Precipitation and Flash Flood Prediction from Minutes to Days

RealPEP

Improving very short range hydrological forecast Using nowcasting technique and data assimilation in a meteorological model

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ISAC

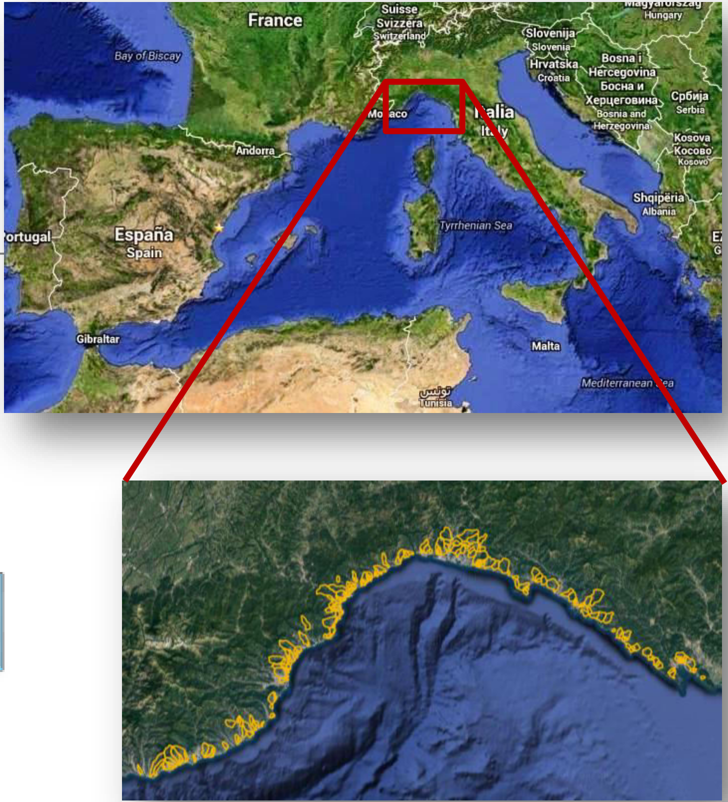
Introduction and motivations (1)

Why nowcasting is important in hydrological application?

Area of application: Liguria Region

Catchments with small drainage area

Short response time (few hours!)



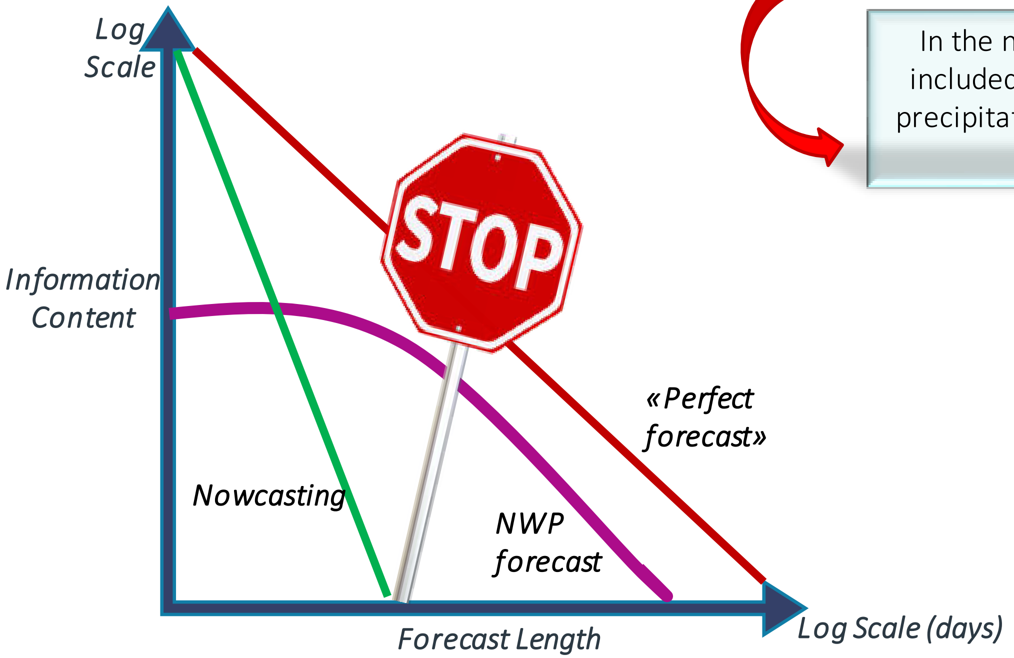
Mediterranean area (Spain, France, Italy) 9-10-11 October 2018 16 victims.

Forecast at short lead time is essential!

