POLITECNICO DI MILANO

Real-time hydro-meteorological forecasting in the upper Po river basin

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Aims and tools of the study

Goal

- Assessing the reliability of a real time flood forecasting system, coupling meteorological and hydrological models, analysing the quantitative forecasting precipitation and temperature fields over mountain basins in different weather conditions

Tools

- Set up an hydro-meteorological chain as an operative real time flood forecasting tool in mountain basins: MAP-D-PHASE Project
- Evaluation of the forecasted atmospheric forcing errors: in particular the key role of air temperature that can affect the Quantitative Discharge Forecast (QDF) and the whole hydro-meteorological alert system in the Alpine region

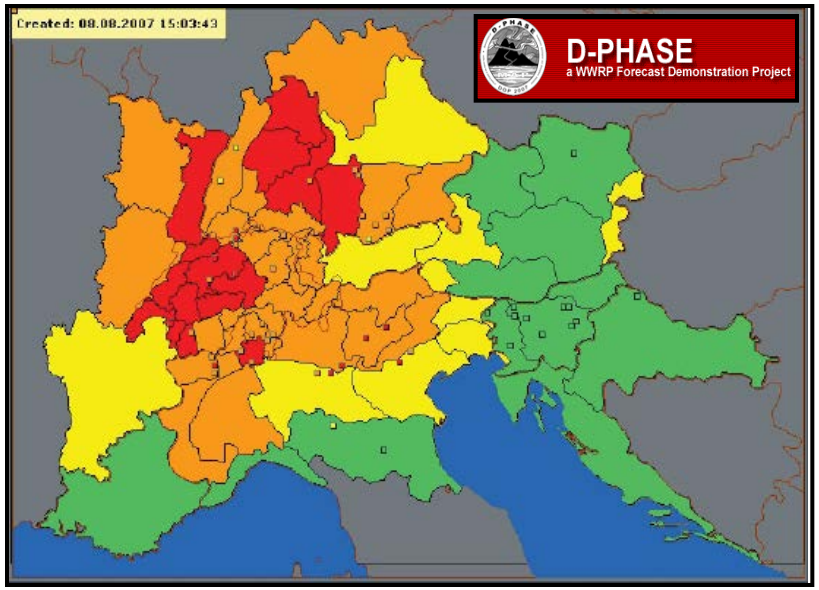
MAP-D-PHASE Project

• A **Forecast Demonstration Project (FDP) of the WWRP** (World Weather Research Programme of WMO). It aims at demonstrating some of the many achievements of the **Mesoscale Alpine Programme (MAP)**, in particular the ability of forecasting heavy precipitation and related flooding events in the Alpine region.

• The **MAP FDP** addresses the entire forecasting chain ranging from limited-area ensemble forecasting, high-resolution atmospheric modelling, hydrological modelling and nowcasting to decision making by the end users, by setting up an **end-to-end forecasting system**.

• The **D-PHASE Operations Period (DOP)** has been from **1 June to 30 November 2007**, but it is still working!

• The real-time end-to-end forecasting system includes: centralised Visualisation Platform (VP, www.d-phase.info) and Data Archive (DA, cera-www.dkrz.de)



Visualisation platform for the Map-D-Phase

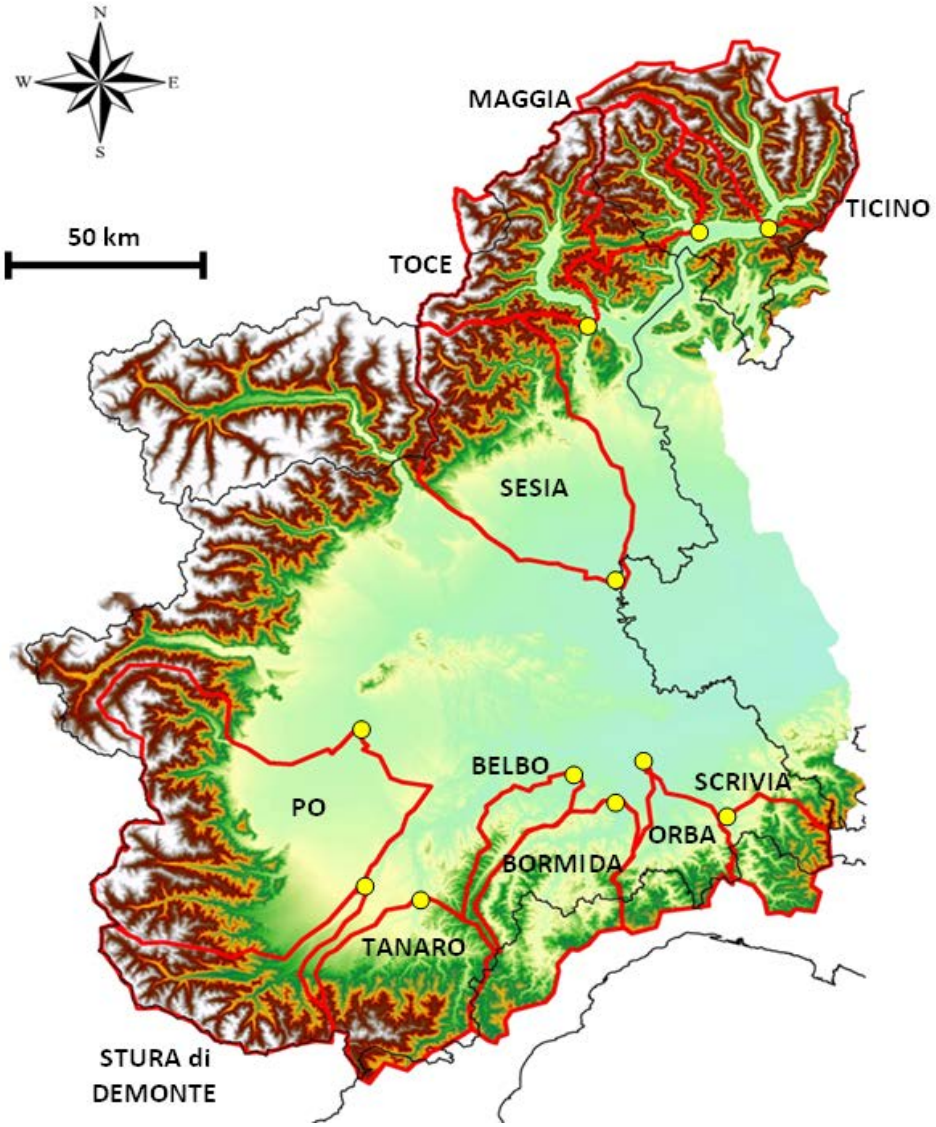
Source: *Ravazzani, G., Ceppi, A., Rabuffetti, D., Mancini, M. 2009; dphase_fest: hydrological model FEST run by Politecnico di Milano for the MAP D-PHASE project. World Data Center for Climate. [doi: 10.1594/WDCC/dphase_fest]*

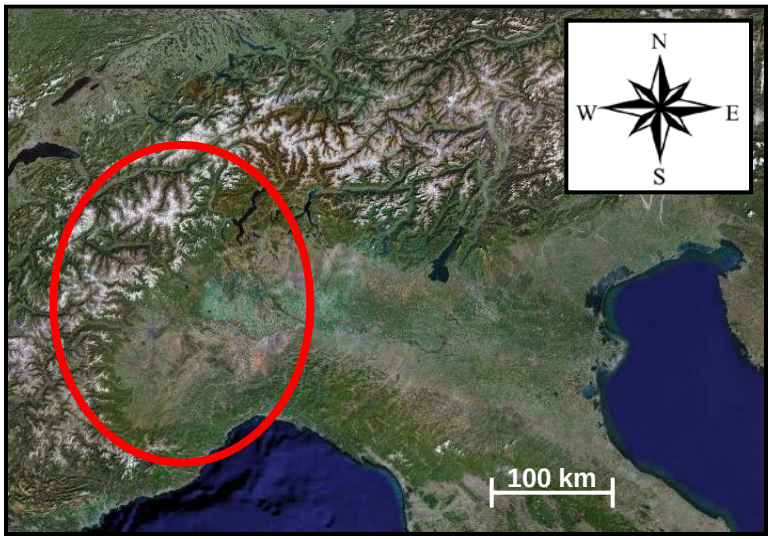
Analyzed watersheds by POLIMI: the Toce, Maggia, Ticino

