POLITECNICO DI MILANO

Vienna, 18 - 22 April 2016

Session HS4.1/AS4.30/GM9.12/NH1.7
Flash floods and associated hydro-geomorphic processes: observation, modelling and warning

Real time probabilistic precipitation forecasts in the Milano urban area: comparison between a physics and pragmatic approach

A. Ceppi[1] G. Ravazzani[1], A. Amengual[2], G. Lombardi[1], V. Homar[2], R. Romero[2] and M. Mancini[1]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy

[2] Grup de Meteorologia, Departament de Física, Universitat de les Illes Balears, Palma de Mallorca, Spain

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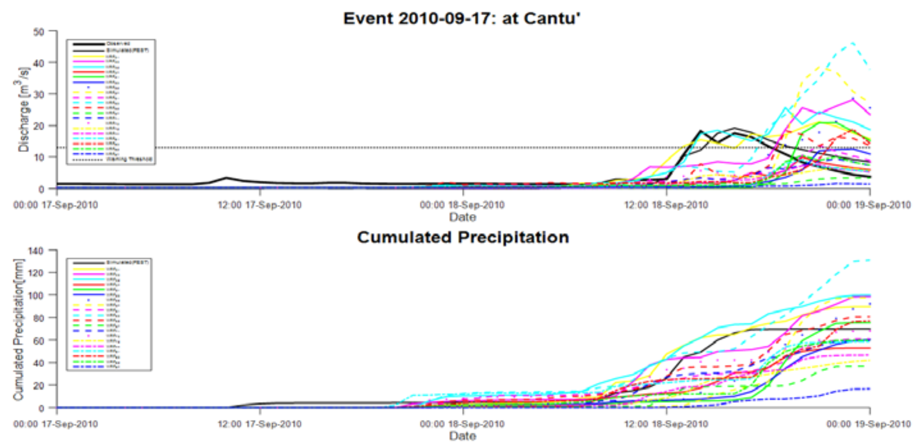
Background

Precipitation forecasts from mesoscale numerical weather prediction (NWP) models often contain features that are not deterministically predictable. In particular, accurate forecasts of deep moist convection and extreme rainfall are arduous to be predicted in terms of amount, time and target over small hydrological basins due to uncertainties arising from the numerical weather prediction, physical parameterizations and high sensitivity to misrepresentation of the atmospheric state, therefore they require a probabilistic forecast approach.

Objectives

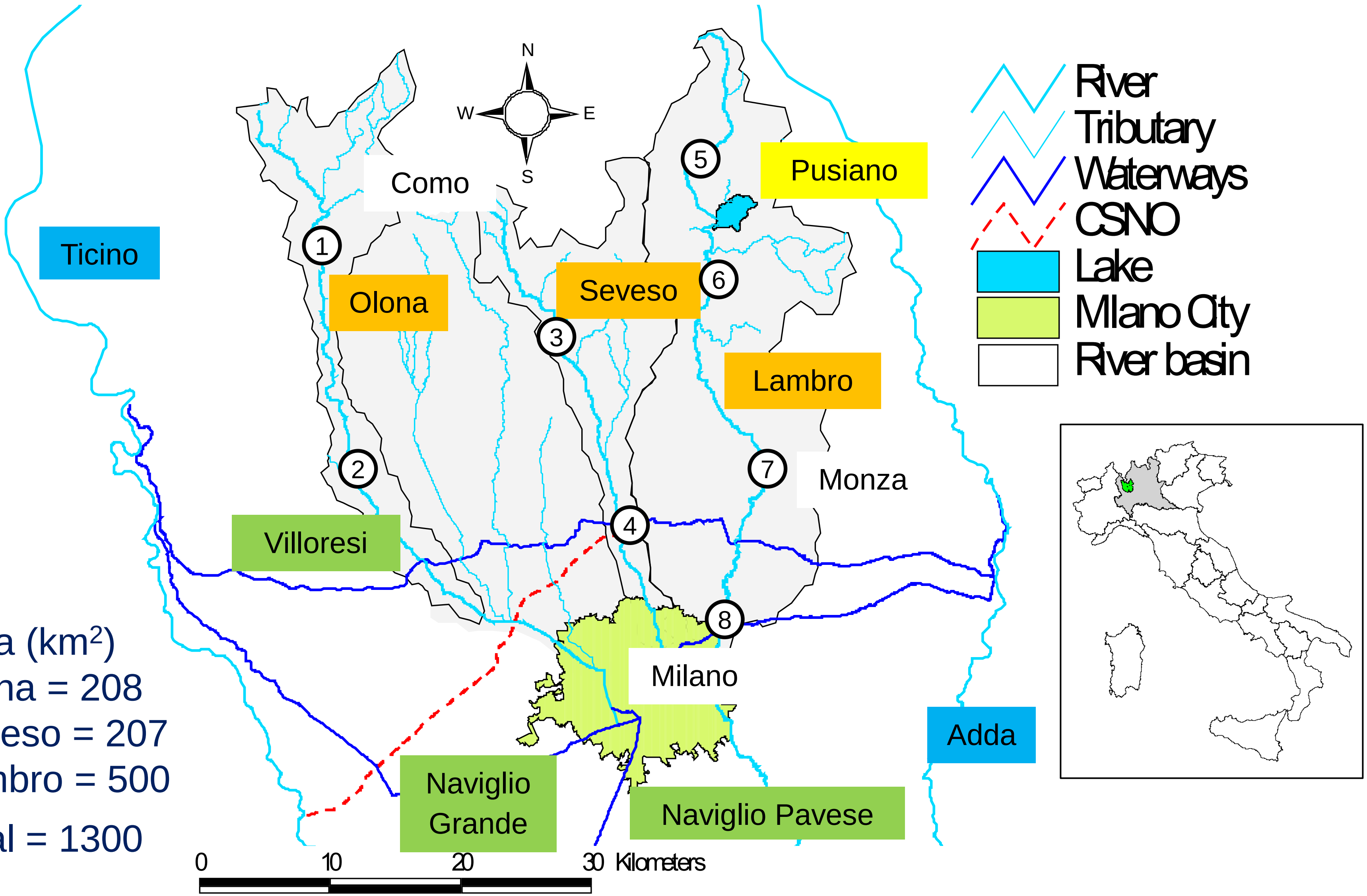
Explore different set-ups of ENSEMBLE simulations to detect what is the most reliable for real time flood forecasting of convective events in Milan



Approach

The first approach is based on a hydrological ensemble prediction system (HEPS) designed to explicitly cope with uncertainties in the initial and lateral boundary conditions (IC/LBCs) and physical parameterizations of the NWP model. The second involves a pragmatic post-processing procedure by randomly shifting in space the precipitation field provided by the deterministic WRF control run in order to get a cluster of different simulations.

Area of study

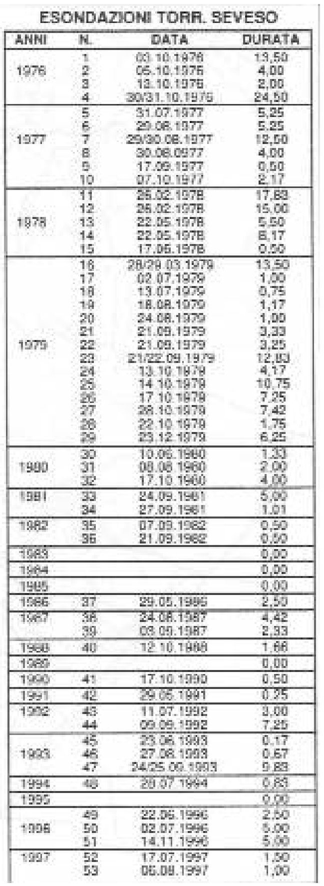


Area (km^2)
Olona = 208
Seveso = 207
Lambro = 500

Total = 1300

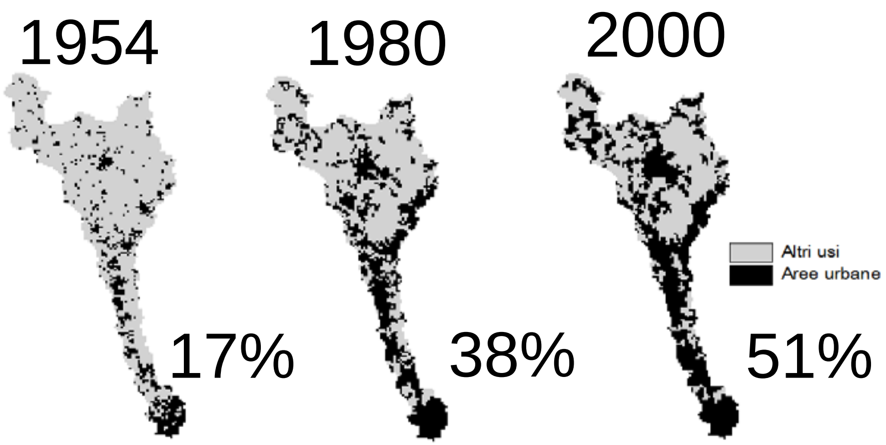
Flood and urbanization problem

Milan city is a flood prone area that has been frequently flooded in the past and recent years.



ESONDAZIONI TORR. SEVESO

ANNI	N.	DATA	DURATA
1976	1	03.10.1976	13,50
	2	05.10.1976	4,00
	3	13.10.1976	2,00
	4	30/31.10.1976	24,50
1977	5	31.07.1977	5,25
	6	29.08.1977	5,25
	7	29/30.08.1977	12,50
	8	30.08.0977	4,00
	9	17.09.1977	0,50
	10	07.10.1977	2,17
1978	11	26.02.1978	17,83
	12	26.02.1978	15,00
	13	22.05.1978	5,50
	14	22.05.1978	8,17
	15	17.06.1978	0,50
1979	16	28/29.03.1979	13,50
	17	02.07.1979	1,00
	18	13.07.1979	0,75
	19	18.08.1979	1,17
	20	24.08.1979	1,00
	21	21.09.1979	3,33
	22	21.09.1979	3,25
	23	21/22.09.1979	12,83
	24	13.10.1979	4,17
	25	14.10.1979	10,75
	26	17.10.1979	7,25
	27	28.10.1979	7,42
	28	22.10.1979	1,75
	29	23.12.1979	6,25
1980	30	10.06.1980	1,33
	31	08.08.1980	2,00
	32	17.10.1980	4,00
1981	33	24.09.1981	5,00
	34	27.09.1981	1,01
1982	35	07.09.1982	0,50
	36	21.09.1982	0,50
1983			0,00
1984			0,00
1985			0,00
1986	37	29.05.1986	2,50
1987	38	24.08.1987	4,42
	39	03.09.1987	2,33
1988	40	12.10.1988	1,66
1989			0,00
1990	41	17.10.1990	0,50
1991	42	29.06.1991	0,25
1992	43	11.07.1992	3,00
	44	09.09.1992	7,25
1993	45	23.06.1993	0,17
	46	27.08.1993	0,67
	47	24/25.09.1993	9,83
1994	48	28.07.1994	0,83
1995			0,00
1996	49	22.06.1996	2,50
	50	02.07.1996	5,00
	51	14.11.1996	5,00
1997	52	17.07.1997	1,50
	53	06.08.1997	1,00