To predict precipitation at small temporal (few hours) and spatial (few km) scale

Introduction and motivations (2)

Limit of the nowcasting models: forecast horizon up **to few hours**



In the nowcasting models the atmospheric dynamic is not included: the physics representing growth and decay of the precipitation systems becomes progressively more important with increasing lead time

Connection of nowcasting and meteorological model forecasted rainfall fields

To have **rainfall forecasts** more **accurate** as possible

An integrated hydrological nowcasting chain

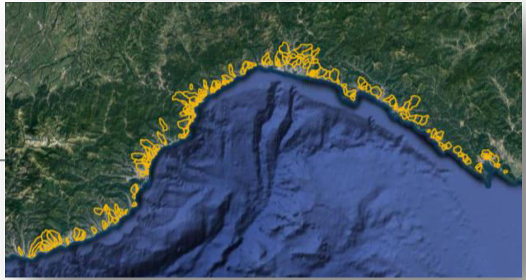
6 hours forecasted rainfall fields

Nowcasted rainfall fields

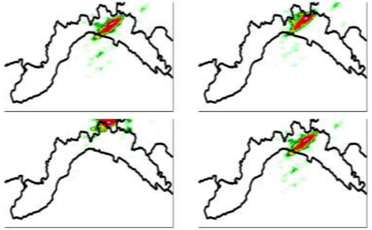
BLENDING

Rainfall fields forecasted by **Numerical Weather Prediction** model corrected with Data Assimilation

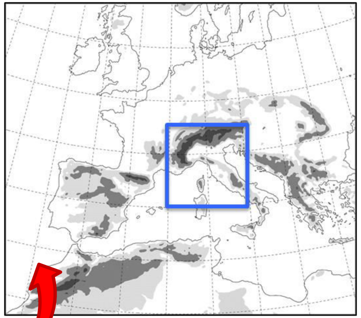
INPUT



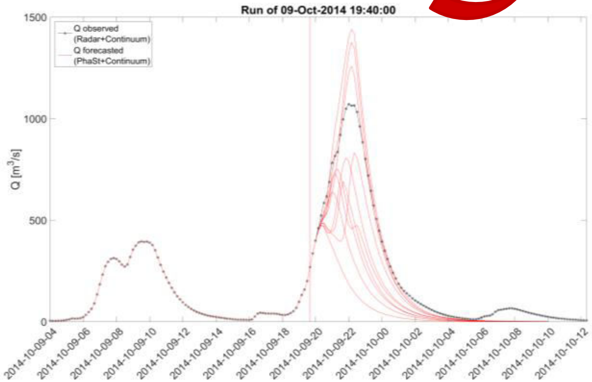
Application on Liguria Region



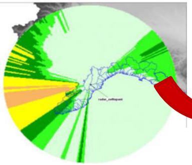
Technique used to combine the forecasted rainfall fields in a smooth way



Hydrological model



The nowcasting algorithm



The NWP model corrected with DA

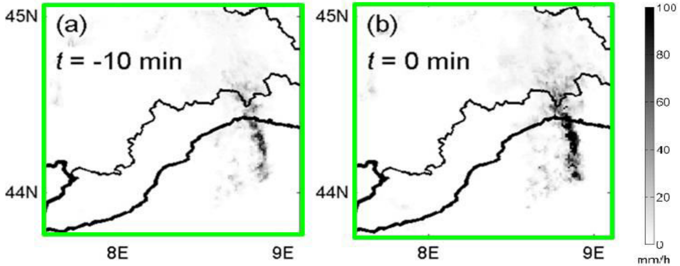
Observed radar rainfall field

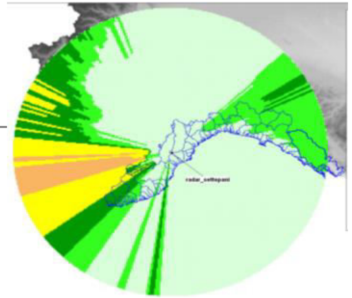
The elements of the chain (1): the nowcasting algorithm

PhaSt

Phase Stochastic nowcasting technique

Metta er al., 2009





1. Starting point: last two rainfall maps provided by the meteorological radar (dx 1km, dt 10 min)

2. Gaussianization of the fields

3. Fourier transformation of the gaussianized fields

Spectral amplitudes are kept constant

Phase velocities (i.e. angular frequencies) evolve

$$
\begin{cases}
k_s = \left(k_x^2 + k_y^2\right)^{\frac{1}{pwr}}, \\
d\Phi_{k_s} = \omega_{k_s} dt, \\
d\omega_{k_s} = -\left(\omega_{k_s} - \omega'\right)\frac{dt}{T} + \sqrt{\frac{2\sigma^2}{T}}\sqrt{1 - \frac{dt}{2T}}\, k_s dW
\end{cases}
$$

(Ornstein–Uhlenbeck process),

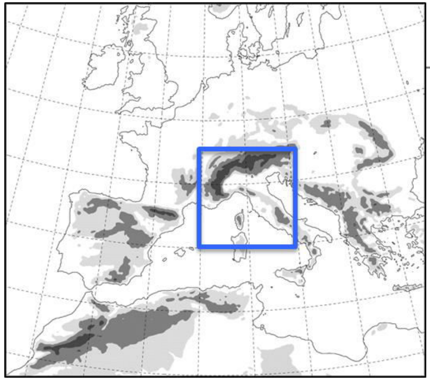
Generation of an ensemble of possible evolution of precipitation field

