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Heavy precipitation events over Liguria (Italy): high-resolution hydro-meteorological forecasting and rainfall data assimilation

Silvio Davolio[1], Francesco Silvestro[2], Thomas Gastaldo[3]

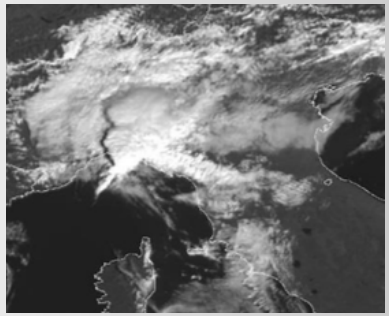
1. CNR – ISAC, Bologna
2. CIMA Research Foundation (Savona)
3. University of Bologna & ARPAE-SIMC (Bologna)

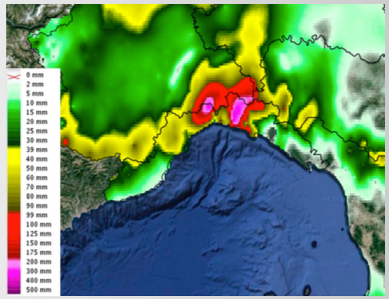
Framework …

- Heavy precipitation and flooding events frequently affect the Mediterranean basin. Improving their understanding and hydro-meteorological forecasting is a scientific topic of great interest (e.g. HyMeX programme).

- QPF for severe rainfall, associated with deep convection, is affected by relevant uncertainty especially at the fine scales required for flood predictions → Improving NWP in the short-range at high-resolution, through model development or data assimilation.

HyMeX





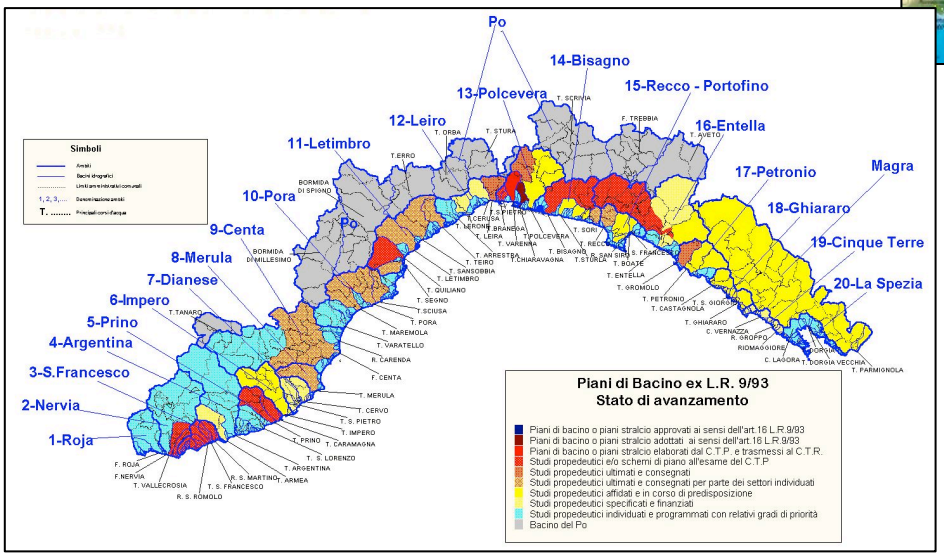
… and Aim

- Extensive quantitative evaluation of the performance of a nudging procedure to assimilate radar rainfall estimates into a CPM, included in a hydro-meteorological operational forecasting chain.

- Explore possible dependence of assimilation impact on the characteristics of the meteorological environment.

- Provide a practical evaluation of the QPF at the catchment scale, relevant for operational hydrological application in the region

Area of interest: Liguria



Coastal area characterized by complex orography reaching high elevation (~2000 m) within few km from the coastline.