URBAN AREA

List of main floods in the 70s, 80s and 90s

Recent floods: the seven analyzed events

7 February 2009

- Strafitorm precipitation
- Basins: Olona, Seveso and Lambro

15 July 2009

- Convective precipitation
- Basin: Olona

18 September 2010

- Strafitorm precipitation
- Basins: Seveso and Lambro

8 July 2014

- Convective precipitation
- Basins: Seveso and Lambro

27 April 2009

- Strafitorm precipitation
- Basins: Olona, Seveso and Lambro

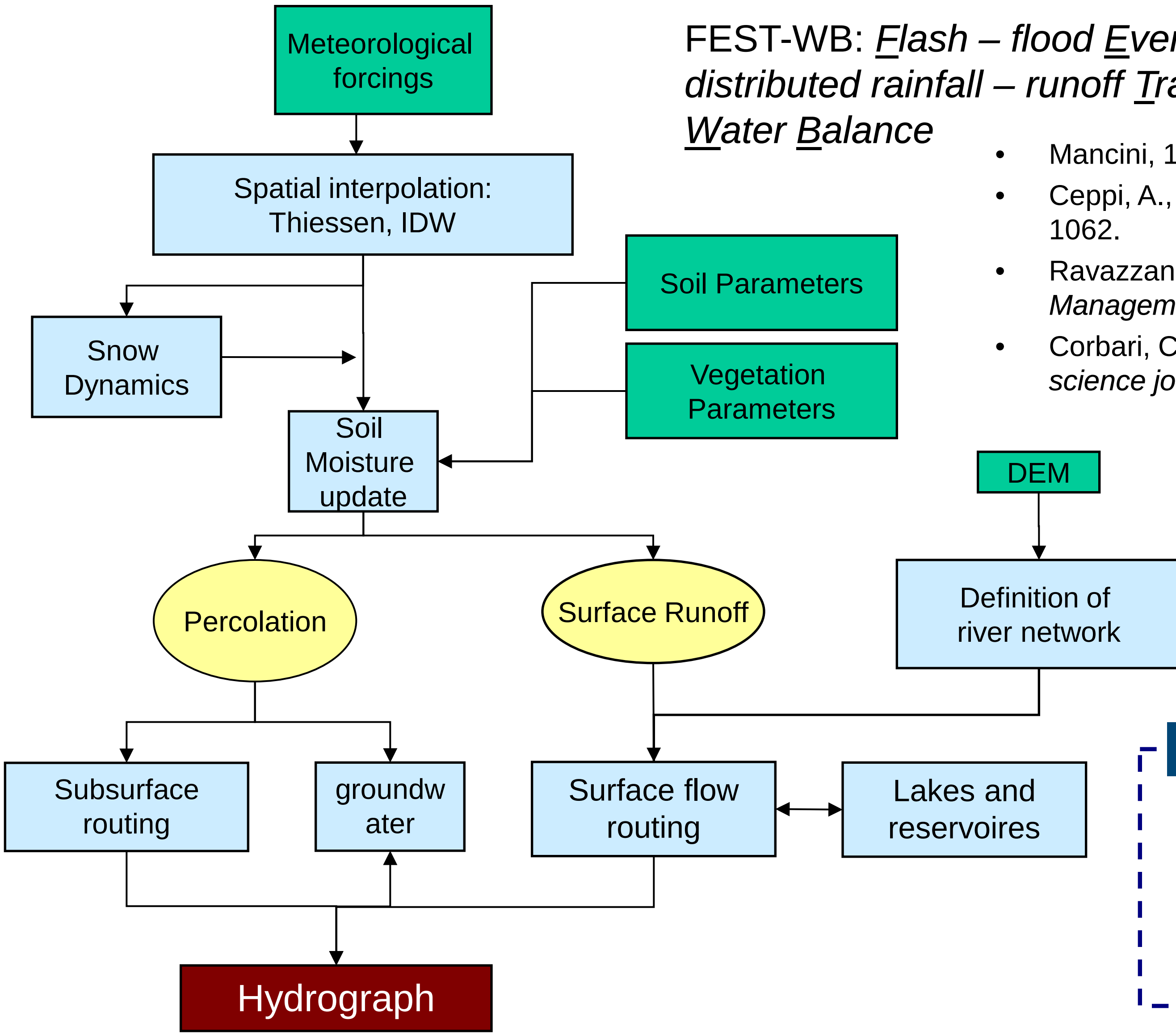
12 August 2010

- Convective precipitation
- Basins: Seveso and Lambro

1 November 2010

- Strafitorm precipitation
- Basins: Olona, Seveso and Lambro

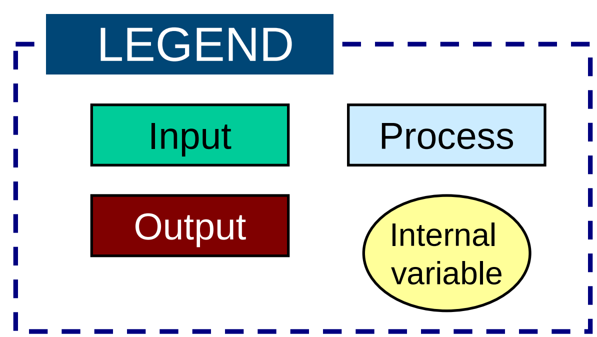
Hydrological model: FEST-WB



FEST-WB: *Flash – flood Event – based Spatially – distributed rainfall – runoff Transformation – including Water Balance*

- Mancini, 1990: *PhD thesis*
- Ceppi, A., et al. 2013: *NHESS*, 13(4), 1051-1062.
- Ravazzani, G. et al., 2014: *Water Resources Management*, 28(4), 1033-1044
- Corbari, C., Mancini, M., 2014: *Hydrological science journal*, 59 (10), 1830-1843

⊗x = 200 m ⊗t = 1 h

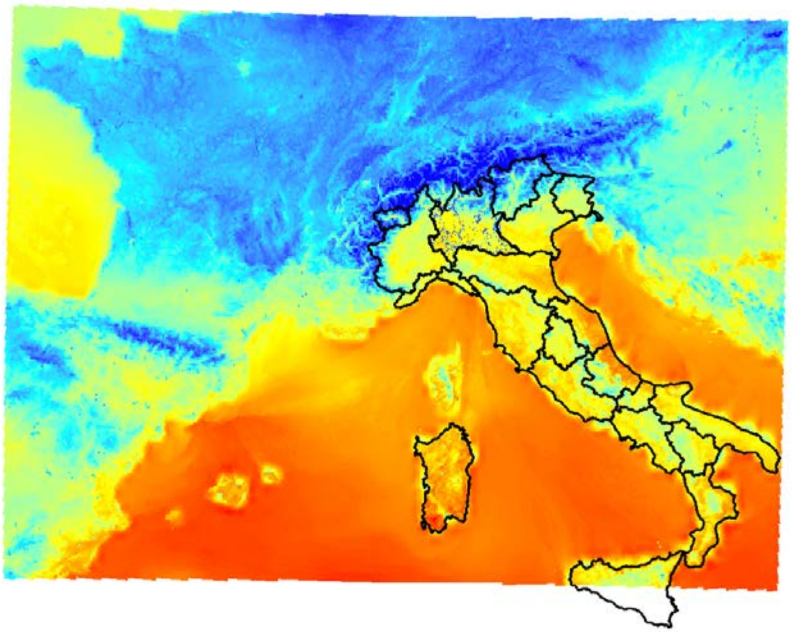


Dynamical downscaling performed with WRF 3.4 with: 2.5 km grid spacing and 28 vertical levels

Initial and Boundary Conditions coming from the global ECMWF

HIGH RESOLUTION => CONVECTION EXPLICITLY SOLVED

The WRF model domain



Initial and Boundary condition: ECMWF 0.25°
WRF grid: 2.5 km
Forecast horizon: 48h
Temporal output: 1 hour
Starting run: 00:00 UTC
Vertical levels: 28
Shortwave radiation scheme for the WRF: Dudhia; Dudhia (1989, JAS)
Longwave radiation scheme for the WRF: RRTM; Mlawer et al. (1997, JGR)
Microphysics scheme for the WRF: WSM6; Hong and Lim (2006, JKMS)
Land surface model: Noah
Planetary boundary layer for the WRF: MYJ; Janjic (1994, MWR)

Different approaches: physics vs pragmatic

Determistic

- Control Run

Perturbed Initial and Lateral Boundaries (PILB) ensemble

- Different initial and lateral boundaries conditions

Mixed-physics (MPS) ensemble

- A mix of microphysical scheme and boundary layer scheme

Mixed-physics1h (MPS1h) ensemble

- As MPS but with lateral boundary conditions hourly update

Lagged ensemble

- Different lag time

Lagged1h ensemble

- As Lagged but with lateral boundary conditions hourly update

physics

Shift Target (ST) ensemble

- Shift of the precipitations maps

pragmatic

PILB: Perturbed Initial and Lateral Boundaries (PILB) ensemble

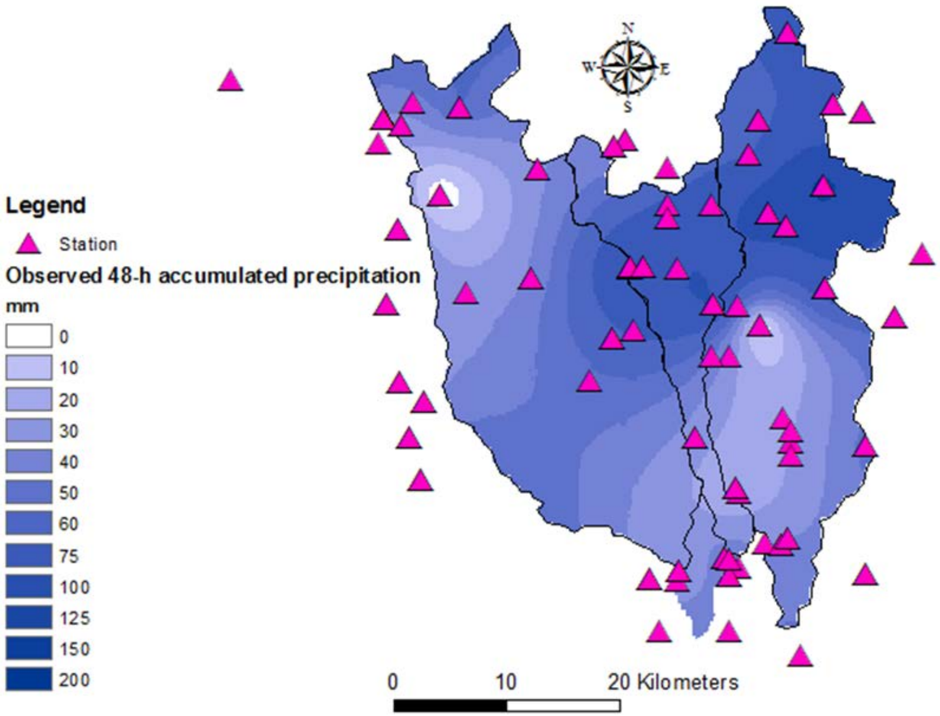
European Center for Medium range Weather Forecasts – global Ensemble Predictions System (ECMWF-EPS) consists of 50 members, operating at T639 spectral resolution (~32 km), that are generated by perturbing an initial analysis. Perturbations are derived from flow-dependent singular vectors computed daily at ECMWF in order to span the synoptic-scale uncertainties of the day (Buizza and Palmer, 1995; Molteni et al., 1996). The 20 ECMWF-EPS members exhibiting the largest diversity over our numerical domain are identified and used as initial and boundary conditions for the entire PILB ensemble. To this end, we applied to the 50 ECMWF-EPS members a k-means clustering algorithm using the Principal Components of the 500 hPa geopotential and 850 hPa temperature fields over the area spanned by the WRF domain.