D-PHASE hydro-meteorological warning codes

No data	No alert	6 times a year	Twice a year	Every 10 years

Area of study



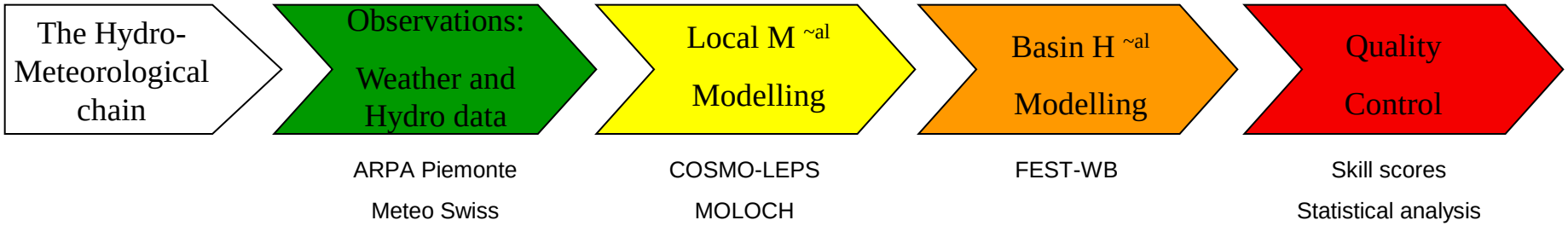


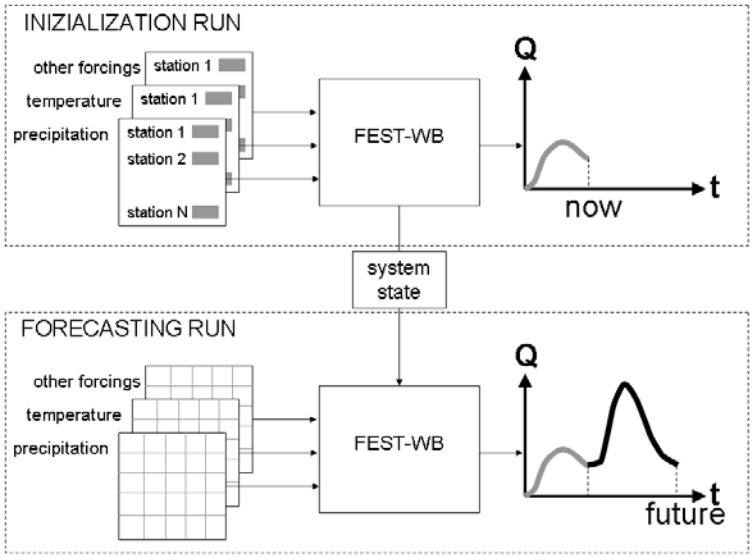
11 BASINS	Lag time [h]	Area [km^2]
Ticino basin (closed at Bellinzona)	9	1537
Maggia basin (closed at Solduno)	6.8	902
Toce basin (closed at Candoglia)	9	1534
Sesia basin (closed at Palestro)	18.8	2606
Po basin (closed at Carignano)	18	3960
Stura basin (closed at Fossano)	9.5	1239
Tanaro basin (closed at Farigliano)	14.8	1457
Belbo basin (closed at Castelnuovo)	15.1	421
Bormida basin (closed at Cassine)	23.2	1523
Orba basin (closed at Casal Cervelli)	14.2	750
Scrivia basin (closed at Serravalle)	10	617

The POLIMI hydro-meteorological chain: the forecasting cascade system

• Weather forecasts are useful to predict possible extreme hydrological events, in order to active in advance mitigation measures and alert systems, above all over small-medium size mountain basins where lag times are low.

• In the present day, operational real time hydro-meteorological forecast systems are realized by use of one-way coupling, i.e. the meteorological output variables are driven into hydrological models.





- The initial hot start is sent daily by ARPA-Piemonte which runs the same hydrological model with weather observations.

- The current hydro-meteorological chain includes:

a) probabilistic forecasts based on ensemble prediction systems with lead time of a few days

b) short-range forecasts based on high resolution deterministic atmospheric model

- The hydrological model used to generate the runoff simulations is the FEST-WB model, developed at Politecnico di Milano.

- Statistical analyses are used to calculate the skill scores for hydrological applications

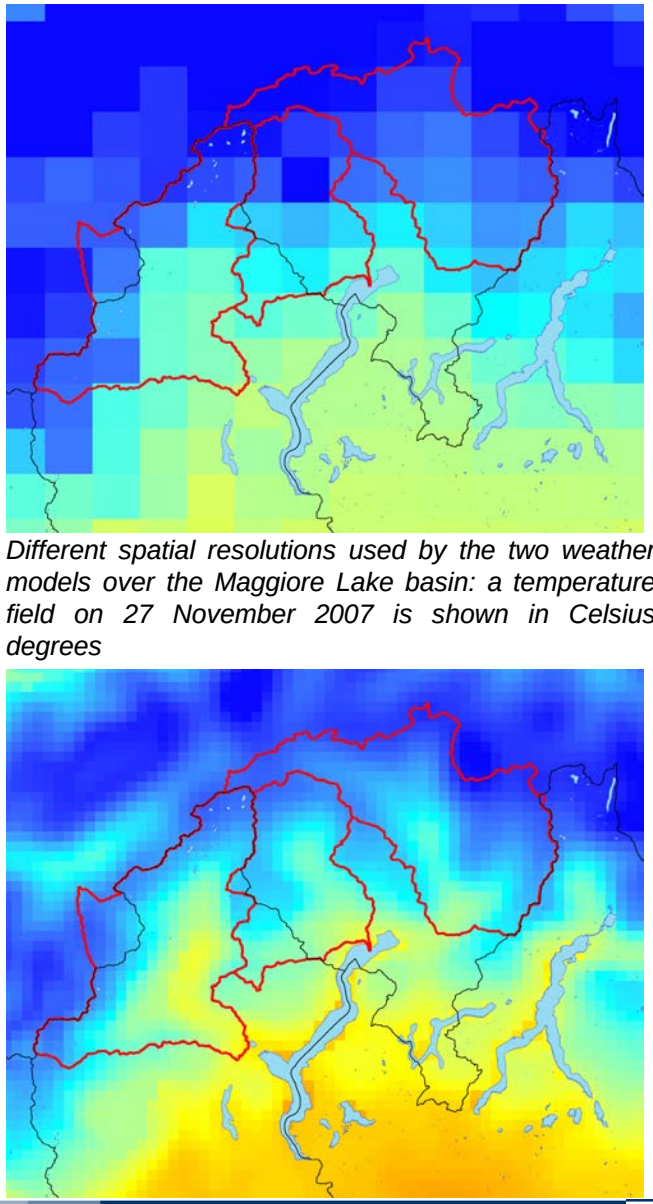
Meteorological models: Cosmo-Leps and Moloch

COSMO-LEPS Model (Marsigli et al., 2005)

- **Spatial Resolution:** 10.0 km (0.09°)
- **Temporal Resolution:** 3 h
- **Vertical levels:** 40 (non-hydrostatic)
- **Ensemble members: 16** nested on ECMWF EPS
- **Forecast range:** +132 h
- **Run starting at:** 12:00 UTC
- **Owner:** ARPA Emilia-Romagna