4. Non-linear anti - transformation of the predicted gaussian field

OUTPUT

Rainfall ensemble

Elements of the chain (2) Numerical Weather Prediction model corrected with Data Assimilation



NWP model

MOLOCH

Malguzzi et al., 2006
Buzzi et al., 2014

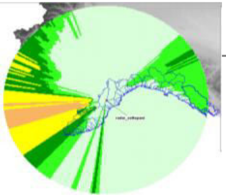
Spatial resolution ≈ 2.2 km

non-hydrostatic; it explicitly solves deep convection

Integration domain north and central Italy

Initial and boundary conditions provided at 1-hour interval by the BOLAM (Limited Area Model) forecasts

Use of the **deterministic** forecast



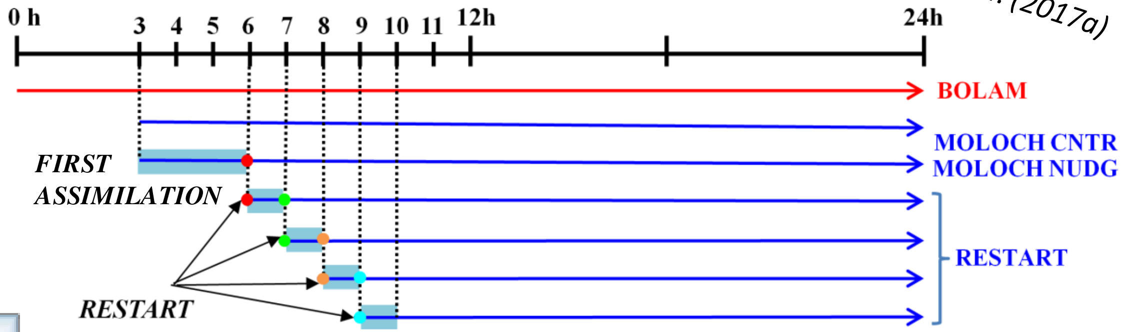
Hourly precipitation estimates provided by Settepani radar are used as observations

DA technique

Nudging

Model specific humidity profiles at each grid point are progressively modified depending on the comparison between observed and forecast rainfall

Davolio et al. (2017a)



Elements of the chain (3): the hydrological model

Continuous distributed hydrological model

Continuum

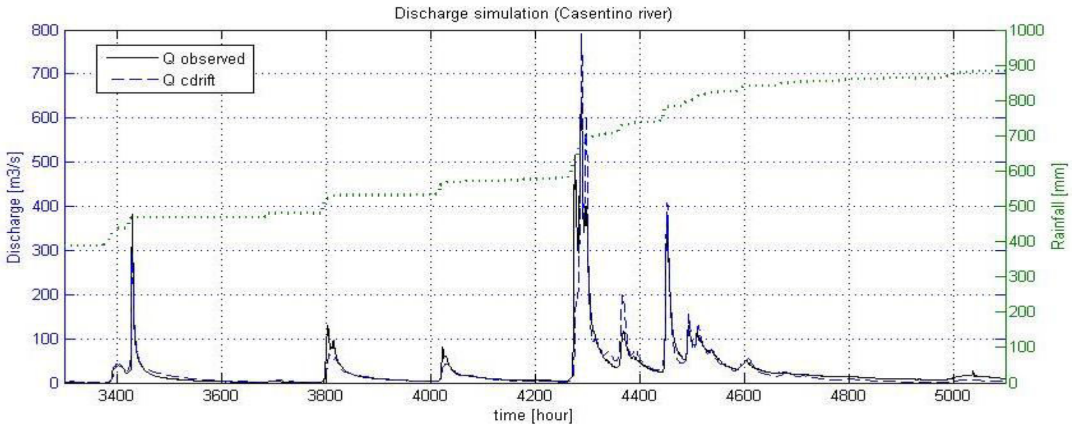
Silvestro et al., 2013
Silvestro et al., 2015b

It solves the hydrological processes on a longer period of time. It considers all the processes involved in the hydrologic cycle (overland and channel flow, infiltration and subsurface flows, deep flow, vegetation interception, energy balance and evapotranspiration)

The model is based on a space-filling representation of the network, directly derived from a DEM, that allows to identify flow directions on the basis of the directions of maximum slope.