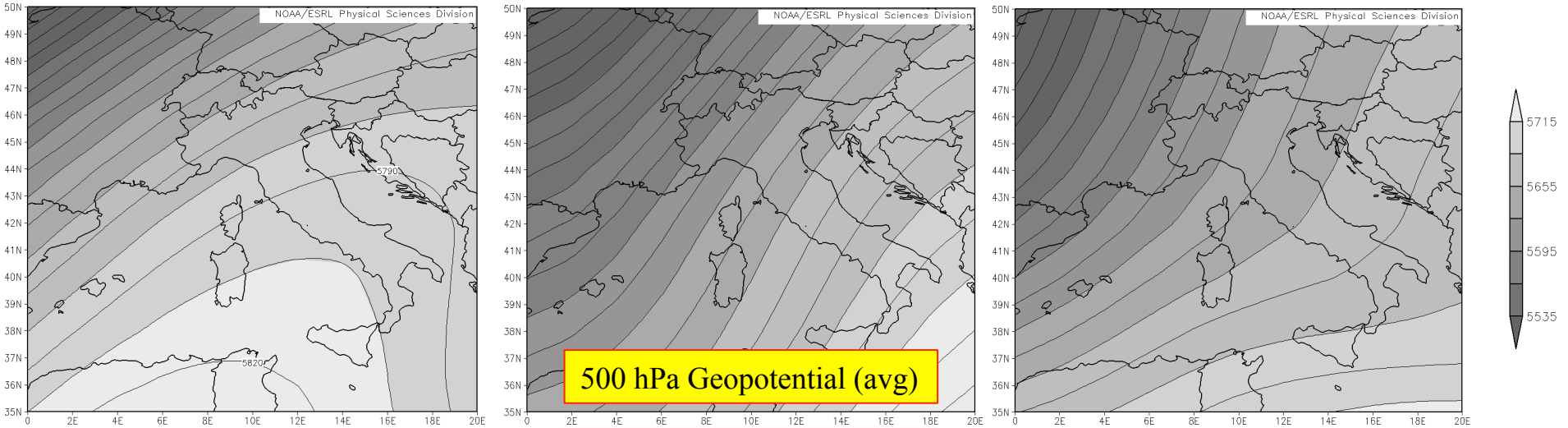
Catchments of small dimensions (only a few larger than 200 km^2) and short response time.

Urban areas mostly along the coast in proximity of river outlets.

Prone to heavy rainfall and floods, whose mechanisms have been recently investigated and identified (*Rebora et al., 2013; Buzzi et al., 2014; Davolio et al., 2015; Fiori et al., 2014, 2017; Silvestro et al., 2016*).

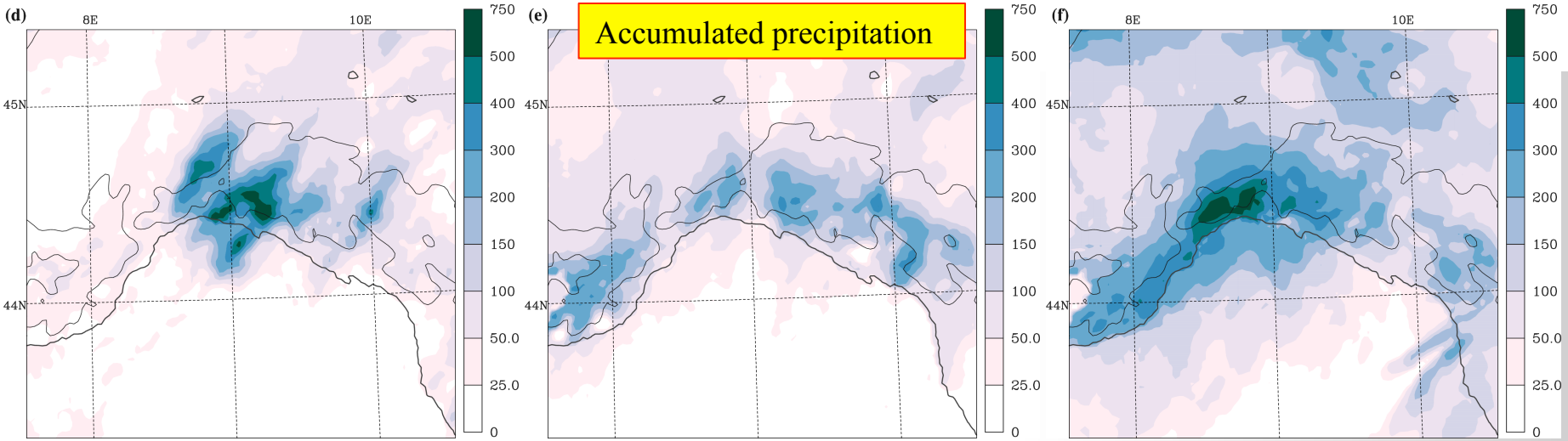
Severe weather events in October-November 2014

Autumn 2014 was particularly severe with intense precipitation events in quick succession, several flash floods and a devastating flood on 9 October. Large scale trough deepening over the Mediterranean, SW moist flow favouring the development of precipitation (convective) systems.