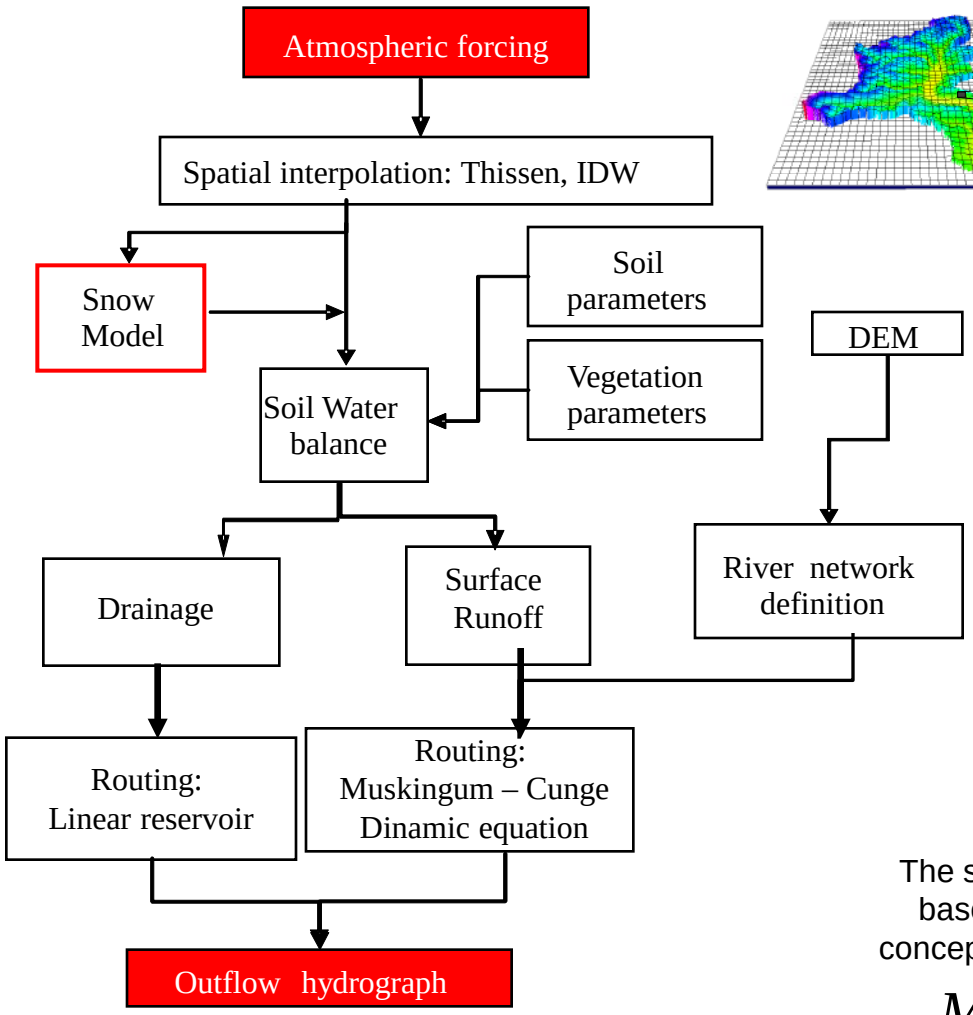
MOLOCH Model (Malguzzi et al., 2006)

- **Spatial Resolution:** 2.3 km (0.02°)
- **Temporal Resolution:** 1 h
- **Vertical levels:** 50 (non-hydrostatic)
- **Deterministic model,** nested on BOLAM, nested on ECMWF
- **Forecast range:** +48 h
- **Run starting at:** 00:00 UTC
- **Owner:** ISAC-CNR



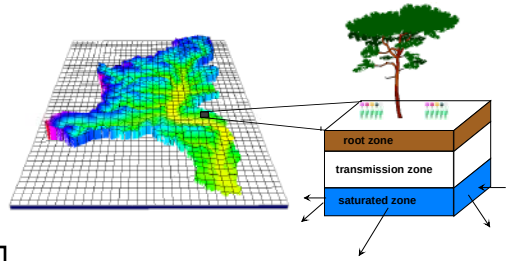
Different spatial resolutions used by the two weather models over the Maggiore Lake basin: a temperature field on 27 November 2007 is shown in Celsius degrees

PoliMi - Distributed Hydrological Model: FEST-WB



Full scheme of the rainfall-runoff distributed hydrological model FEST-WB, physically based

(Mancini,1990 → Ravazzani et al., 2010)



The snow model includes the snow melt and the snow accumulation dynamics

1) snow accumulation dynamic

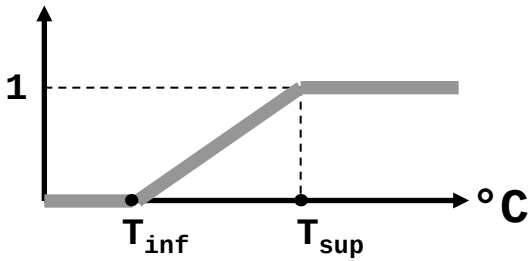
$$\begin{cases} P_L = \alpha P \\ P_S = (1-\alpha) P \end{cases}$$

$$\alpha P = \begin{cases} 0 & \Leftrightarrow T_a \le T_{\inf} \\ \dfrac{T_a - T_{\inf}}{T_{\sup} - T_{\inf}} & \Leftrightarrow T_{\inf} < T_a < T_{\sup} \\ 1 & \Leftrightarrow T_a > T_{\sup} \end{cases}$$

The partitioning of total precipitation, P, in liquid, Pl, and solid, Ps, phase is a function of air temperature,Ta (Tarboton et al., 1994).

T_{inf} and T_{sup} are calibrated parameters

(Corbari et al., 2009).



2) snow melt dynamic

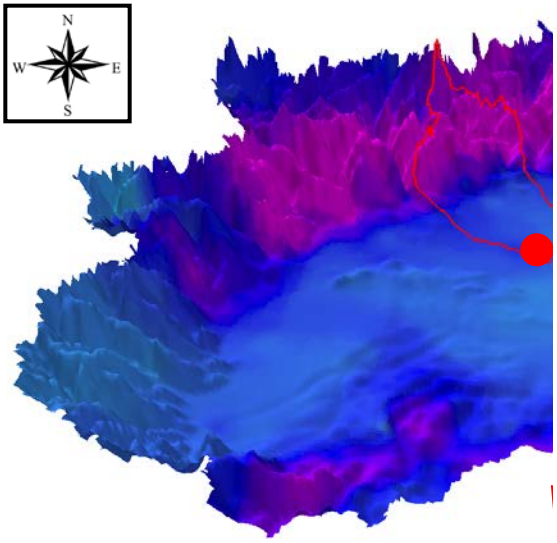
The snow melt simulation is based on the degree day concept *(Martinec et al., 1960)*

C_m is an empirical coefficient depending on meteorological conditions and geographic location

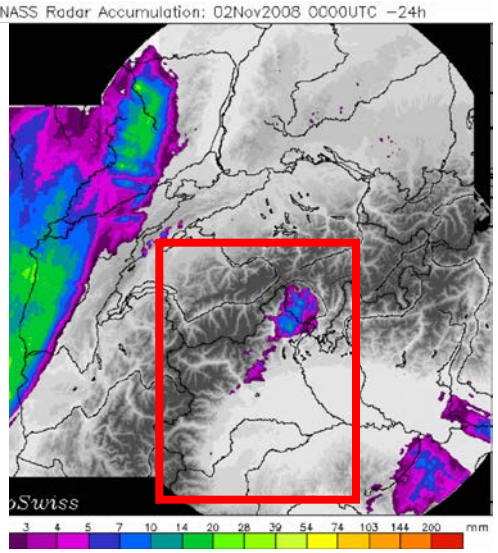
$$M_s = C_m (T_a - T_b)$$

The melt rate in ms^{-1}, M_s, is proportional to the difference between air temperature T_a and a predefined threshold temperature, T_b *(Salandin et al., 2004)*

1-5 November 2008: stratiform event



South-East winds



accumulation (mm) over
nte and South Switzerland

ALLERTA METEOIDROLOGICA

BOLLETT. N°	DATA EMISSIONE	VALIDITÀ	AGGIORN AMENTO	SERVIZIO A CURA	AMBITO TERRITORIALE
309/2008	04/11/2008 ore 13:00	36 ore	05/11/2008 ore 13:00	Arpa Centro Fu	Regione Piemonte

VIGILANZA METEOROLOGICA

Zone di Allerta	Prossime 36 ore: Livelli di vigilanza	Prossime 36 ore: Fenomeni rilevanti	Prossime 36 ore: Quota neve	Oltre 36 ore: Fenomeni rilevanti	RISCH… Livel…	…territorio
A	AVVISO METEO	Piogge Forti	1700 - 2100	-		…ti fenomeni di frane ed esondazioni
B	AVVISO METEO	Piogge Forti	1800 - 2100			Limitati fenomeni di frane ed esondazioni
C	AVVISO METEO	Piogge Forti	170…		…ecipitazioni Diffuse	Limitati fenomeni di frane ed esondazioni
D	AVVISO METEO	Piogge Forti			1 ORDINARIA Precipitazioni Diffuse	Ordinaria Criticità conseguente a piogge forti
E	SITUAZIONE ORDINARIA	-	-	-	- -	-
F	AVVISO METEO			-	1 ORDINARIA Precipitazioni Diffuse	Ordinaria Criticità conseguente a piogge forti
G	AVVISO METEO			-	1 ORDINARIA Precipitazioni Diffuse	Ordinaria Criticità conseguente a piogge forti
H	AV… M…	…ito	1700 - 2300	-	1 ORDINARIA Precipitazioni Diffuse	Ordinaria Criticità conseguente a piogge forti
I	M…	…ogge Forti	-	-	1 ORDINARIA Precipitazioni Diffuse	Ordinaria Criticità conseguente a piogge forti
L	AVVISO METEO	Piogge Forti	-	-	1 ORDINARIA Precipitazioni Diffuse	Ordinaria Criticità conseguente a piogge forti
M	SITUAZIONE ORDINARIA	-	-	-	- -	-