MPS: Mixed-physics ensemble

Microphysics scheme	Planetary boundary scheme (PBL)
Purdue Lin (Lin et al., 1983)	Yonsei University (YSU; Hong et al, 2009)
Ferrier (1994)	***Mellor-Yamada-Janjic*** (MYJ; Janjic, 1994)
WRF single-moment 6-class (WSM6; Hong and Lim, 2006)	Mellor-Yamada Nakanishi Niino level 2.5 (MYNN; Nakanishi and Niino, 2006)
Goddard scheme (Tao et al., 1989)	Asymmetric convection model 2 scheme (ACM2; Pleim, 2007)
New Thompson (Thomson et al., 2008)	

Ravazzani., G., Amengual, A., Ceppi, A., Lombardi, G., Romero, R., Homar, V., Mancini, M. A hydro-meteorological ensemble prediction system for real-time flood forecasting purposes in the Milano area. ***Submitted to Journal of hydrology.*** *Special issue "Flash floods, hydro-geomorphic response and risk management"*

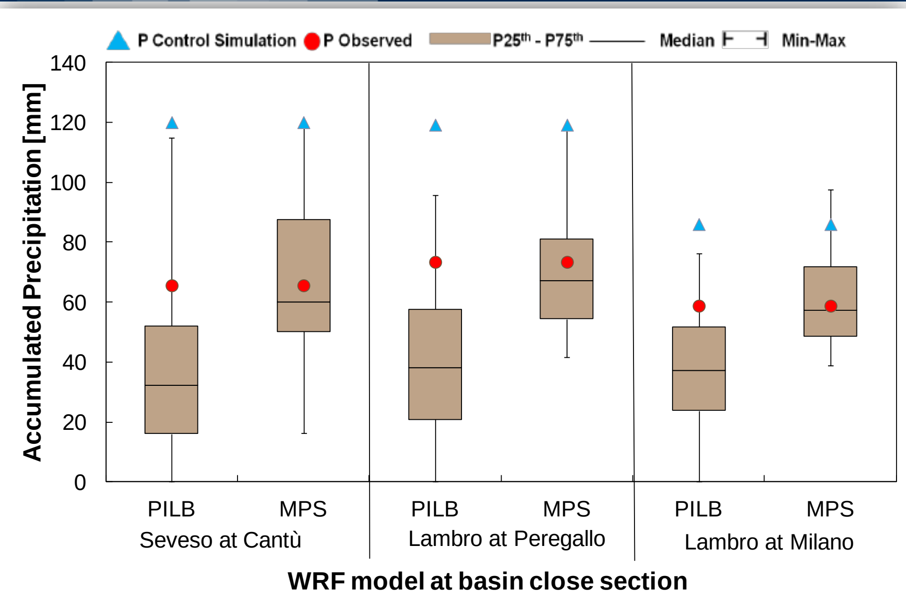
18 SEPTEMBER 2010

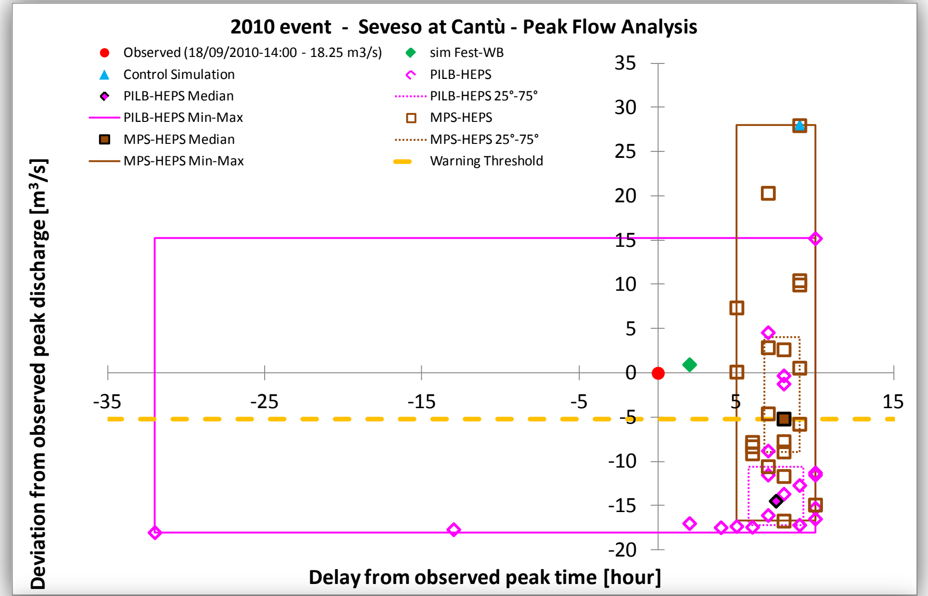


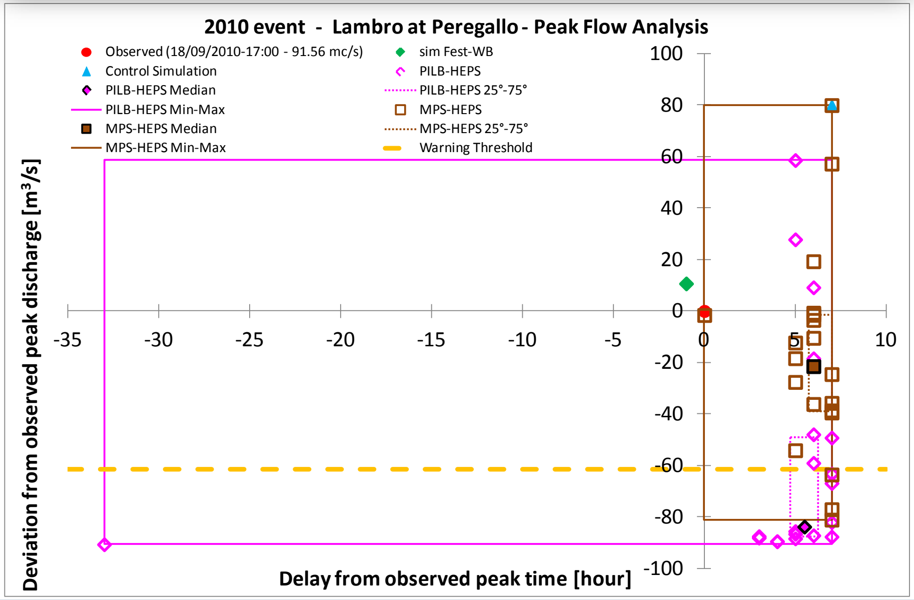
80 milion € as total damages!

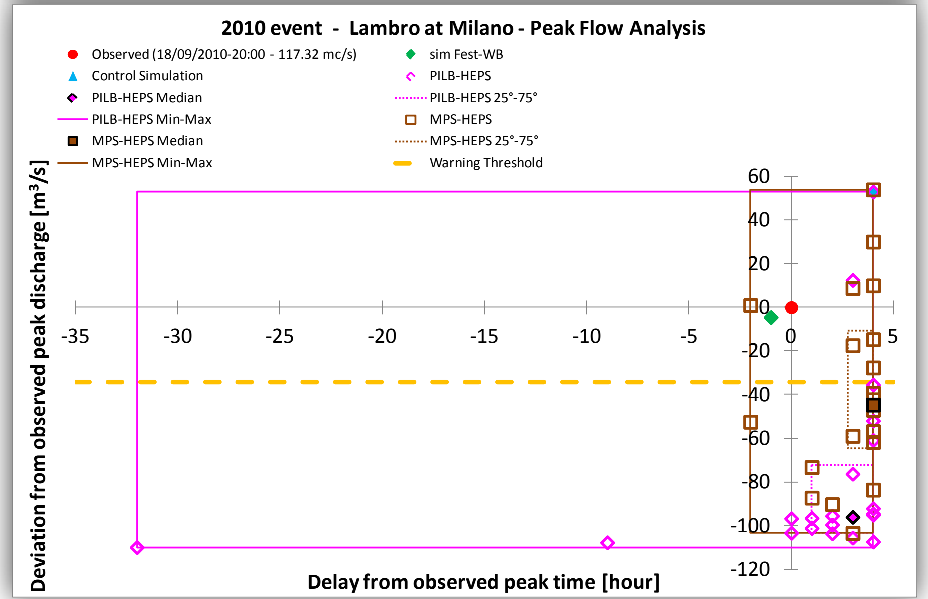
Results: Precipitation and Discharge PILB vs MPS

Peak Box plot, Zappa et al, 2013 (*Hydrological processes*)