500 hPa Geopotential (avg)

Accumulated precipitation

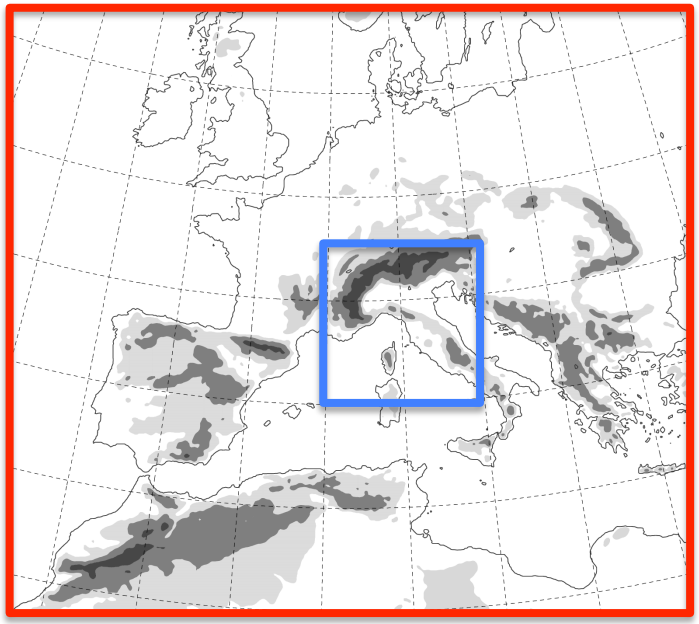


7-13 October

3-6 November

9-15 November

The hydro-meteorological forecasting chain

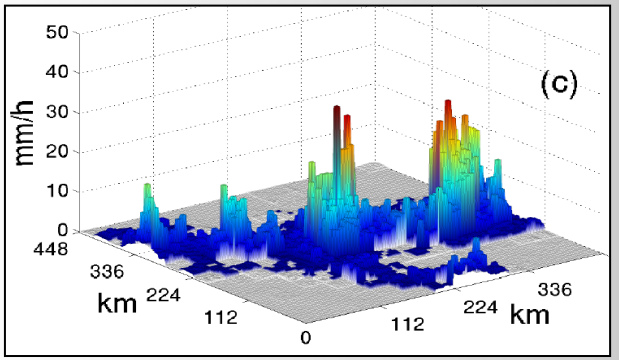


NWP Models

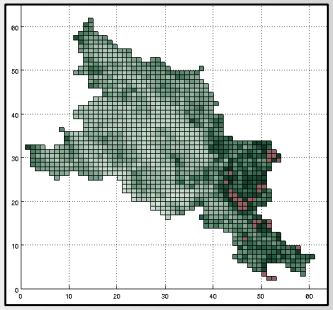
BOLAM hydrostatic model, driven by IFS forecasts, horizontal resolution 8.3 km, 50 levels, provides hourly BCs to MOLOCH.

MOLOCH non-hydrostatic model, nested in BOLAM, horizontal resolution 2.2 km, 50 levels.