NOTA:

LEGENDA delle Zone di Allerta

A Toce (NO-VB)
B Chiusella, Cervo, Val Sesia (BI-NO-TO-VC)
C Valli Orco, Lanzo, Sangone (TO)
D Valli Susa, Chisone, Pellice, Po (CN-TO)
E Valli Varaita, Maira, Stura di Demonte (CN)
F Valle Tanaro (CN)
G Belbo, Bormida (AL-AT-CN)
H Scrivia (AL)
I Pianura Settentrionale (AL-AT-BI-NO-TO-VC)
L Pianura Torinese, Colline (AL-AT-CN-TO)
M Pianura Cuneese (CN-TO)

LEGENDA dei simboli

Nessuna icona: assenza di fenomeni significativi
Icona chiara: fenomeno non intenso
Icona scura: fenomeno intenso - AVVISO METEO

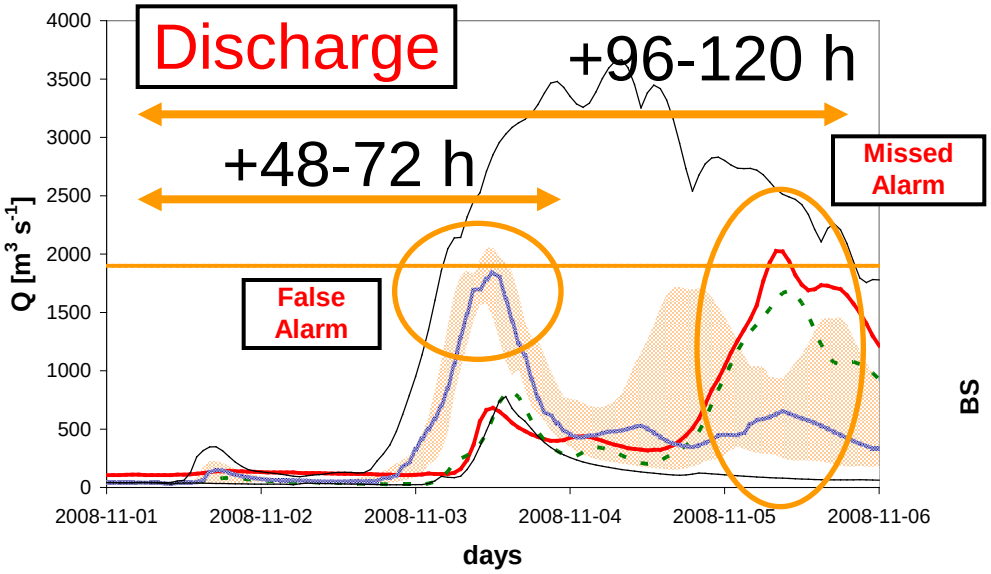
Pioggia, Temporale, Nevicata, Anomalia di Freddo, Anomalia di Caldo, Vento

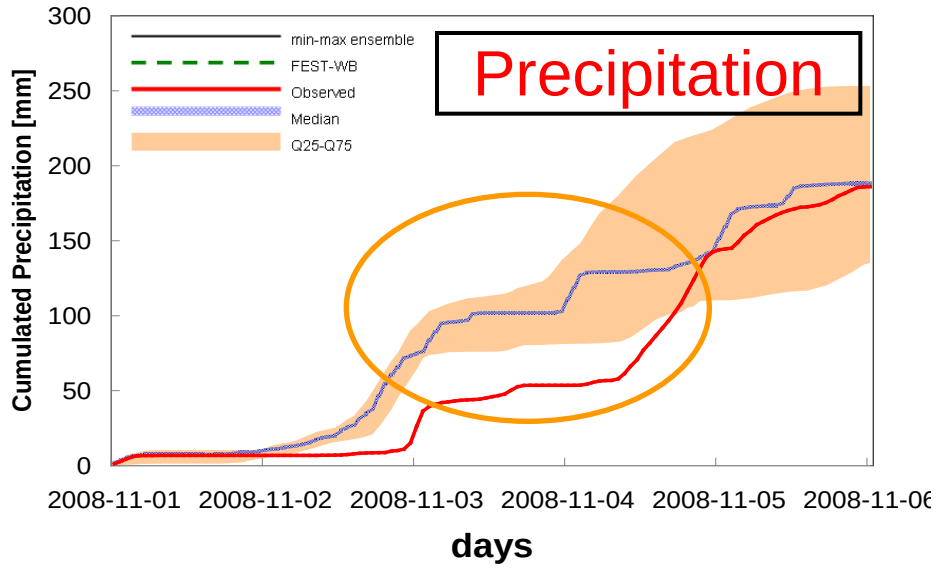
Attenzione: per una corretta interpretazione ed approfondimenti consultare sempre il disciplinare
Diffusione: http://www.ruparpiemonte.it/meteo/ - http://intranet.ruparpiemonte.it/meteo/ con password di accesso
www.arpa.piemonte.it

ALERT

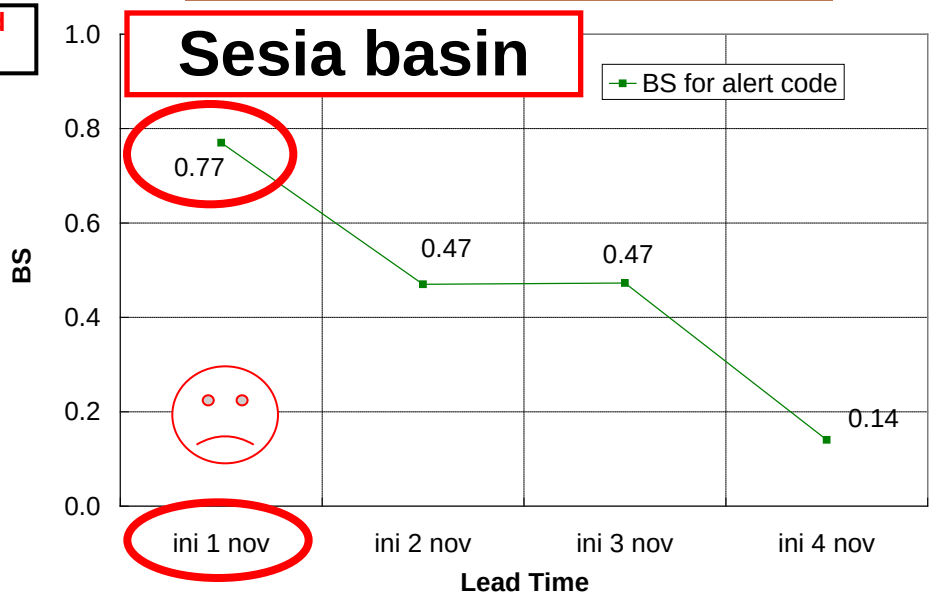
Days	Toce	Ticino	…lbo	Bormida	Orba	Scrivia
1 November 2008	6.5	4.4	…7	1.4	3.4	1.7
2 November 2008	7.2	0.0	…9.0	53.3	6.6	0.4
3 November 2008	52.2	31.8	…7	10.3	22.3	14.1
4 November 2008	79.0	22.7	…2.9	63.8	82.5	42.0
5 November 2008	95.4	48.1	…3.0	25.0	37.1	32.4
Cumulated Precipitation [mm]	**240.3**	**107.0**	**…7.3**	**153.8**	**119.6**	**90.6**