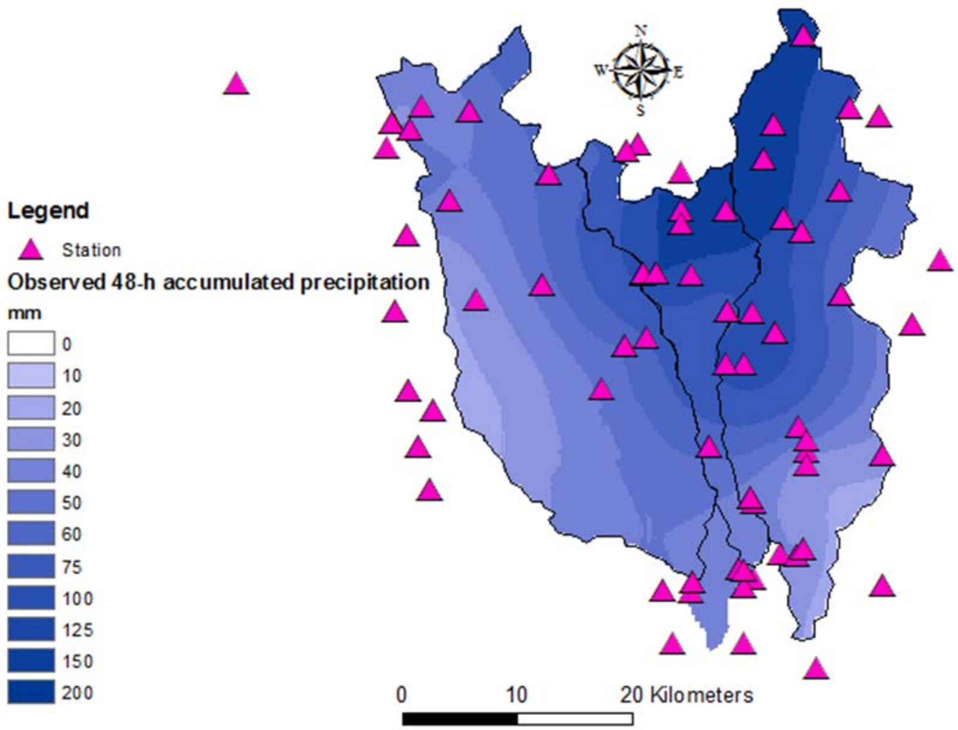






Reanalysis of the two major convective flood events

8 JULY 2014

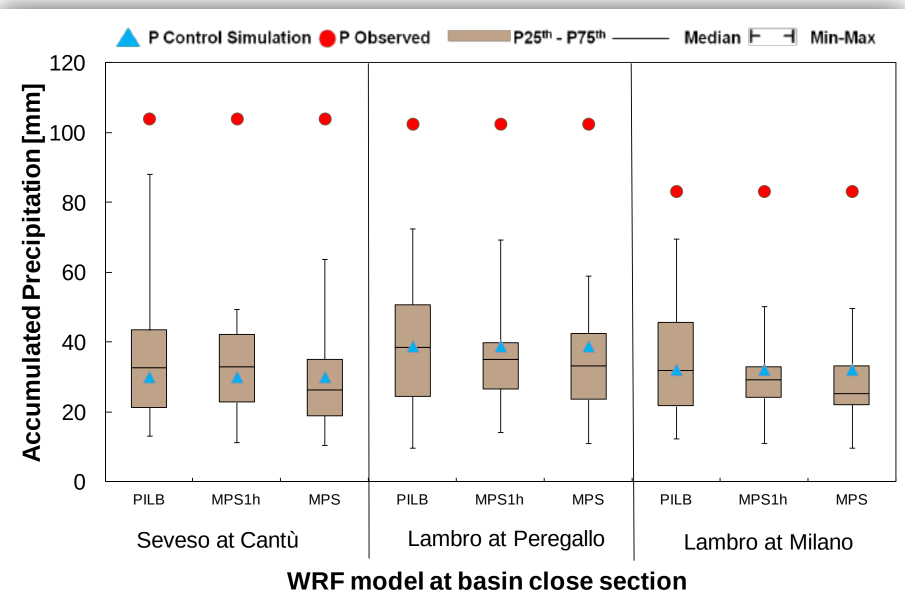


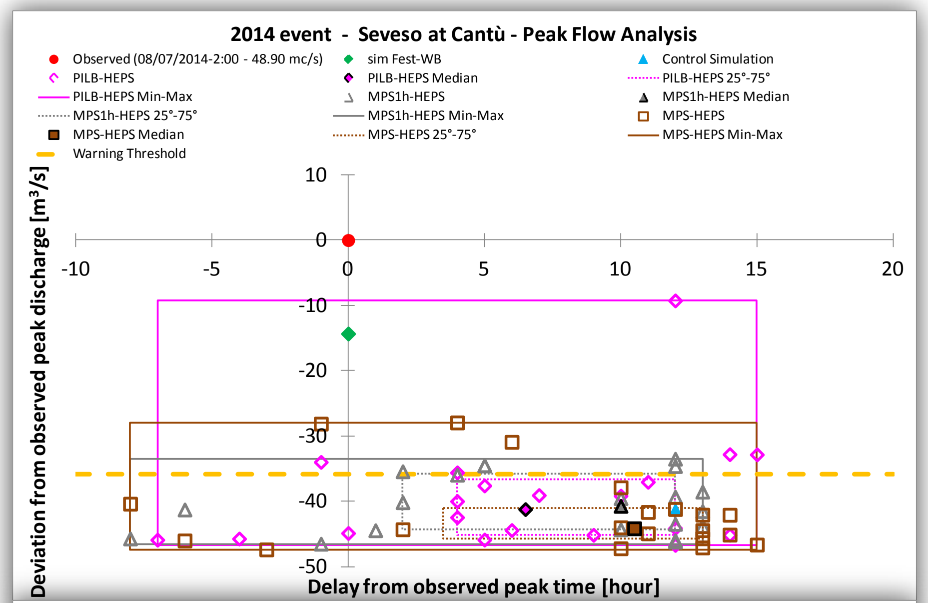
Return period of this meteorological event: 100-200 years

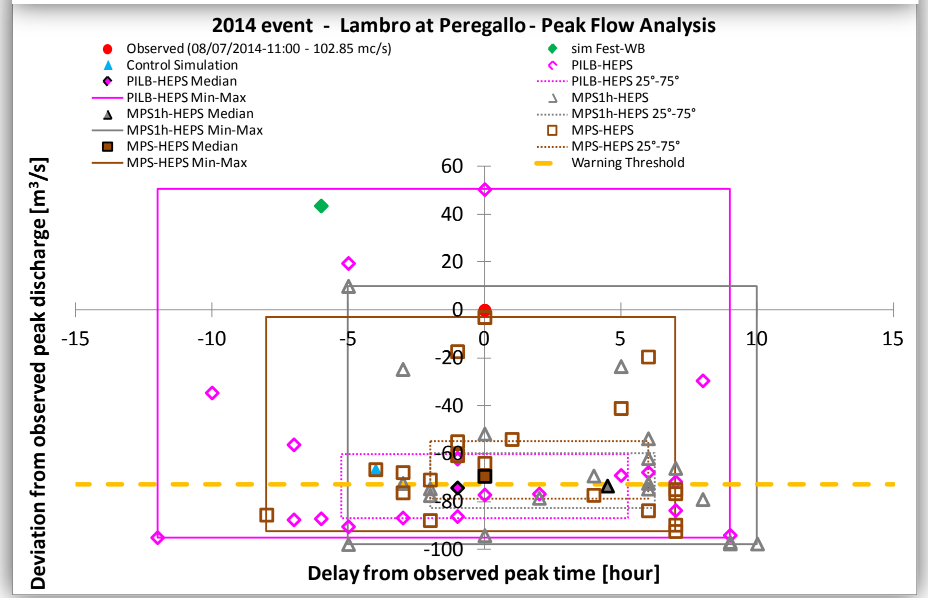
55 milion € as total damages!

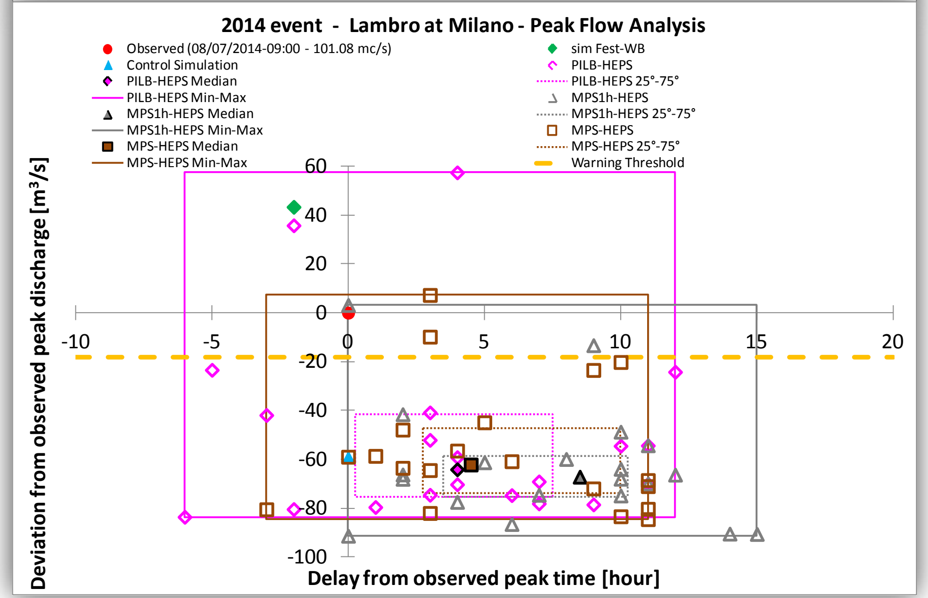
Results: Precipitation and Discharge **PILB, MPS, MPS1h**

Peak Box plot, Zappa et al, 2013 (*Hydrological processes*)





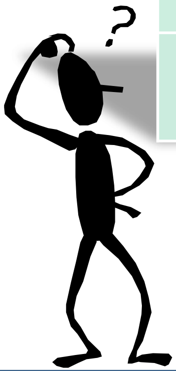




Results – Probabilistic PILB, MPS, MPS1h, Lagged and Lagged 1h

% Ensemble exceeding the warning threshold		18 September 2010		
		PILB	MPS	Lagged
Seveso	Cantù	20%	50%	18%
Lambro	Peregallo	35%	85%	55%
	Milano	10%	40%	27%

% Ensemble exceeding the warning threshold		8 July 2014				
		PILB	MPS1h	MPS	Lagged1h	Lagged
Seveso	Cantù	25%	25%	15%	17%	42%
Lambro	Peregallo	50%	50%	55%	25%	42%
	Milano	10%	10%	10%	0%	0%