OUTPUT

Discharge forecast



The blending technique: a new approach

1

Modification of the nowcasted rainfall field with the volume trend estimated by the rainfall field forecasted with NWP corrected with DA

Spectral amplitudes were kept constant in the original version of PhaSt

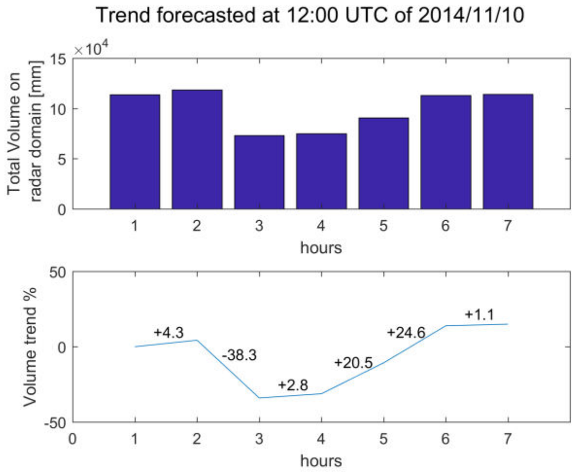
Volume is kept constant along the forecast

In order to **extend the forecast horizon**

Modification of the Volume

Volume trend

Forecasted by NWP model corrected with data assimilation



The blending technique: a new approach

2

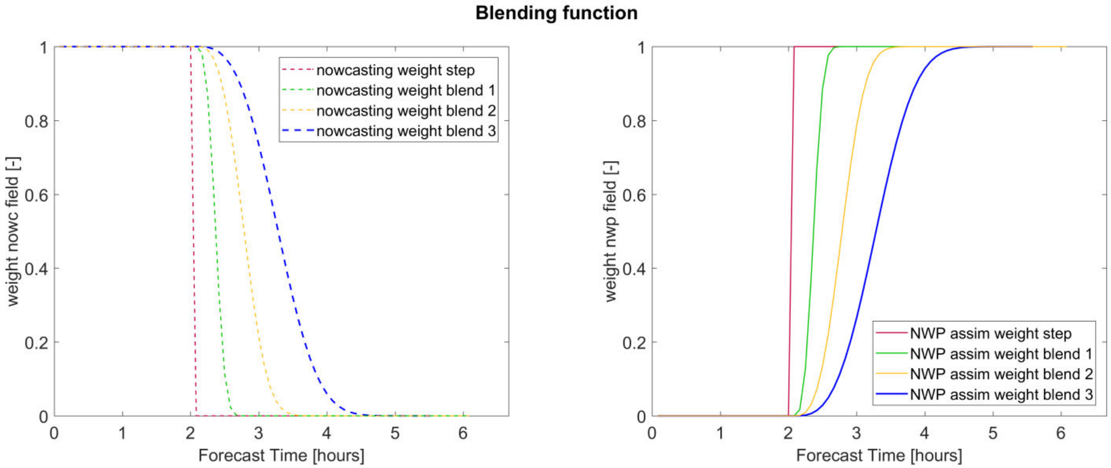
«Standard blending» technique: linear combination of the nowcasted rainfall fields with the NWP forecasted rainfall field corrected with DA

Linear combination obtained through **weighting** of the different fields according to the blending function

Short lead time: more weight to nowcasted rainfall fields

Longer lead time: more weight to NWP forecasted rainfall fields

$$Rainfall\ field_{blended}(T) = (weight_{nowc}(T) * rain_{nowc}(T)) + (weight_{nud}(T) * rain_{nud}(T))$$