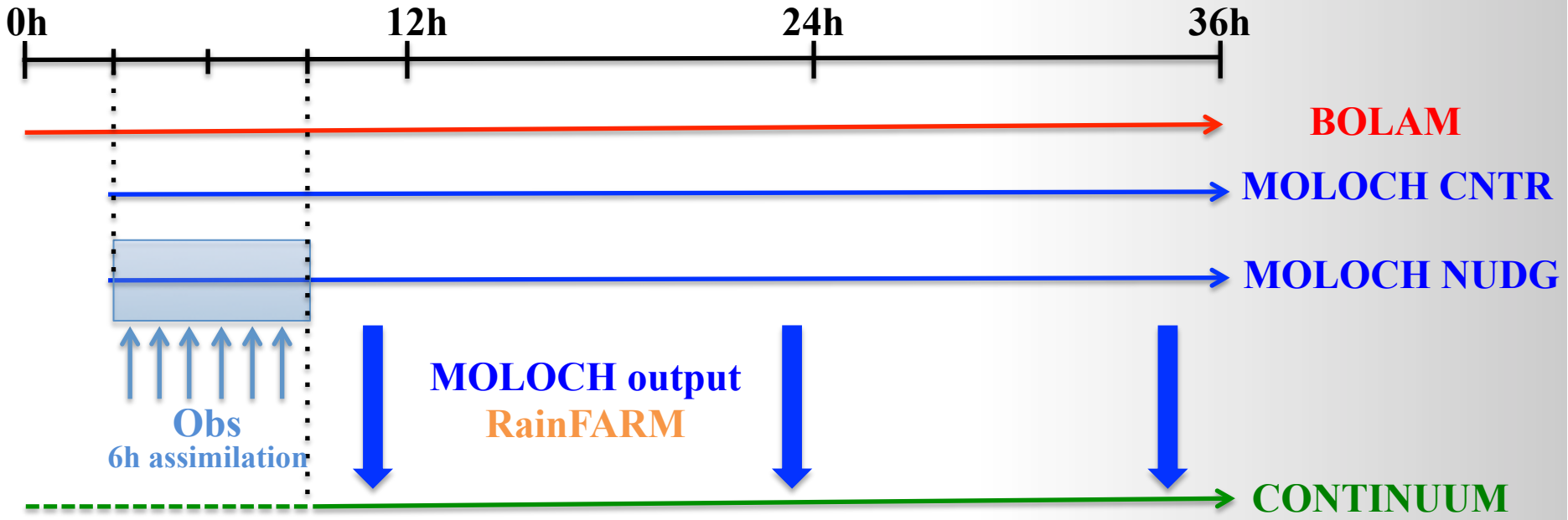
RainFARM: It is a stochastic downscaling algorithm to generate an ensemble (100 members) of hourly precipitation fields consistent with MOLOCH rainfall predictions. It preserves the information at large scale (volume and spatial structure) of the QPF and generate fine-scale structures, so to account for rainfall variability at smaller scales.

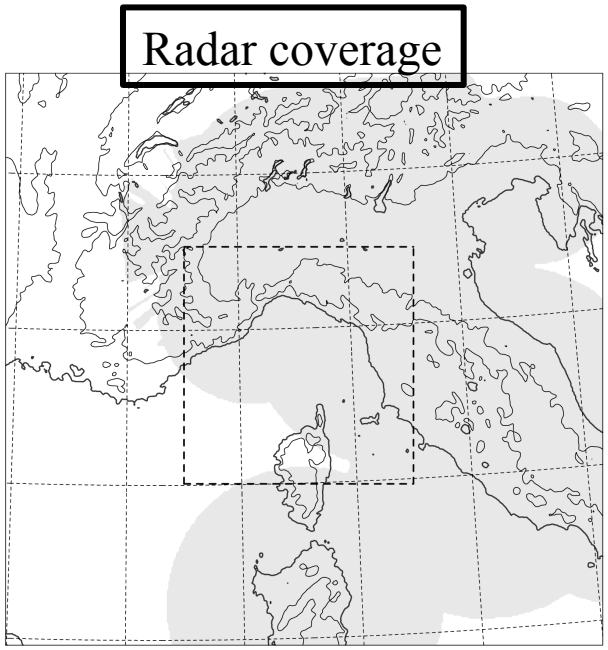


CONTINUUM fully distributed hydrological model, 0.005° resolution; calibration period 2013-2014 over 11 sections; open Fortran code: http://continuum.cimafoundation.org
Run period: 01 Jan. – 31 Dec 2014 to avoid spin up. Each run is initialized with the state variables estimated during the 1-year long run.



Experimental setup





29 deterministic forecasts initialized at 00 or 12 UTC covering the days with intense precipitation.
For each of them, one CNTR and one NUDG simulation.

6h assimilation window compatible with an envisaged operational implementation for short-range forecasts.