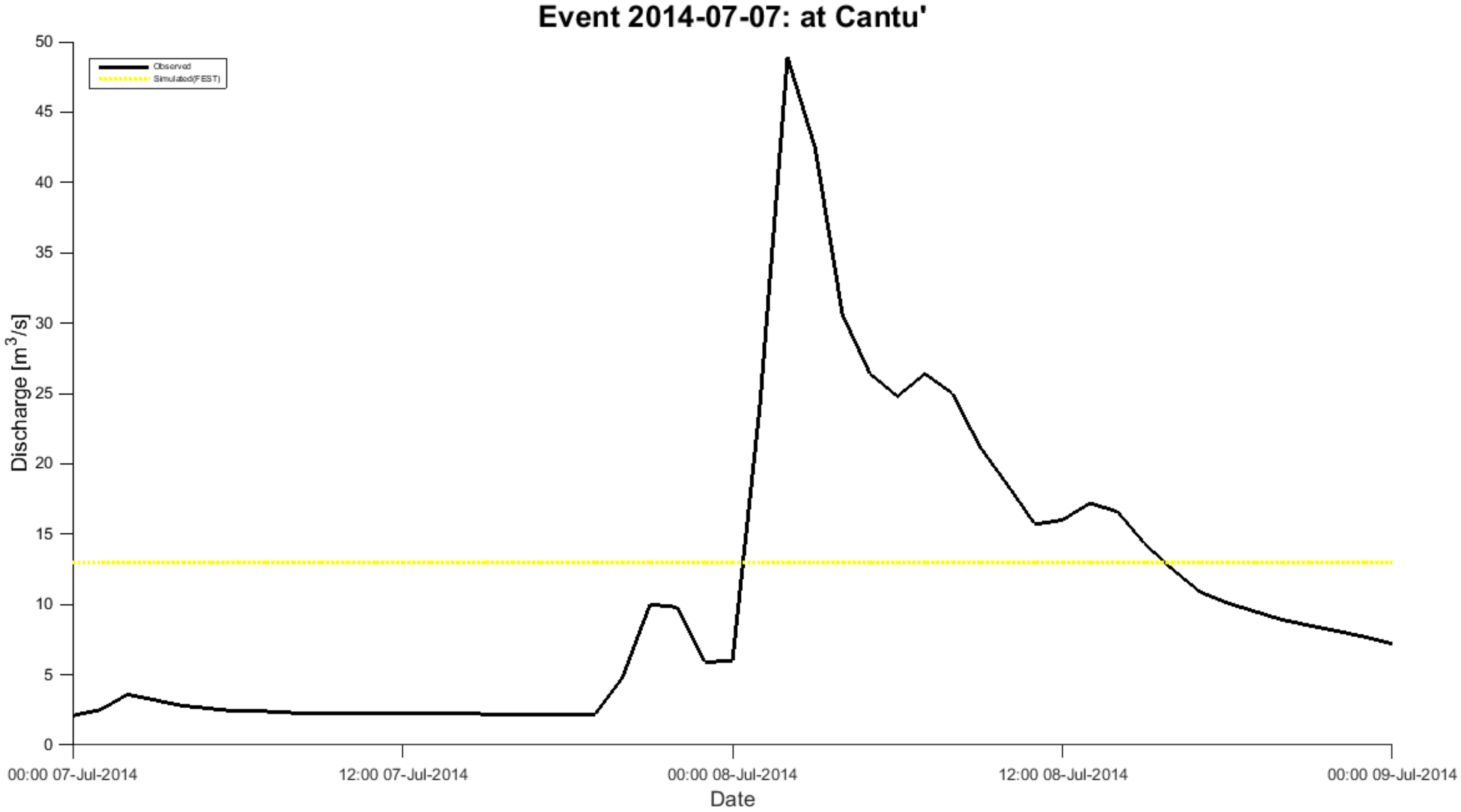


This physics approach has a high computational cost!