The role of atmospheric forcing: precipitation





1 November output run:
96-120 h before the main peak flow



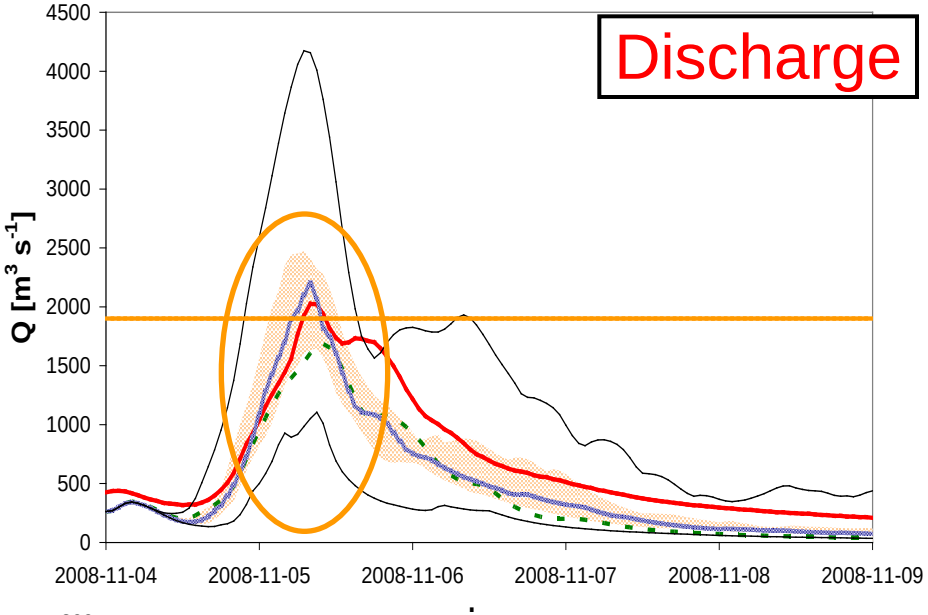
- Brier Score

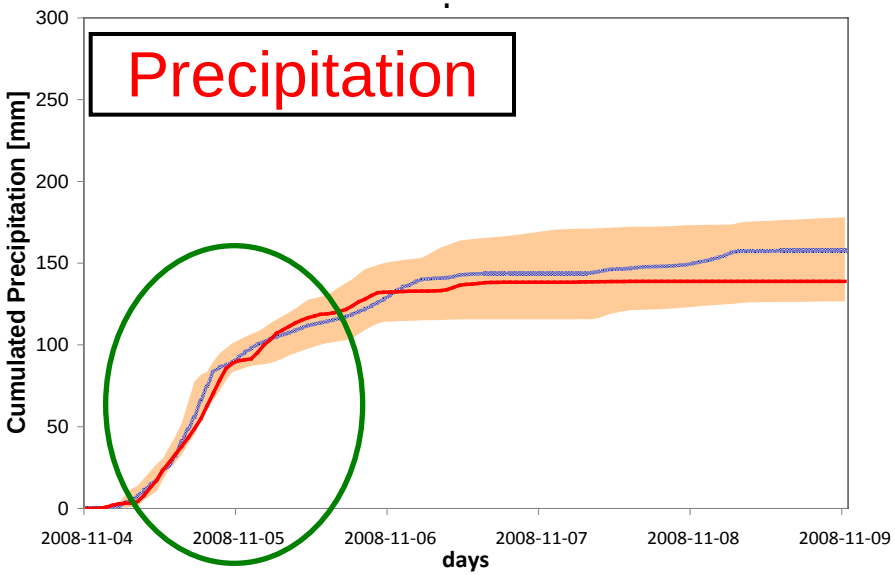
$$BS = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k)^2$$

- **n** = number of forecasting istances
- $\mathbf{y_k}$ = the probability that an event was forecasted
- $\mathbf{o_k}$ = the actual outcome of the event at instance k (0 if it doesn't happen and 1 if it happens)
- Best score = 0

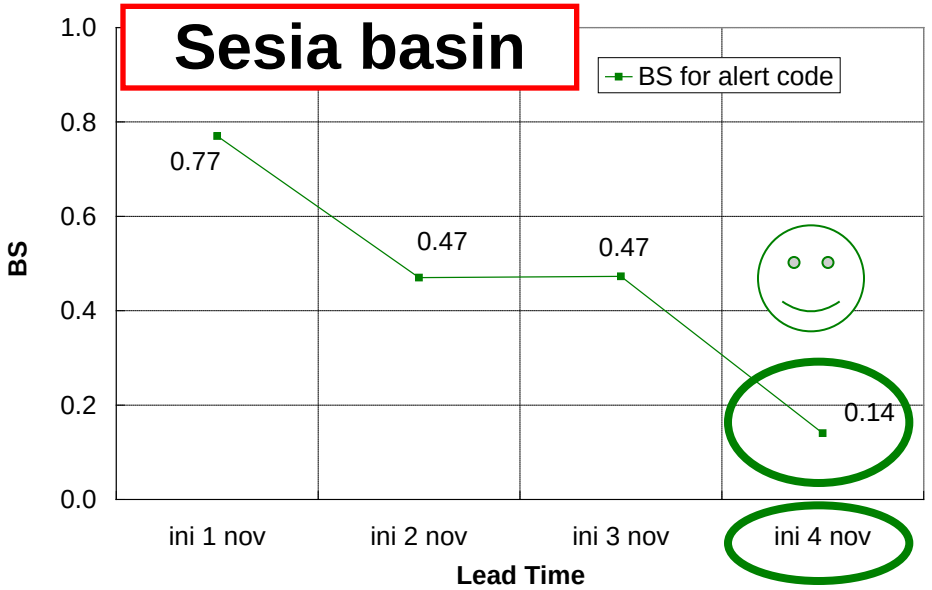
The BS is essentially the mean-squared error of the probability forecasts, considering that the observation is *o*=1 if the event occurs and *o*=0 if the event does not occur. The score averages the squared differences between pairs of forecast probabilities and the subsequent observations (Wilks, 2006).

The role of atmospheric forcing: precipitation

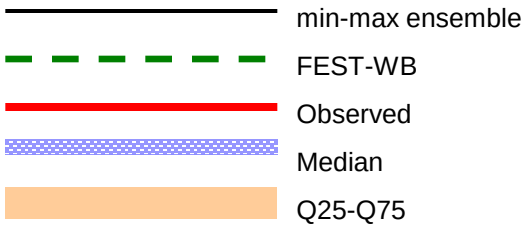




4 November output run:
24-48 h before the main peak flow



Hit



The reliability of the hydro-meteorological chain: brief summary

Sesia basin
November event

BS for alert code
hours before the main peak

0.77	0.47	0.47	0.14
96-120	72-96	48-72	24-48

Hit

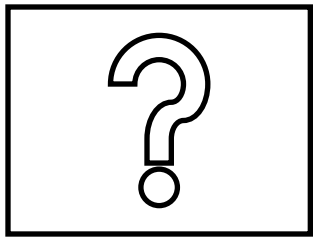
Toce basin
November event

BS for alert code
hours before the main peak

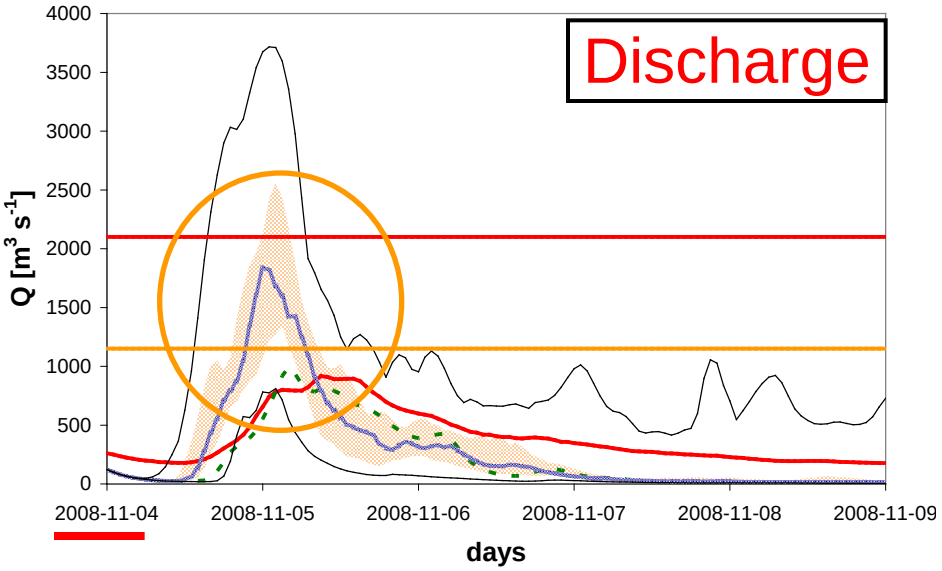
0.31	0.25	0.31	0.88
96-120	72-96	48-72	24-48