The assimilation scheme

$$\frac{\partial q(k)}{\partial t} = -\frac{\nu(k)}{\tau}\left[q(k) - \varepsilon_{\pm} q^{*}(k)\right] \cdot \sqrt{\left|P_{DIFF}\right|}$$

q(k) model specific humidity profile

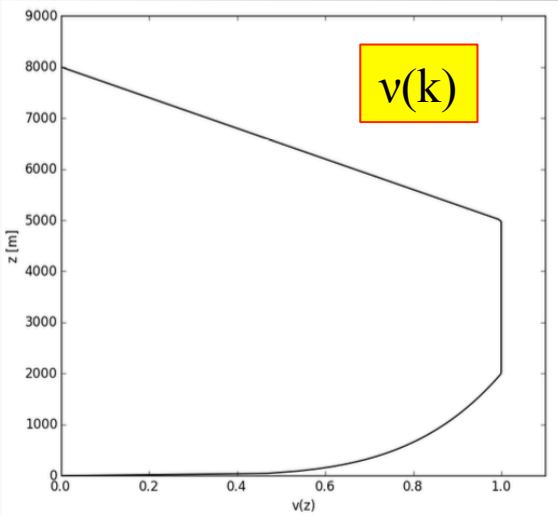
q*(k) model specific humidity profile at saturation

$P_{DIFF} = R_{MOD} - R_{OBS}$ R = acc. rainfall up to the current time step (in mm/h); OBS hourly data

If $P_{DIFF} < 0$ → nudging of model specific humidity profile q(k) towards over (ε_+) saturation

If $P_{DIFF} > 0$ → nudging of model specific humidity profile q(k) towards under (ε_-) saturation

τ = relaxation time = 15'
$\varepsilon_+ = 1.02$
$\varepsilon_- = 0.95$
$\nu(k)$ = [0÷1] = modulation profile to limit q adjustment in the PBL and in the upper troposphere



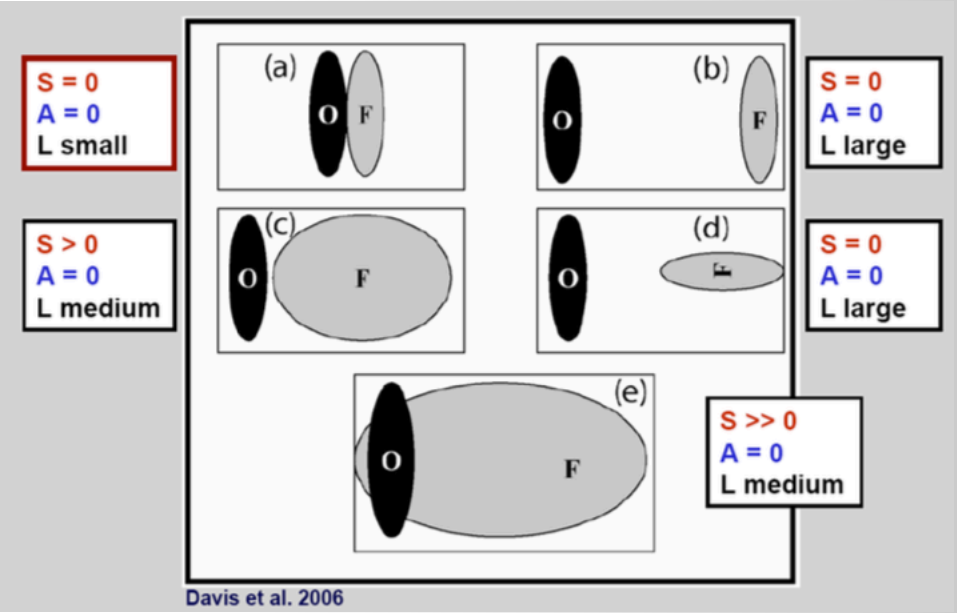
Meteorological evaluation: SAL

SAL is based on identification and comparison of precipitation objects (Wernli et al., 2008). SAL provides information about errors of QPF in terms of:

Structure → too sharp/flat, too broad/small
Amplitude → over/under estimation
Location → correct location

Perfect match with observation S=A=L=0

Selection of threshold and suitable area.