The convective event of 8 July 2014 on the Seveso basin

Cantù gauging section

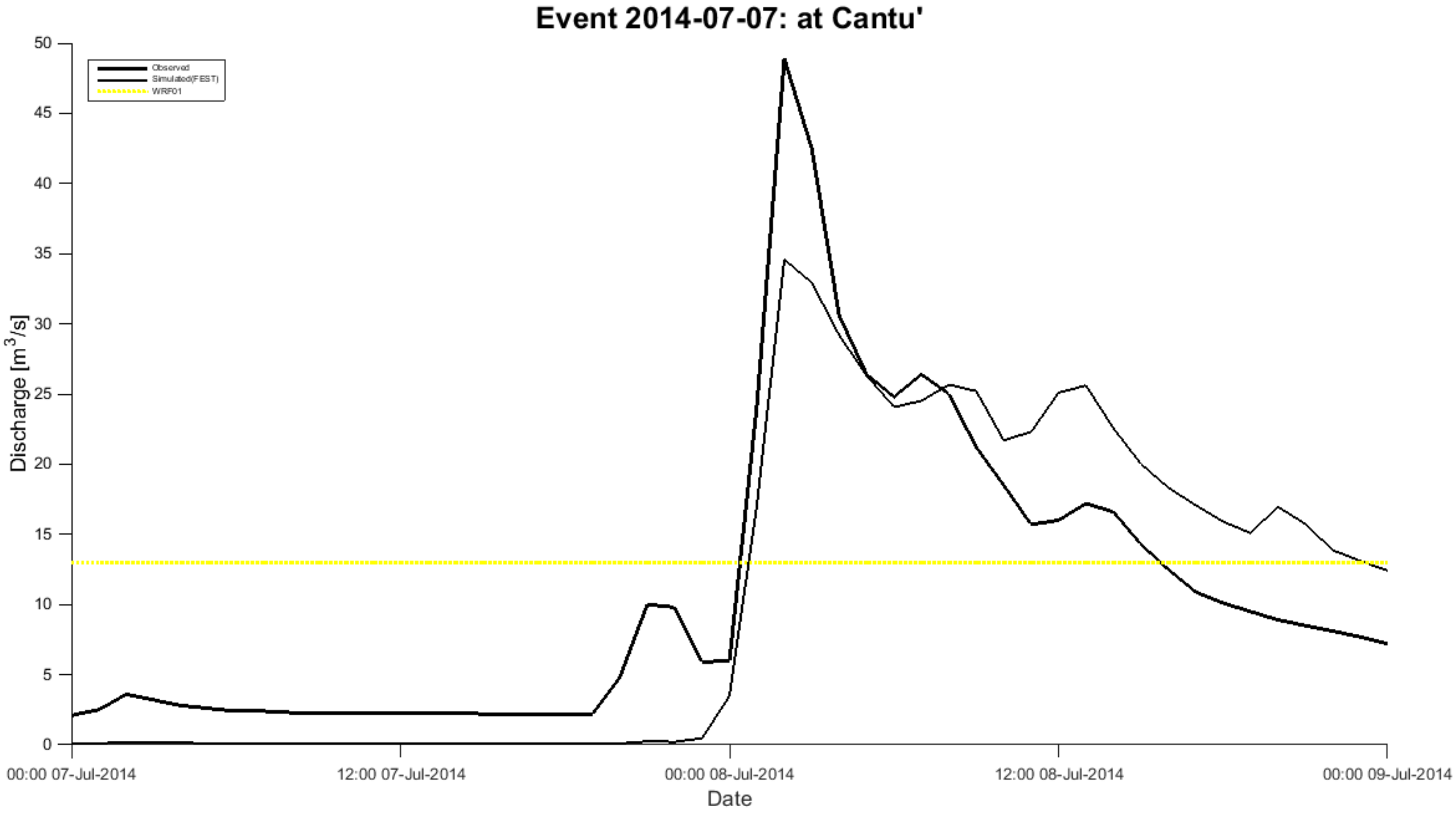
Q observed: 48.9 m^3/s



The convective event of 8 July 2014 on the Seveso basin

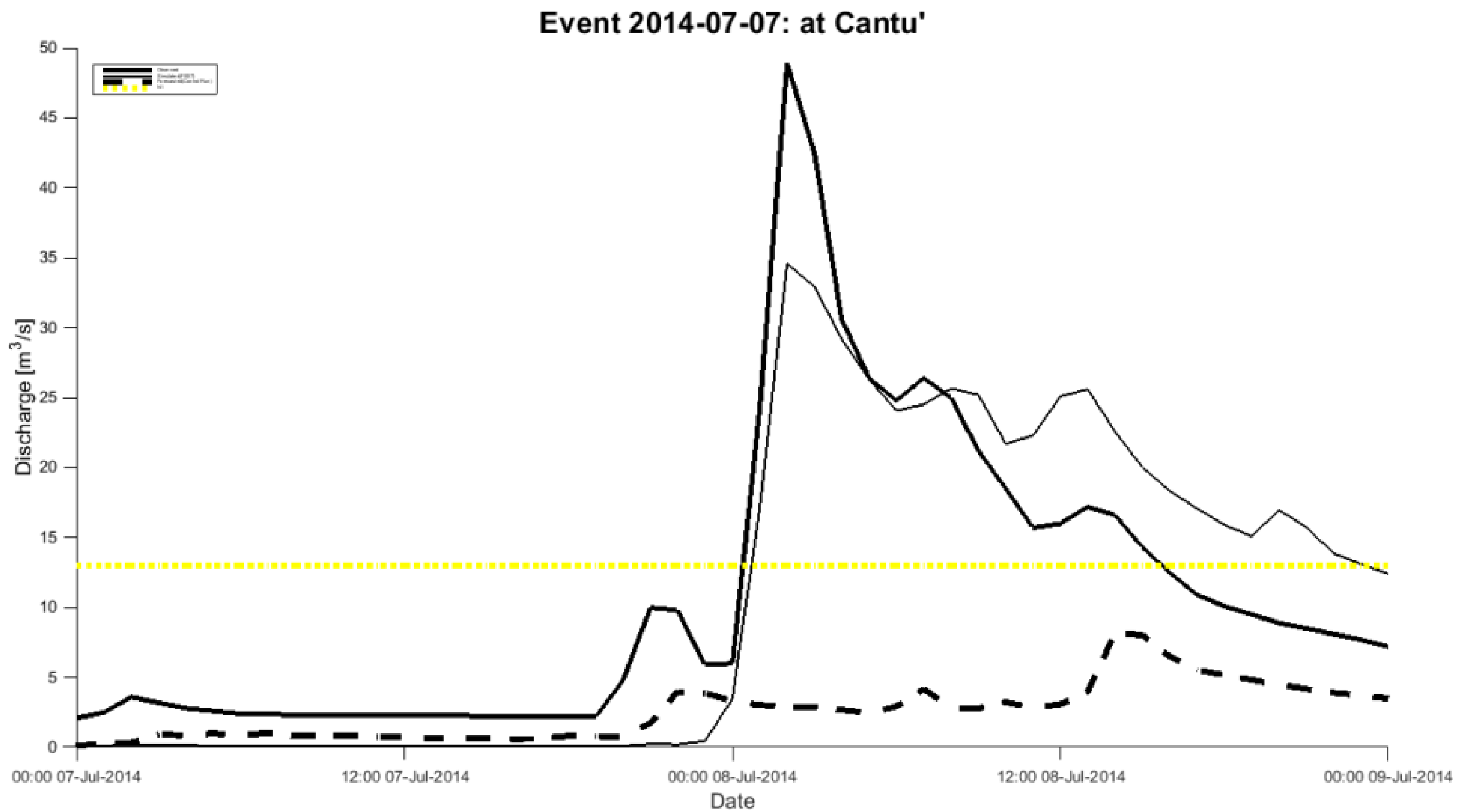
Cantù gauging section

Q simulated by the hydrological model FEST-EWB: 34.6 m^3/s



Cantù gauging section

Q forecasted by the meteorological WRF deterministic model: 8.2 m^3/s

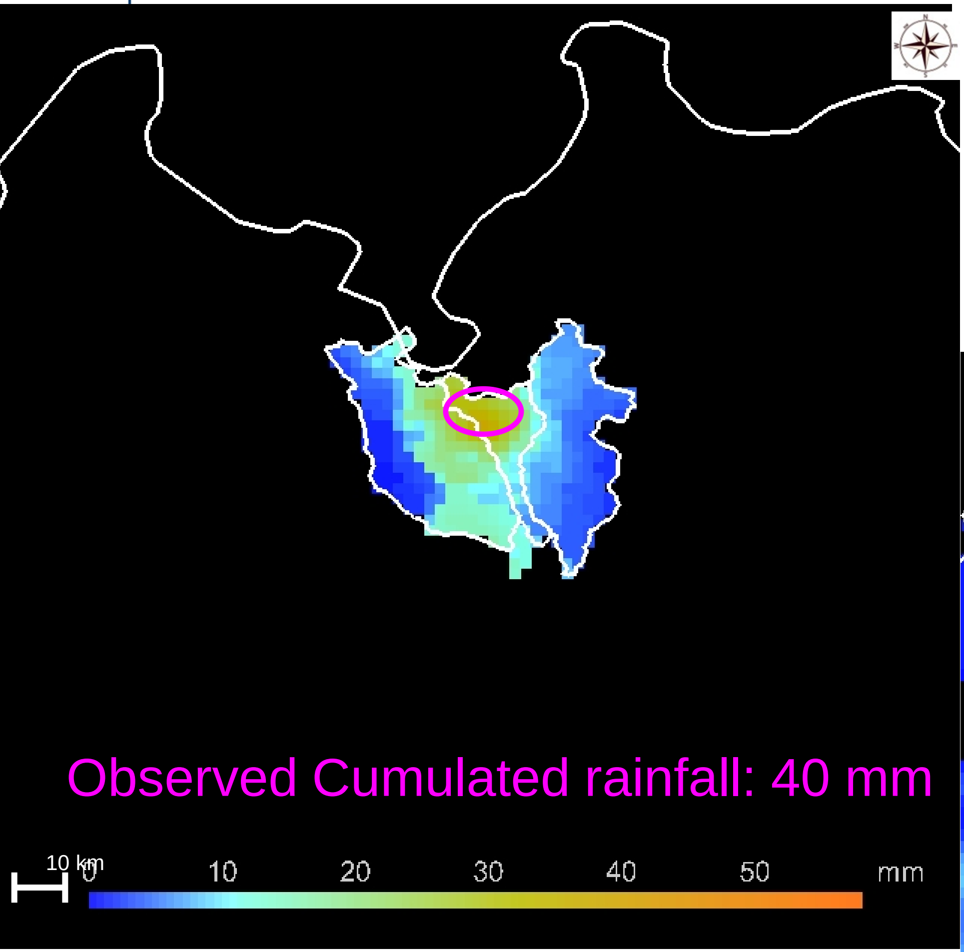


Spatial comparison of the target rainfall: observed vs forecasted

Observed precipitation

00:00UTC-08/07/2014

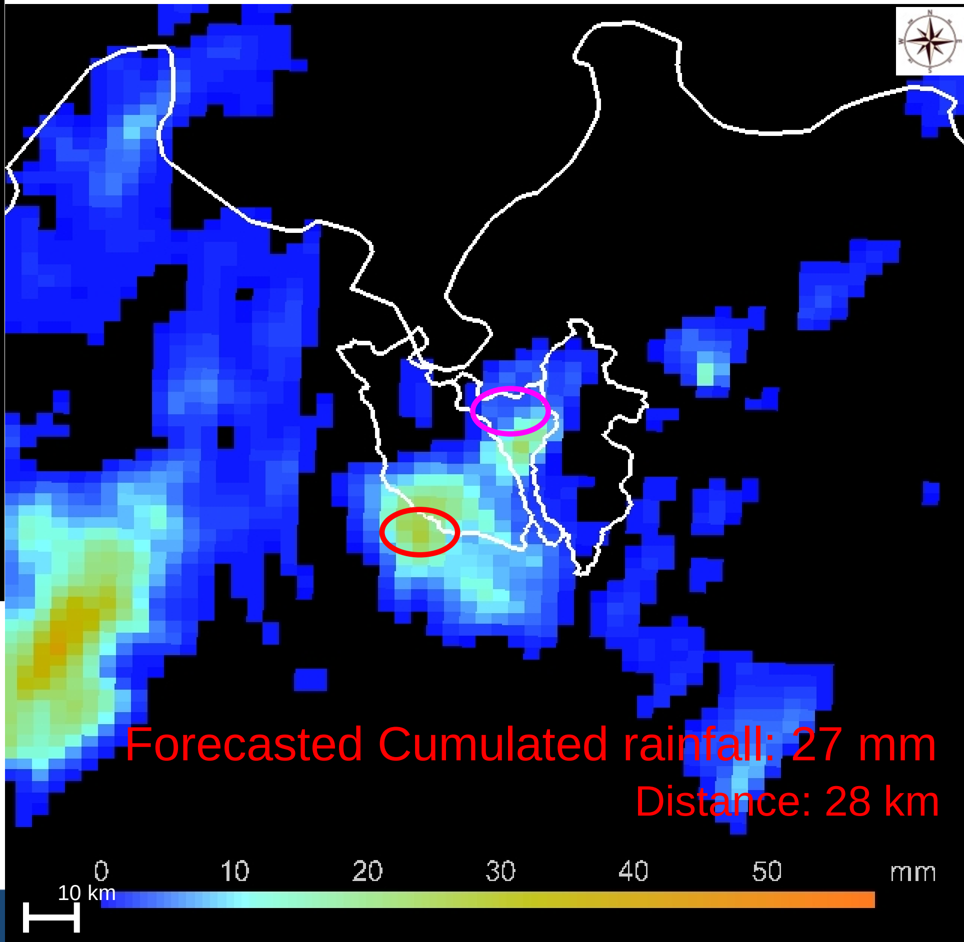
01:00UTC-08/07/2014



Forecasted precipitation

20:00UTC-07/07/2014

21:00UTC-07/07/2014

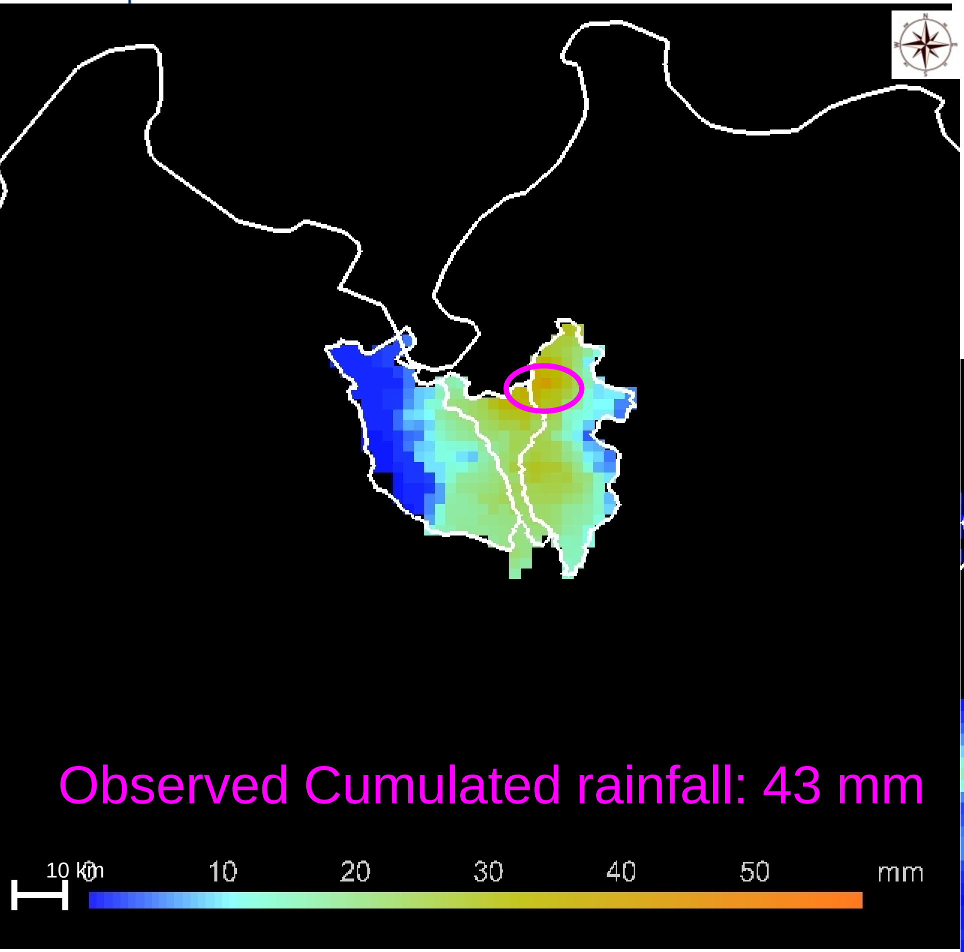


Spatial comparison of the target rainfall: observed vs forecasted

Observed precipitation

00:00UTC-08/07/2014

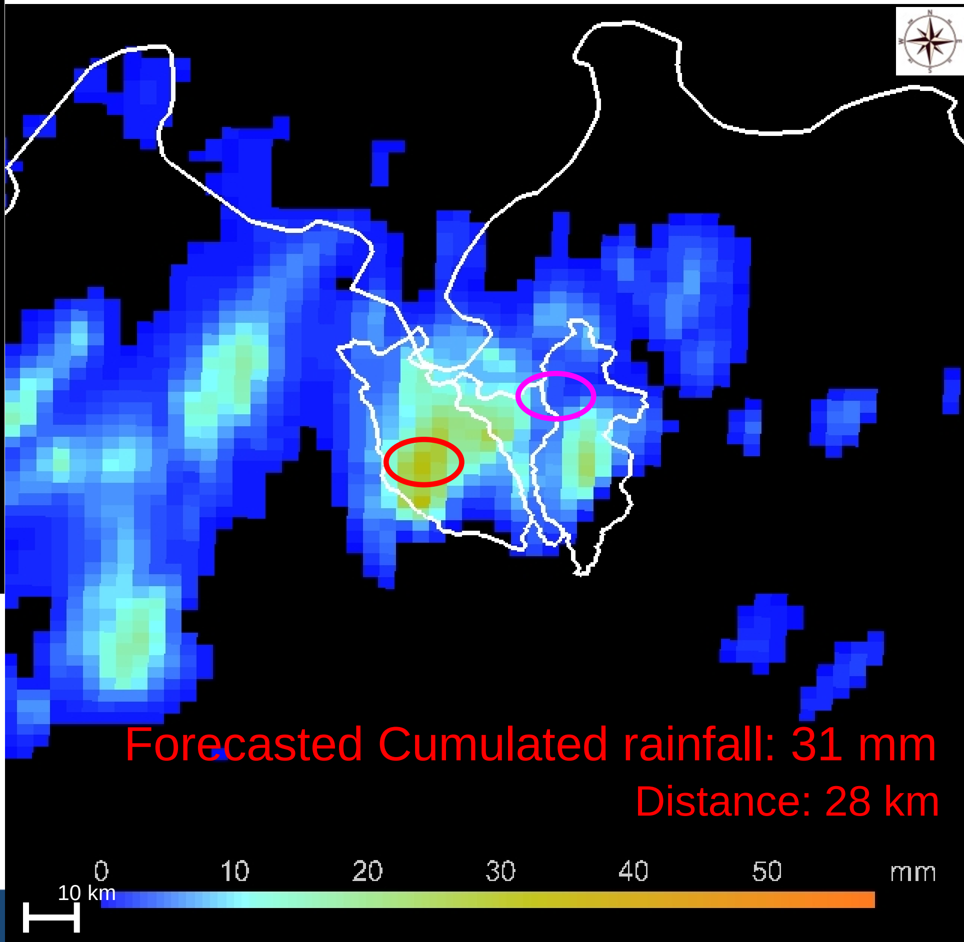