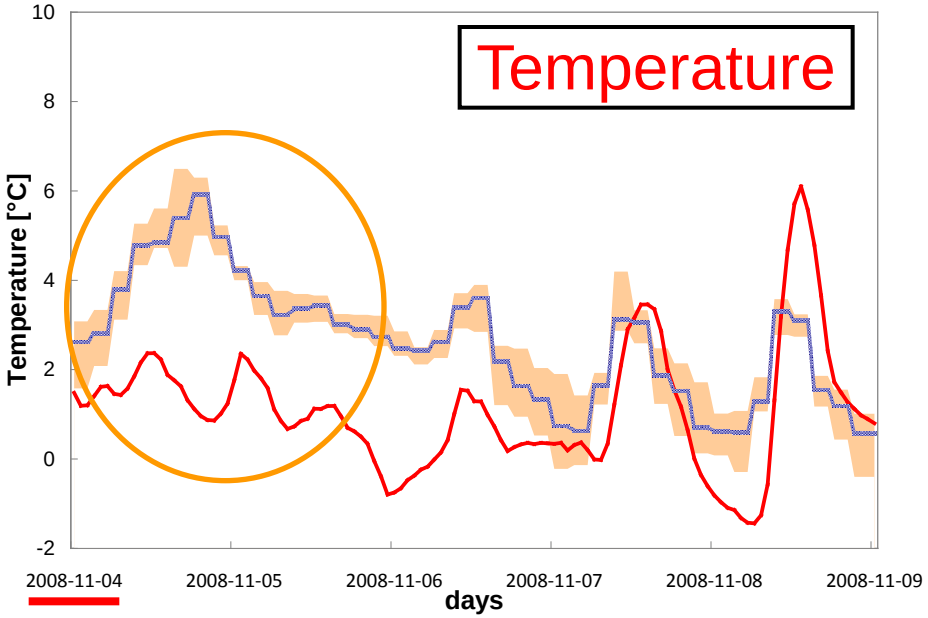
Why does not this reliability subsist over Toce (and Stura) basins?

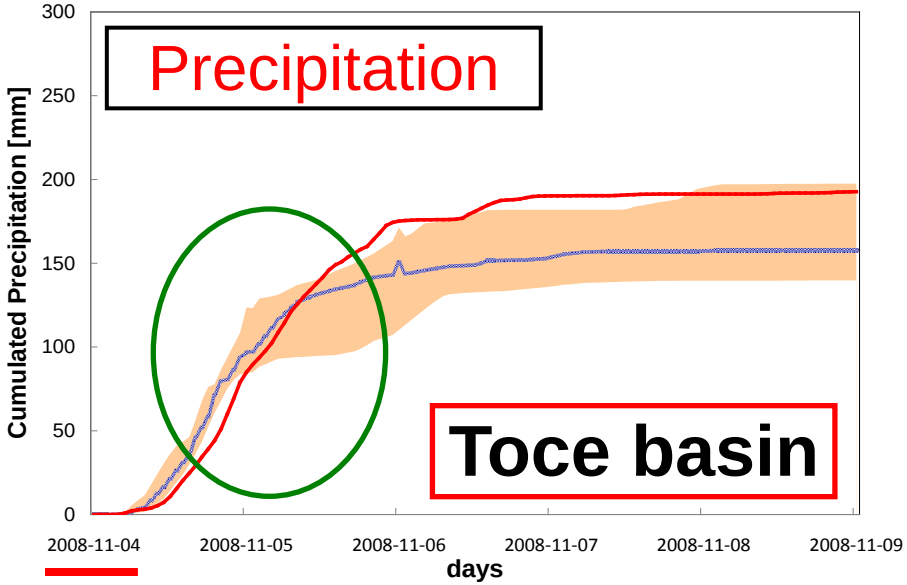
False Alarm

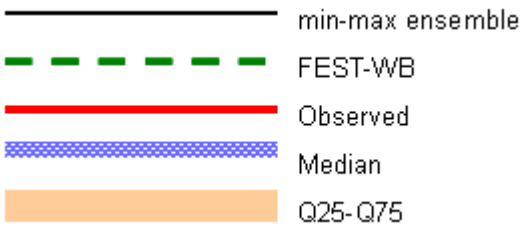


The role of atmospheric forcing: temperature



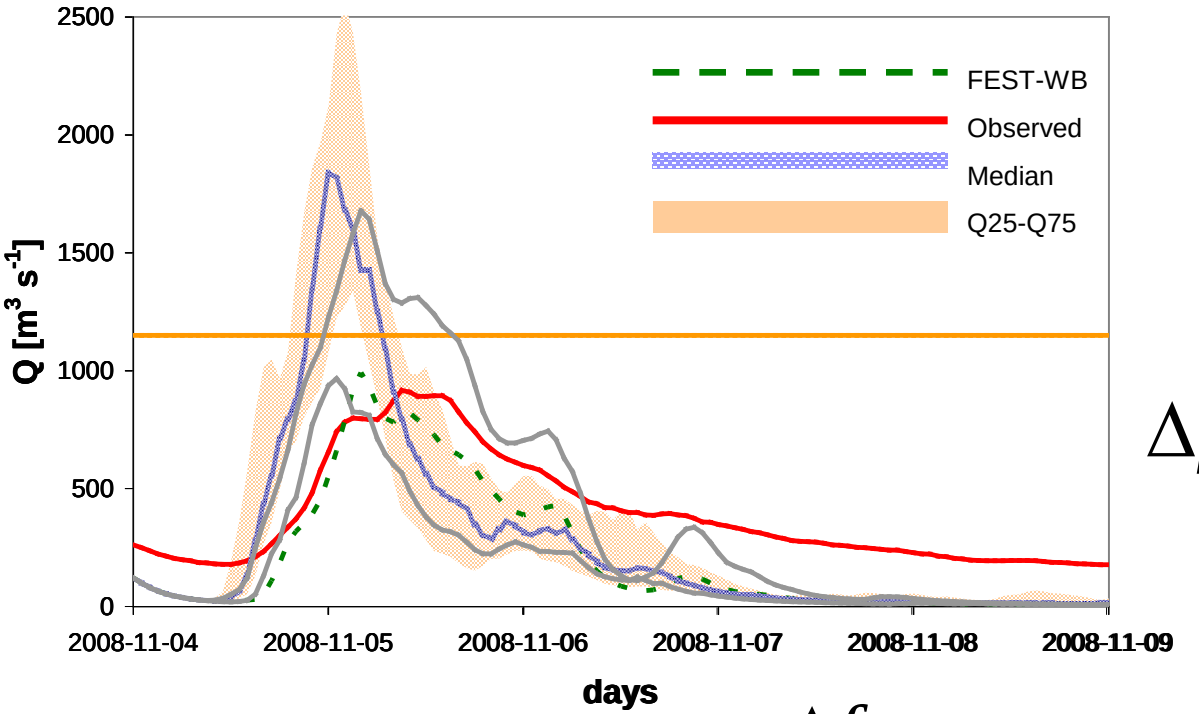






Which is the interaction between forecasted temperature and precipitation errors affecting the peak discharge in a mountain basins during Autumn/Winter period?

Sensitivity analysis at finite changes: the key role of temperature



Observed Precipitation

Observed Temperature

$$\Delta f = \Delta f_P + \Delta f_T + \Delta f_{P,T}$$

Source: Borgonovo, 2010

Finite changes sensitivity indices

Q_{max} observed = 916 $m^3 s^{-1}$

Q_{max} FEST-WB = 992 $m^3 s^{-1}$

median(Q_{max}|P) = 966 $m^3 s^{-1}$

median(Q_{max}|T) = 1678 $m^3 s^{-1}$

median(Q_{max}|P_{and}T) = 1841 $m^3 s^{-1}$

Δf median(Q_{max}|P_{and}T) – Q_{max} FEST-WB = +849 $m^3 s^{-1}$

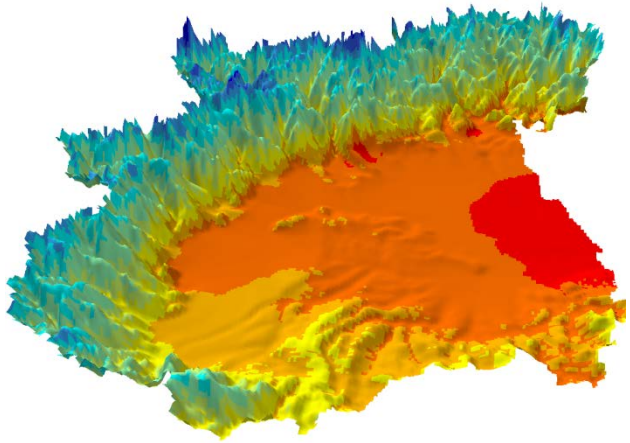
Δf_P median(Q_{max}|P) – Q_{max} FEST-WB = -26 $m^3 s^{-1}$

Δf_T median(Q_{max}|T) – Q_{max} FEST-WB = +686 $m^3 s^{-1}$

$\Delta f_{P,T}$ marginal effects of interaction = +189 $m^3 s^{-1}$

Effects of temperature on the peak discharge: quantification of errors

Which is the acceptable temperature error in the discharge forecast over mountain basins?