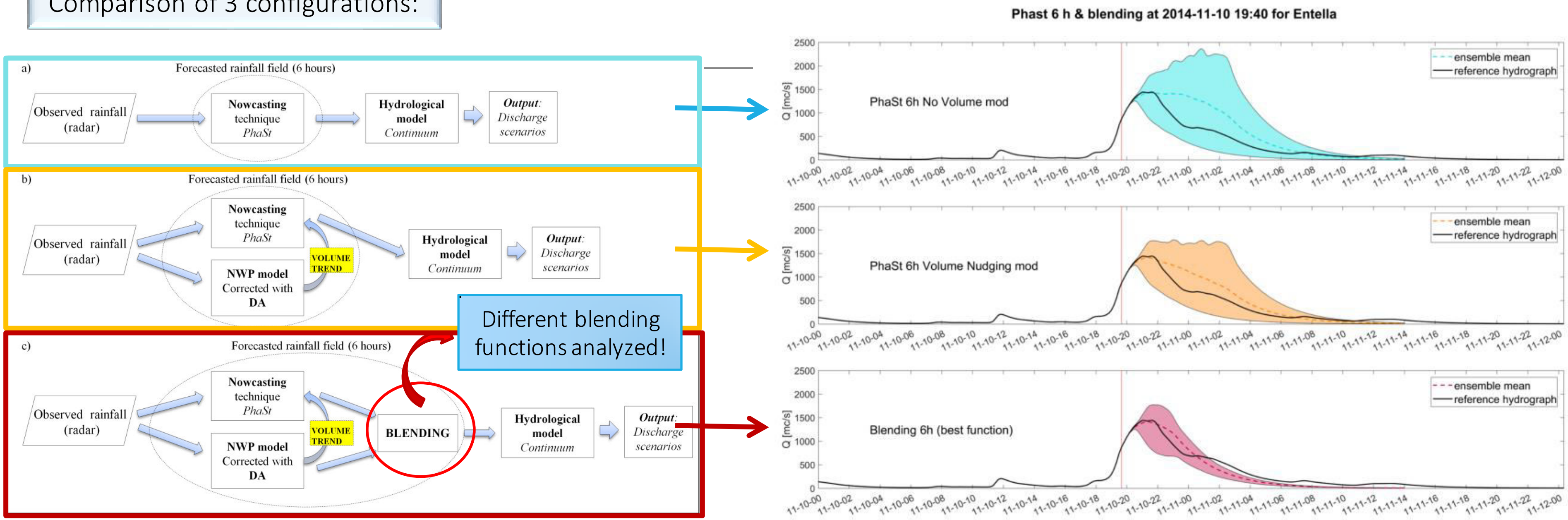


$$Weight_{NWP} = 1 - Weight_{NOWC}$$

In the application all the framework is updated every 20 minutes bacause radar data are frequently updated. Assimilation on NWP is carried out every 60 minutes

Results: analysis of the hydrological output

Comparison of 3 configurations:



The spread of the discharge forecast ensemble is markedly smaller when input rainfall is provided by blending (red envelope) instead of nowcasting alone (blue and orange envelopes) → smaller variance!

Results: some case studies

2 analysis

1 **Point** analysis → at basin scale

2 **Distributed** analysis → all over the computation domain of the hydrological model

Even if the events analysed are few the sampling points that can be analysed are thousands (even in many cases they are correlated)!

Scores used for the analysis:

Nash Sutcliffe efficiency

$$NS = 1 - \frac{\sum_{t=1}^{T}(Q_m(t) - Q_{obs}(t))^2}{\sum_{t=1}^{T}(Q_{obs} - \overline{Q_{obs}})^2}$$

Variance

$$Var(X) = E[(X - \mu)^2]$$

Reduced Continuous Rank Probability Score

$$RCRPS(F,x) = \frac{1}{\sigma^2}\int_{-\infty}^{\infty}(F(y) - \mathbb{1}(y - x))^2 dy$$

Results: point analysis at basin scale (1)

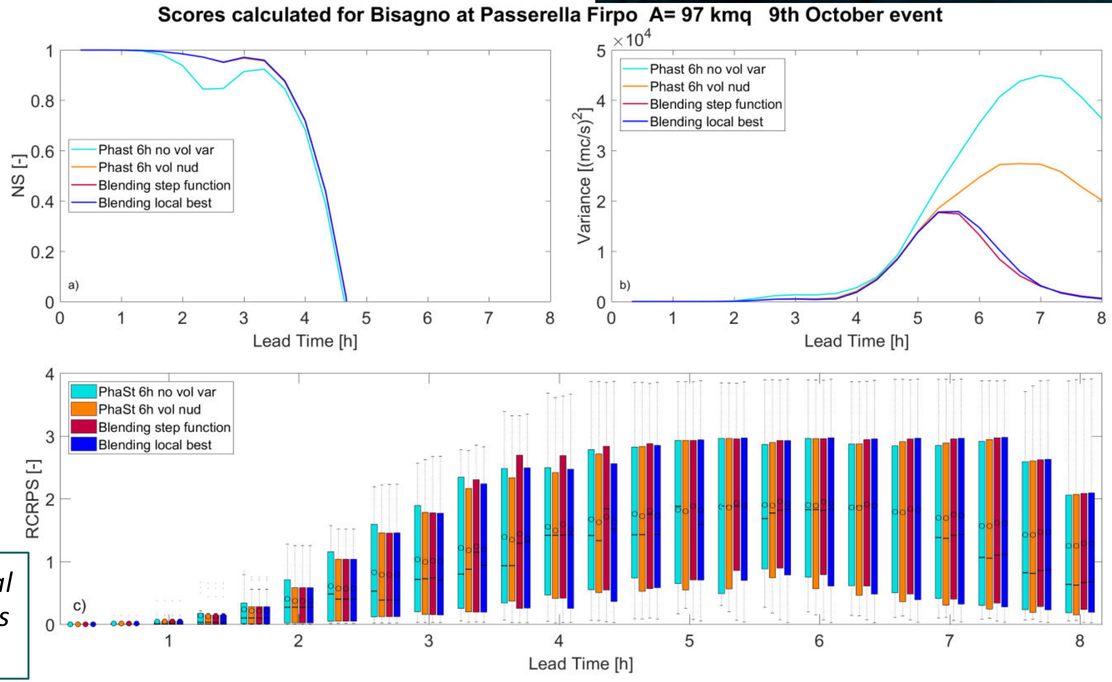
Case event: 9th October 2014

Bisagno creek flood (Genova)

Nash Sutcliffe *coefficient shows similar performances of the different configurations*

Variance *is actually smaller for the configurations with blending*

RCRPS *shows no clear enhancing of the performance of the chain with the use of blending*