01:00UTC-08/07/2014



Forecasted precipitation

20:00UTC-07/07/2014

21:00UTC-07/07/2014



The pragmatic approach: Shift Target (ST) ensemble

Conceptual scheme

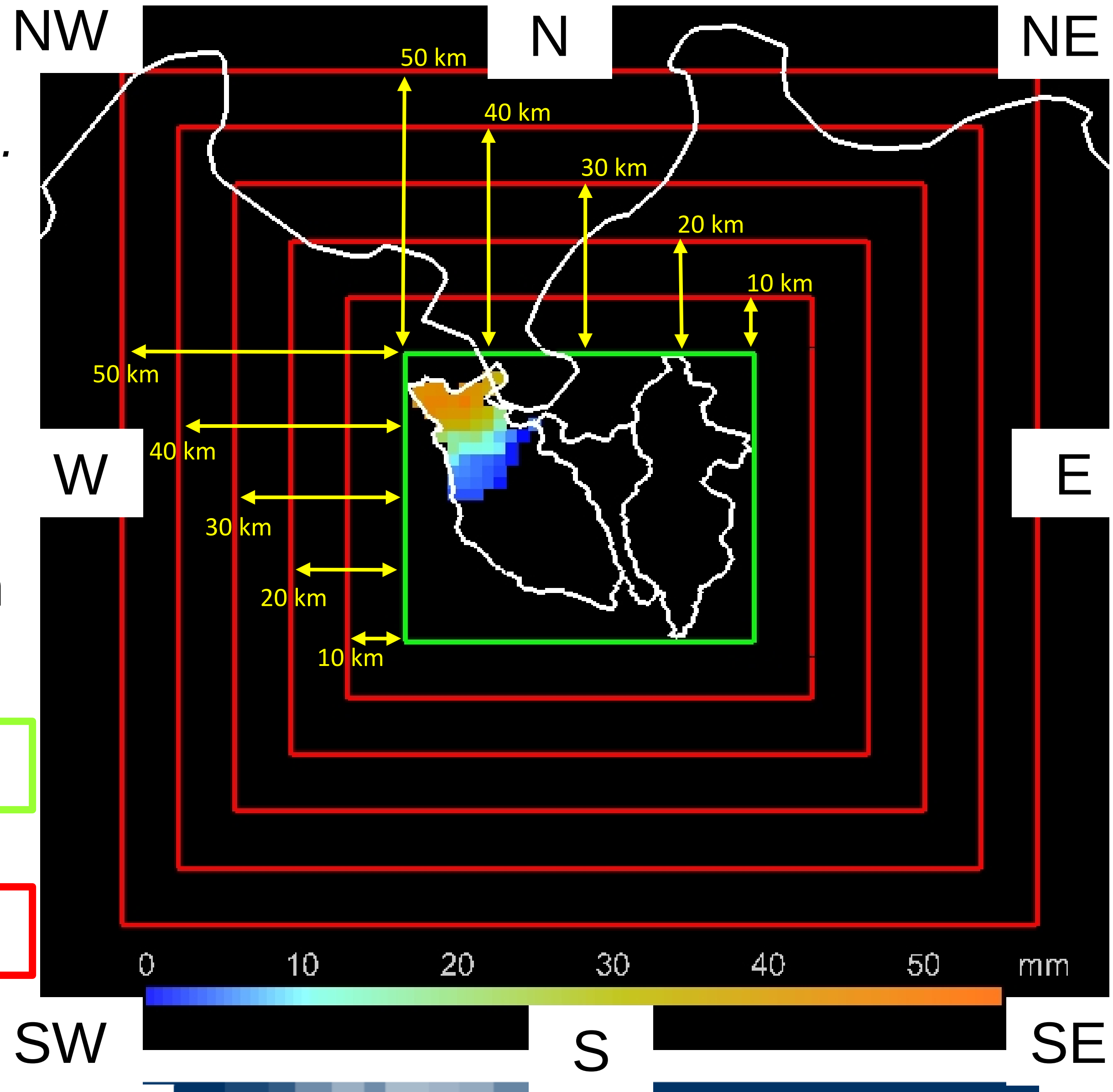
Theis et al., 2005, *Met. App.*

40 translations

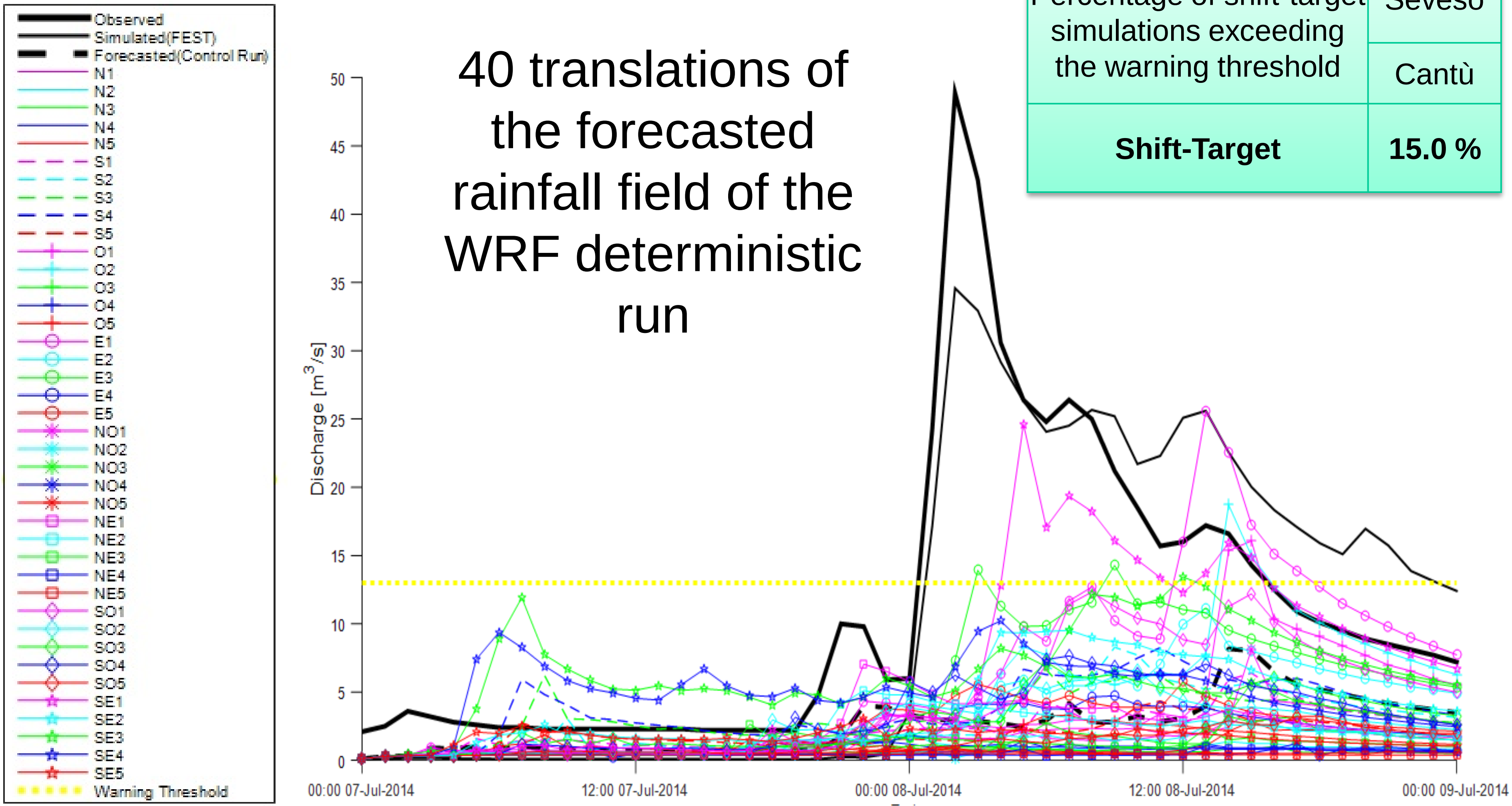
(N, NE, E, SE, S, SW, W, NW by 10, 20, 30, 40, 50 km) of the forecasted rainfall field of the WRF deterministic (control) run

Real domain, no shift

Shifted domain



The pragmatic approach: Shift Target (ST) ensemble



40 translations of the forecasted rainfall field of the WRF deterministic run

Percentage of shift-target simulations exceeding the warning threshold	Seveso Cantù
Shift-Target	**15.0 %**

The convective event of 7-8 July 2014 on the Seveso basin: shift-target simulations

From rainfall Shift Target (ST) simulations to probabilistic hydrological ensembles: the Union Jack plot