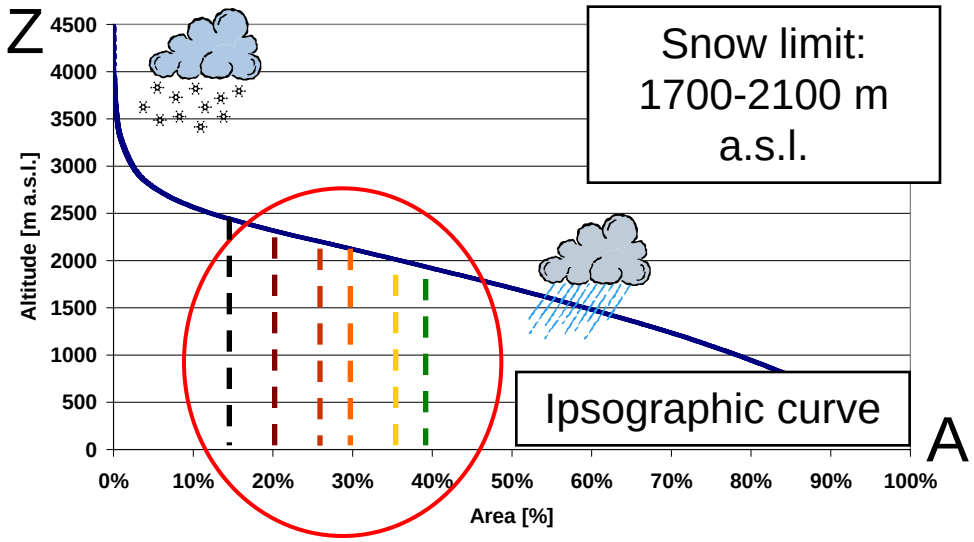
Set the precipitation input using the observed precipitation field (raingauges)

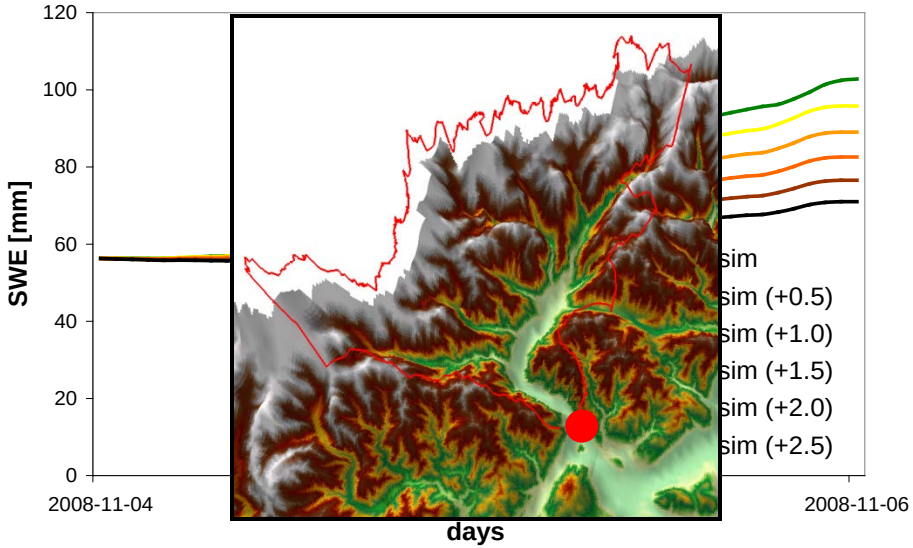
I calculated the Q differences, changing the temperature input only, keeping the other hydro-meteorological variables unchanged (observed precipitation and initial conditions)