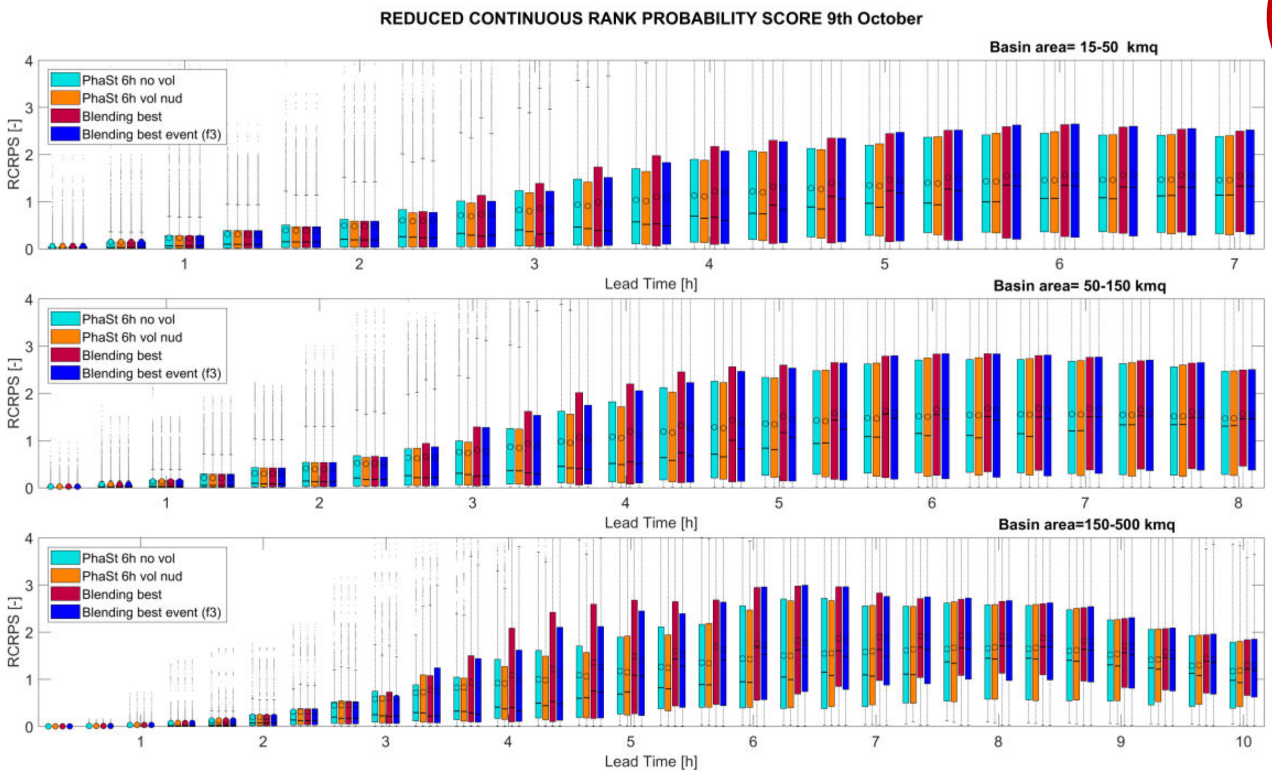


For this event, the forecast of the meteorological model, even corrected with data assimilation, is not able to improve the QPF.

Results: distributed analysis (1)

9th October 2014

*In this case the **RCRPS** behavior shows that the use of the information retrieved by the NWP model in the rain forecast worsen the hydrological forecast.*



*Particular **type of event**: stationary and persistent heavy precipitation on the same portion of territory*

The event was not forecast precisely by the NWP model, but well reproduced by the nowcasting model

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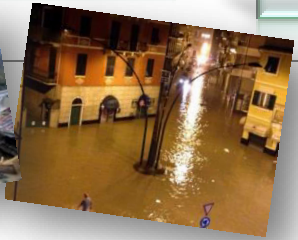
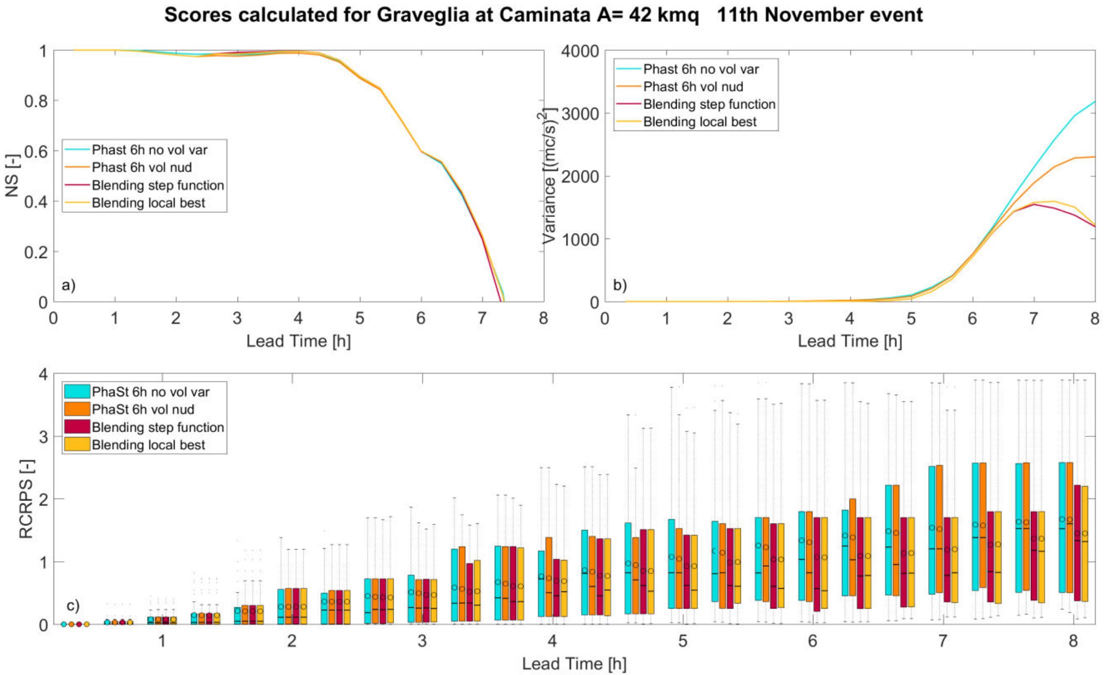
Results: point analysis at basin scale (2)