NO	-50	-40	-30	-20	-10	N	10	20	30	40	50	NE
50	0.93					2.87					0.54	50
40		1.25				1.64				1.05		40
30			5.67			1.41			2.65			30
20				2.93		2.09		5.12				20
10					8.12	3.92	7.05					10
O	3.30	1.42	3.22	**18.71**	**16.07**	8.18	**25.60**	11.16	**14.28**	4.73	5.77	E
-10					12.33	6.39	**24.63**					-10
-20				6.58		8.28		9.53				-20
-30			7.20			6.64			**13.44**			-30
-40		7.65				8.26				10.21		-40
-50	3.24					4.35					3.09	-50
SO	-50	-40	-30	-20	-10	S	10	20	30	40	50	SE

The values show each peak discharge for the 40 Shift-Target simulations

Key:

Not exceeding

Exceeding threshold

Exceeding rate:

Results – Deterministic (Control Run)

Date	Basin	Section	Q Observed[m³/s]	Warning Threshold[m³/s]	Q FEST-WB[m³/s]	Q Control Run[m³/s]
7 february 2009	Olona	Lozza	57.09	36	54.57	18.06
		Castellanza	57.04	43	61.64	20.21
	Seveso	Cantù	18.72	13	11.68	5.20
	Lambro	Peregallo	68.96	30	70.64	41.76
		Milano	-	-	-	-
27 april 2009	Olona	Lozza	38.99	36	28.17	26.97
		Castellanza	51.14	43	36.23	31.64
	Seveso	Cantù	18.89	13	21.52	12.47
	Lambro	Peregallo	49.48	30	19.48	30.00
		Milano	-	-	-	-
15 luglio 2009	Olona	Lozza	77.97	36	34.13	1.37
		Castellanza	54.59	43	18.94	1.45
	Seveso	Cantù	-	-	-	-
	Lambro	Peregallo	-	-	-	-
		Milano	-	-	-	-
12 august 2010	Olona	Lozza	-	-	-	-
		Castellanza	-	-	-	-
	Seveso	Cantù	15.40	13	10.56	23.17
	Lambro	Peregallo	145.82	30	108.66	83.38
		Milano	108.29	83	101.81	87.21
18 september 2010	Olona	Lozza	-	-	-	-
		Castellanza	-	-	-	-
	Seveso	Cantù	18.25	13	19.22	46.79
	Lambro	Peregallo	91.56	30	102.25	172.90
		Milano	117.32	83	112.78	172.82
1 november 2010	Olona	Lozza	40.35	36	64.77	46.91
		Castellanza	54.70	43	70.96	54.70
	Seveso	Cantù	24.86	13	32.43	16.71
	Lambro	Peregallo	104.79	30	131.80	34.63
		Milano	114.41	83	154.52	51.80
8 july 2014	Olona	Lozza	-	-	-	-
		Castellanza	-	-	-	-
	Seveso	Cantù	48.90	13	34.58	8.18
	Lambro	Peregallo	102.85	30	146.39	36.61
		Milano	101.08	83	144.39	42.46

Results – Shift Target (ST) ensemble

	Basin	Section	Q Observed[m³/s]	Warning Threshold[m³/s]	Q FEST-WB[m³/s]	Q Control Run[m³/s]	Exceeding % (ST)
7 february 2009	Olona	Lozza	57.09	36	54.57	18.06	7.5%
		Castellanza	57.04	43	61.64	20.21	10.0%
	Seveso	Cantù	18.72	13	11.68	5.20	25.0%
	Lambro	Peregallo	68.96	30	70.64	41.76	72.5%
		Milano	-	-	-	-	-
27 april 2009	Olona	Lozza	38.99	36	28.17	26.97	45.0%
		Castellanza	51.14	43	36.23	31.64	40.0%
	Seveso	Cantù	18.89	13	21.52	12.47	45.0%
	Lambro	Peregallo	49.48	30	19.48	30.00	52.5%
		Milano	-	-	-	-	-
15 luglio 2009	Olona	Lozza	77.97	36	34.13	1.37	0.0%
		Castellanza	54.59	43	18.94	1.45	0.0%
	Seveso	Cantù	-	-	-	-	-
	Lambro	Peregallo	-	-	-	-	-
		Milano	-	-	-	-	-
12 august 2010	Olona	Lozza	-	-	-	-	-
		Castellanza	-	-	-	-	-
	Seveso	Cantù	15.40	13	10.56	23.17	25.0%
	Lambro	Peregallo	145.82	30	108.66	83.38	37.5%
		Milano	108.29	83	101.81	87.21	22.5%
18 september 2010	Olona	Lozza	-	-	-	-	-
		Castellanza	-	-	-	-	-
	Seveso	Cantù	18.25	13	19.22	46.79	32.5%
	Lambro	Peregallo	91.56	30	102.25	172.90	45.0%
		Milano	117.32	83	112.78	172.82	30.0%
1 november 2010	Olona	Lozza	40.35	36	64.77	46.91	70.0%
		Castellanza	54.70	43	70.96	54.70	72.5%
	Seveso	Cantù	24.86	13	32.43	16.71	62.5%
	Lambro	Peregallo	104.79	30	131.80	34.63	75.0%
		Milano	114.41	83	154.52	51.80	55.0%
8 july 2014	Olona	Lozza	-	-	-	-	-
		Castellanza	-	-	-	-	-
	Seveso	Cantù	48.90	13	34.58	8.18	15.0%
	Lambro	Peregallo	102.85	30	146.39	36.61	32.5%
		Milano	101.08	83	144.39	42.46	0.0%

Shift Target (ST) ensemble: Union Jack plot, are they useful for civil protection purposes?

7 August 2010 – Lambro at Peregallo

NO	-50	-40	-30	-20	-10	N	10	20	30	40	50	NE
50	**33.87**					24.81					12.33	50
40		**49.03**				26.96				15.65		40
30			**47.37**			29.19			18.51			30
20				**45.71**		**30.15**		21.72				20
10					**40.58**	27.40	27.50					10
O	**87.62**	**62.34**	**74.69**	**76.53**	**33.16**	**41.76**	**59.26**	25.47	24.04	**40.69**	**53.70**	E
-10					**66.10**	**50.52**	**42.74**					-10
-20				**79.59**		**37.58**		**33.88**				-20
-30			**59.58**			**52.72**			**33.93**			-30
-40		**73.66**				**79.20**				**69.79**		-40
-50	**80.01**					**65.64**					**65.52**	-50
SO	-50	-40	-30	-20	-10	S	10	20	30	40	50	SE

NO	-50	-40	-30	-20	-10	N	10	20	30	40	50	NE
50	0.81					0.82					0.90	50
40		0.81				0.81				2.17		40
30			0.81			0.81			0.91			30
20				0.81		0.82		0.89				20
10					0.83	0.82	0.84					10
O	0.81	0.81	0.81	0.95	0.90	1.37	2.28	1.36	0.88	0.82	0.81	E
-10					2.22	2.65	3.61					-10
-20				3.10		4.06		0.86				-20
-30			1.24			5.32			0.81			-30
-40		0.86				0.94				0.93		-40
-50	0.90					0.83					0.82	-50
SO	-50	-40	-30	-20	-10	S	10	20	30	40	50	SE

NO	-50	-40	-30	-20	-10	N	10	20	30	40	50	NE
50	0.81					0.82					0.90	50
40		0.81				0.81				2.17		40
30			0.81			0.81			0.91			30
20				0.81		0.82		0.89				20
10					0.83	0.82	0.84					10
O	0.81	0.81	0.81	0.95	0.90	1.37	2.28	1.36	0.88	0.82	0.81	E
-10					2.22	2.65	3.61					-10
-20				3.10		4.06		0.86				-20
-30			1.24			5.32			0.81			-30
-40		0.86				0.94				0.93		-40
-50	0.90					0.83					0.82	-50
SO	-50	-40	-30	-20	-10	S	10	20	30	40	50	SE

Legend:

Don't exceeding threshold

Exceeding threshold

Exceeding rate:

NO	-50	-40	-30	-20	-10	N	10	20	30	40	50	NE
50	1.81					6.93					**43.88**	50
40		2.58				9.99				**64.45**		40
30			4.43			20.14			**108.87**			30
20				19.32		21.59		**130.41**				20
10					24.63	33.22	**74.37**					10
O	2.61	5.53	28.55	17.32	22.64	31.64	**93.96**	**110.95**	**57.94**	**96.98**	**120.87**	E
-10					20.92	35.78	**87.80**					-10
-20				13.84		26.40		**59.05**				-20
-30			37.20			40.41			**134.76**			-30
-40		39.38				34.03				**185.24**		-40
-50	8.26					**66.16**					**137.27**	-50
SO	-50	-40	-30	-20	-10	S	10	20	30	40	50	SE

NO	-50	-40	-30	-20	-10	N	10	20	30	40	50	NE
50	1.00					1.88					4.87	50
40		1.93				3.99				1.67		40
30			3.86			2.96			2.76			30
20				12.64		**51.45**		28.19				20
10					**90.97**	**89.70**	**95.83**					10
O	**168.49**	**102.29**	**146.39**	**139.84**	**76.78**	**83.38**	**83.85**	**98.36**	**75.82**	21.40	27.61	E
-10					**54.79**	**40.26**	**58.93**					-10
-20				28.20		10.81		14.03				-20
-30			11.82			2.84			4.56			-30
-40		5.47				3.85				4.64		-40
-50	3.76					8.25					11.15	-50
SO	-50	-40	-30	-20	-10	S	10	20	30	40	50	SE

Conclusions and future developments

% Ensemble exceeding the warning threshold		18 September 2010			
		PILB	**MPS**	**Lagged**	**Shift Target**
Seveso	Cantù	20%	50%	18%	32.5%
Lambro	Peregallo	35%	85%	55%	45.0%
	Milano	10%	40%	27%	30.0%

% Ensemble exceeding the warning threshold		8 July 2014					
		PILB	**MPS1h**	**MPS**	**Lagged1h**	**Lagged**	**Shift Target**
Seveso	Cantù	25%	25%	15%	17%	42%	15.0%
Lambro	Peregallo	50%	50%	55%	25%	42%	32.5%
	Milano	10%	10%	10%	0%	0%	0.0%

Conclusions and future developments

1) Despite structural measures, flood residual risk in Milan is still very high due to land use change in the past years that lead to an increase of flood frequency. Therefore, there is a need to test non-structural measures as real time flood forecasting systems.

2) The multiphysics forecast (MPS) gave better or equal performance to the PILB ensembles.

3) Although the physics-based approach needs a high computational cost, it outperforms the pragmatic set of configurations, which, however, turns out to be an acceptable low-budget alternative for real time flood forecasts over small urban basins when a single deterministic run is available.

4) Future developments involve the analysis of more events in order to detect if there are some physical schemes more capable than the others in simulating convective/stratiform events in Milan area.

Thank you for your attention

alessandro.ceppi@polimi.it