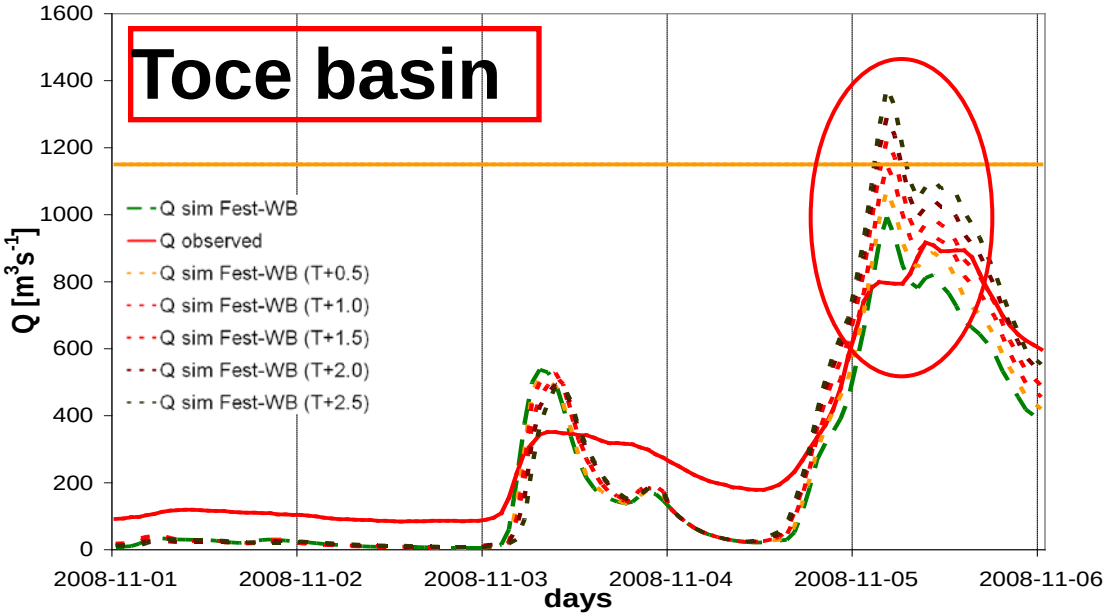
→

Quantify discharge errors

Effects of temperature on flood contributing area: Toce basin

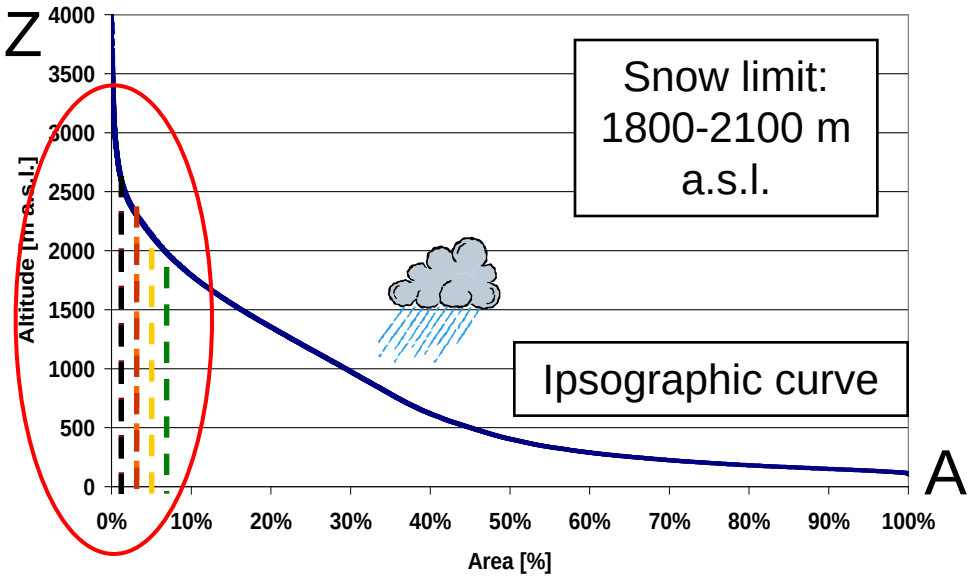


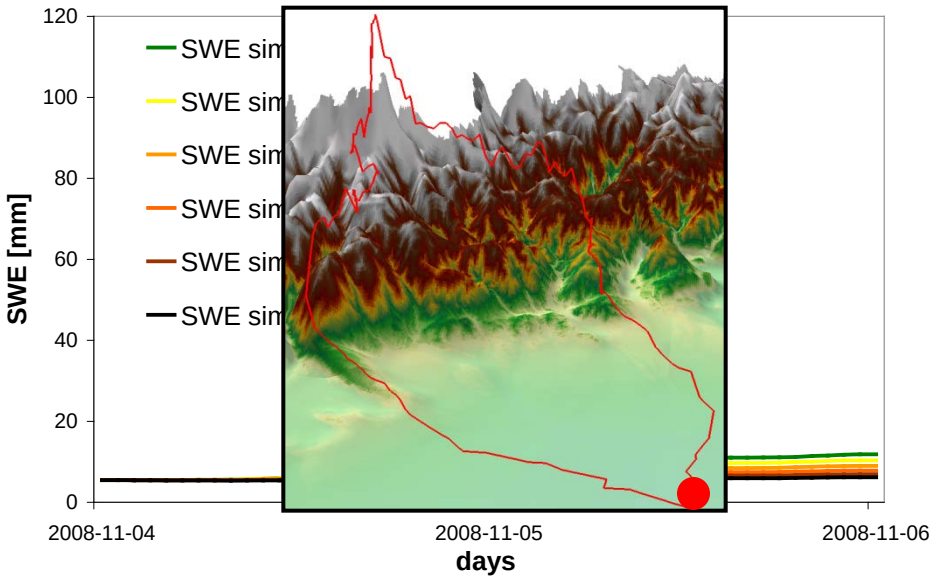


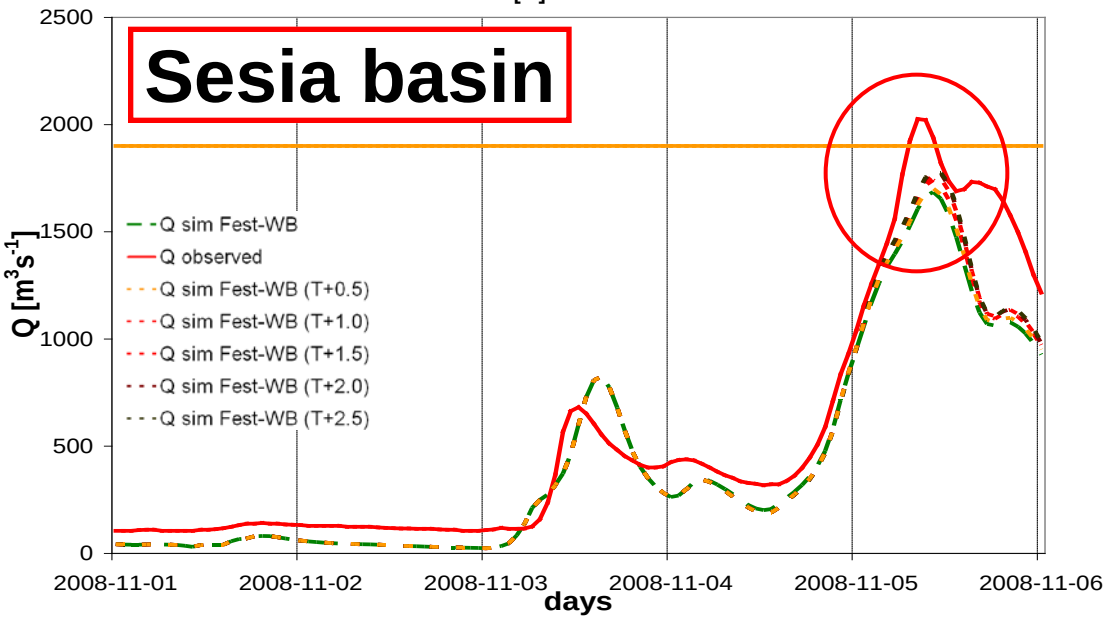


Evaluation Discharge error	
+0.5°C	+8%
+1.0°C	+16%
+1.5°C	+23%
+2.0°C	+30%
+2.5°C	+39%
T [°C]	Error

Effects of temperature on flood contributing area: Sesia basin







Evaluation Discharge error	
+0.5°C	+1%
+1.0°C	+3%
+1.5°C	+5%
+2.0°C	+5.8%
+2.5°C	+6.1%
T [°C]	Error

Conclusions

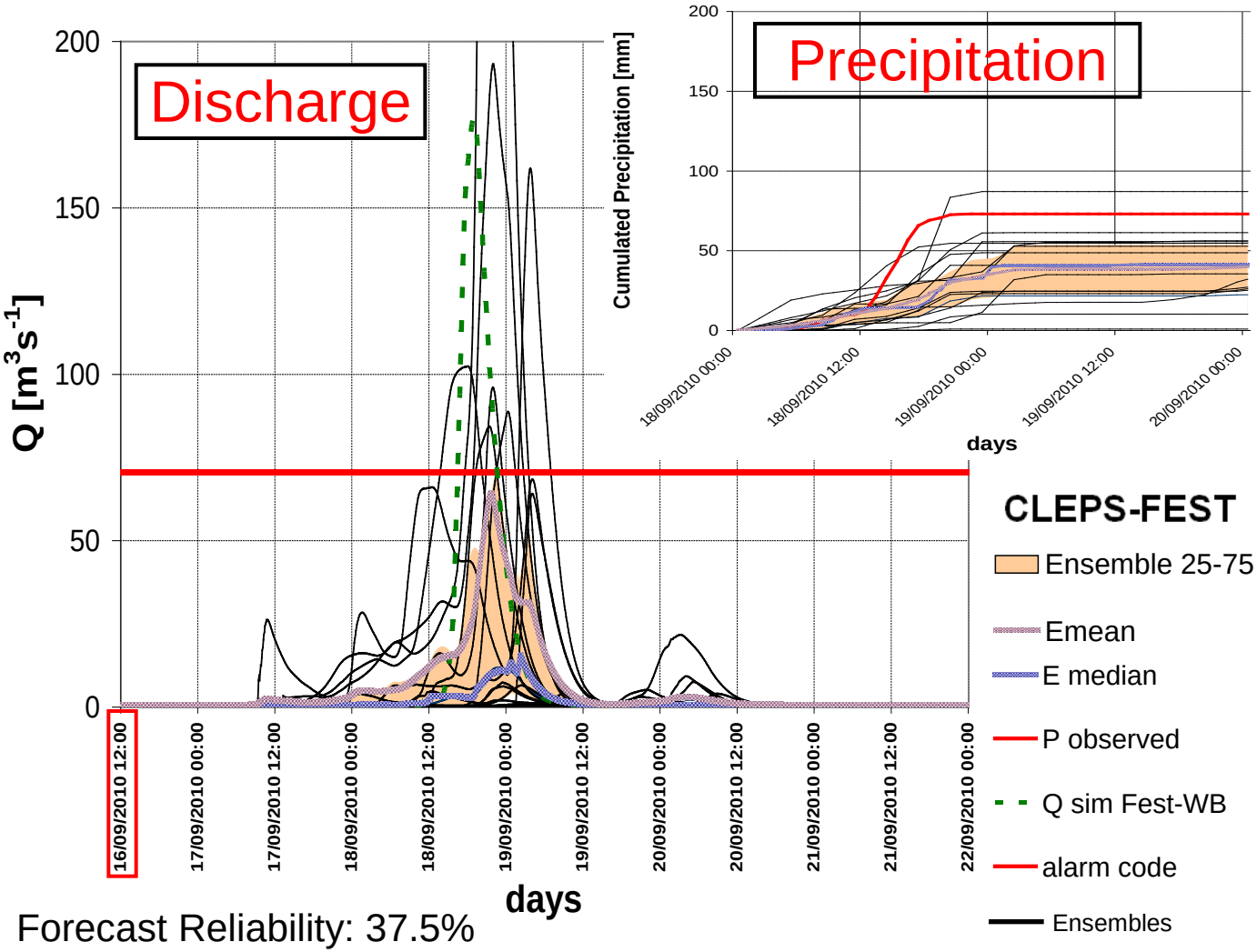
1) The hydro-meteorological chain is a very useful tool to predict in real time (generally with 24-48 hours before the main peak discharge) possible river floods in advance over mountain basins, where lag times are generally lower.

2) Precipitation is not the only atmospheric forcing to be considered. The quantitative discharge forecast (QDF) is influenced by temperature errors and it is related to the basin ipsographic curve, therefore to the percentage of area that contributes with more liquid water (rain) over watershed.

Last flood in Milan urban area: the river Seveso…

16 September 2010 output run:
36-48 h before the main peak flow

Area: 195 km^2



Forecast Reliability: 37.5%

Seveso basin