Case event: 11th November 2014

Event involving Entella basin and its tributaries (Chiavari)





Nash Sutcliffe *coefficient and Variance show the same results of 9 October*

RCRPS *clearly highlight better performances of the configurations that are using the blending*

While rainfall fields from nowcasting techniques lead to an overestimation of the discharge, the rainfall fields obtained through the blending clearly improves the discharge forecast.

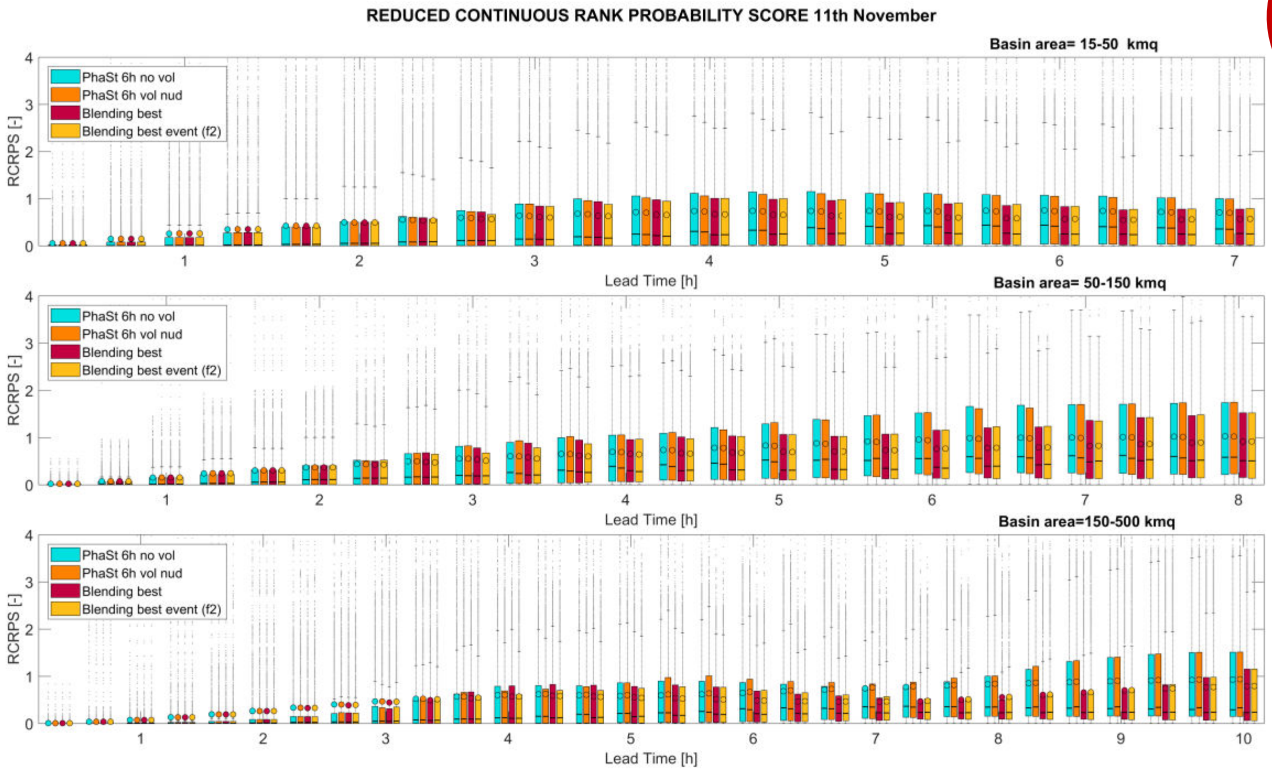
Results: distributed analysis (2)

11th November 2014

*In this case the **RCRPS** behavior shows, as in the punctual analysis, that the configuration using the blending performs markedly better.*

*For this event it is also worth to note the **different behavior of the score depending on the class area** of the point analyzed*

Especially for the bigger basins, due to their longer response time, the effects of a proper rainfall forecast provided with blending are beneficial for longer lead times.



