0	2.78	0.02	6	0.3
	SAT	590.00	1.28	29.09	0.71	44	51.58	0.27	-41	0.45
	G3SAT	319.73	0.69	46.61	0.75	40	13.44	0.04	3	-0.53
	G5SAT	181.07	0.32	25.30	0.91	2	3.5	0.02	5	-0.07
03	GAUGE	335.62	0.86	-86.13	1.86	-5	20.78	0.07	9	1.03
	SAT	143.31	0.42	26.08	0.74	0	3.86	0.05	51	-0.26
	G3SAT	117.41	0.35	18.68	0.81	-4	1.29	0.03	8	-0.18
	G5SAT	179.98	0.41	-26.21	1.26	-5	2.64	0.03	9	0.38
04	GAUGE	278.44	0.61	-34.26	1.34	0	4.21	0.01	0	0.92
	SAT	216.48	0.59	41.06	0.59	-49	2.51	0.01	56	-0.55
	G3SAT	117.59	0.38	38.22	0.62	0	0.67	0	0	-0.42
	G5SAT	123.26	0.37	6.19	0.94	0	0.56	0.01	0	0.22

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6. Results: TANARO BASIN Case Studies

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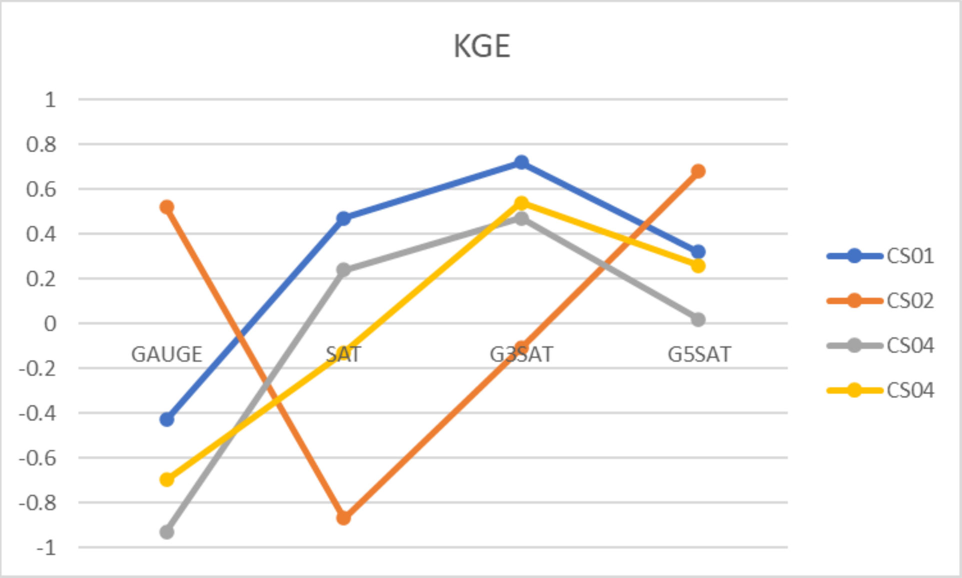

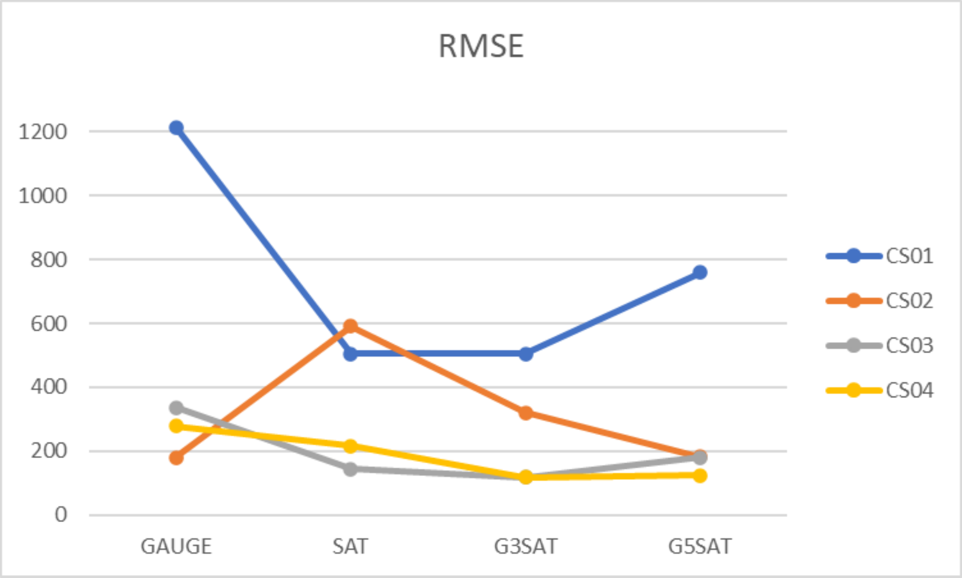

7. Conclusion

- The accuracy of results of many hydrological computations depends on the accuracy of Areal Precipitation Estimation.
- The spatial sampling of the rain gauge monitoring network does not respect a minimum density standard established by the WMO, as in the case of Italy.
- In the areas where rain gauges are very limited or even absent, an improvement using modern remote-sensing techniques such as radar, satellite data is essential.
- Cellular Automata is a strategy tool to rebuilt a more realistic precipitation field using different observed sources.
- The results show an improvement in the performance of hydrological simulations when satellite and rain gauge data are merged.

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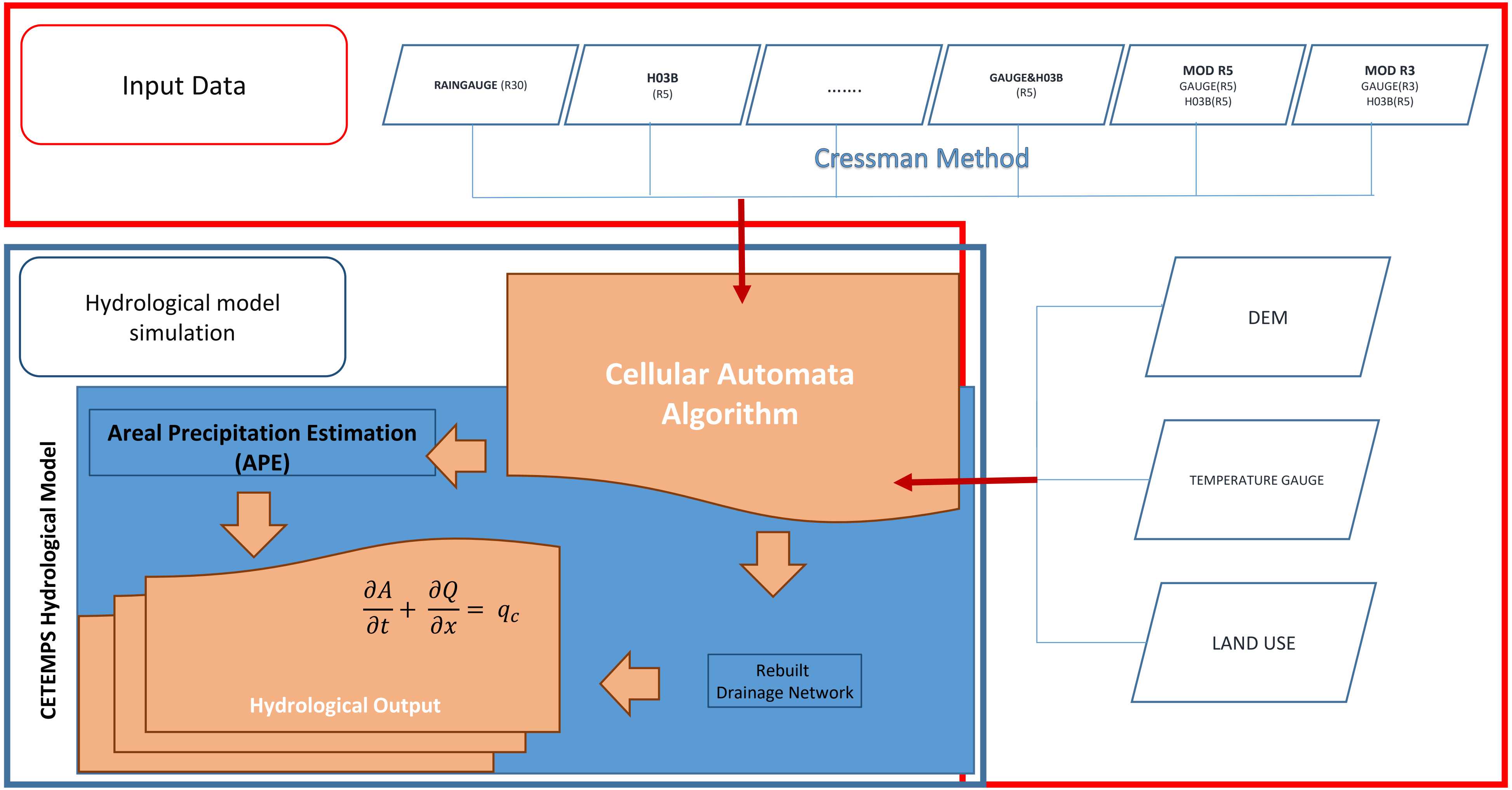
Thank you!!!

Work Flow


Input Data
RAINGAUGE (R30)
H03B (R5)
....
GAUGE&H03B (R5)
MOD R5 GAUGE(R5) H03B(R5)
MOD R3 GAUGE(R3) H03B(R5)
Cressman Method
Hydrological model simulation
CETEMPS Hydrological Model
Cellular Automata Algorithm
Areal Precipitation Estimation (APE)
$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c$$
Hydrological Output
Rebuilt Drainage Network
DEM
TEMPERATURE GAUGE
LAND USE