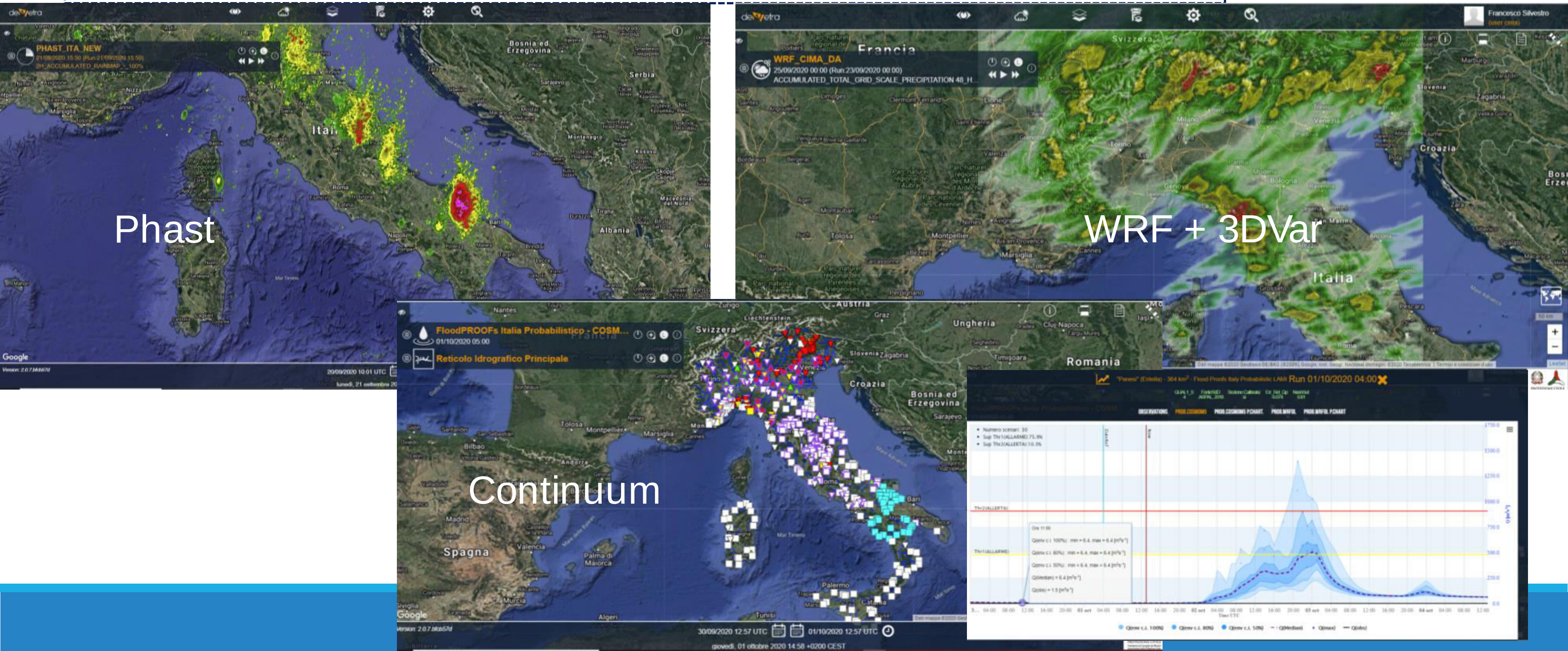
What are we doing?

We are setting up a forecast chain at National Scale:

1)National Mosaic of radar data as input to Phast (Currently pre-operational)

2)WRF with 3D var assimilation system (assimilates: radar reflectivity, ground data)

3)National scale hydrological model (Currently operational for Civil Protection purposes)



Conclusions

- The use of an integrated nowcasting hydrological chain is useful in real time as a support for Civil Protection actions, even if in some condition as performance similar (or event little worsen than) nowcasting.

- The use of the best rainfall forecasts (time horizon 6 hours) frequently updated can improve the hydrological forecast, but it has evident problems in an operational perspective in particular situations (isolated thunderstorm).

- The blending technique is useful to smoothly connect the forecasts result of nowcasting and of the NWP model but the goodness of the resulting rainfall field is really sensitive to the quality of the NWP model forecast, frequent data assimilation seems to be mandatory

- On a operational perspective need to account for calculation time and delay of output availability (negligible for Phast, not negligible for NWP)

TO DO:

- *Extend the analysis to other case studies*
- *Use different NWP models and DA assimilation techniques to be combined with nowcasting*
- *Explore other blending techniques*

Thank you

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