Hydrological evaluation: CRPS

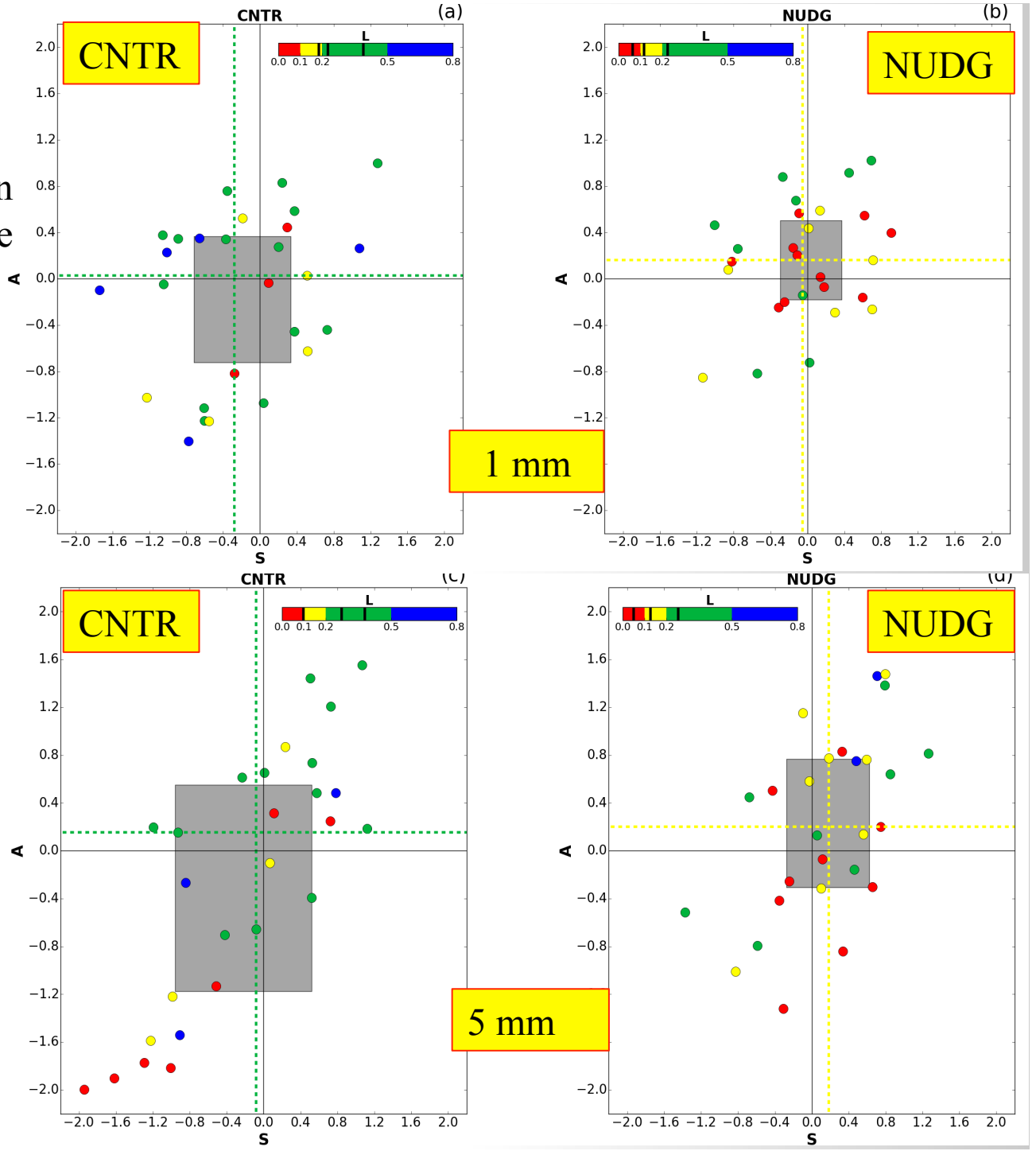
Continuous Rank Probability Score (Stanki et al., 1989) measures the distance between predicted and observed cumulative distribution functions of a scalar variable.
To allow comparison across different basins → Reduction CRPS, dividing by the standard deviation of the observations.
RCRPS = 0 → perfect match.

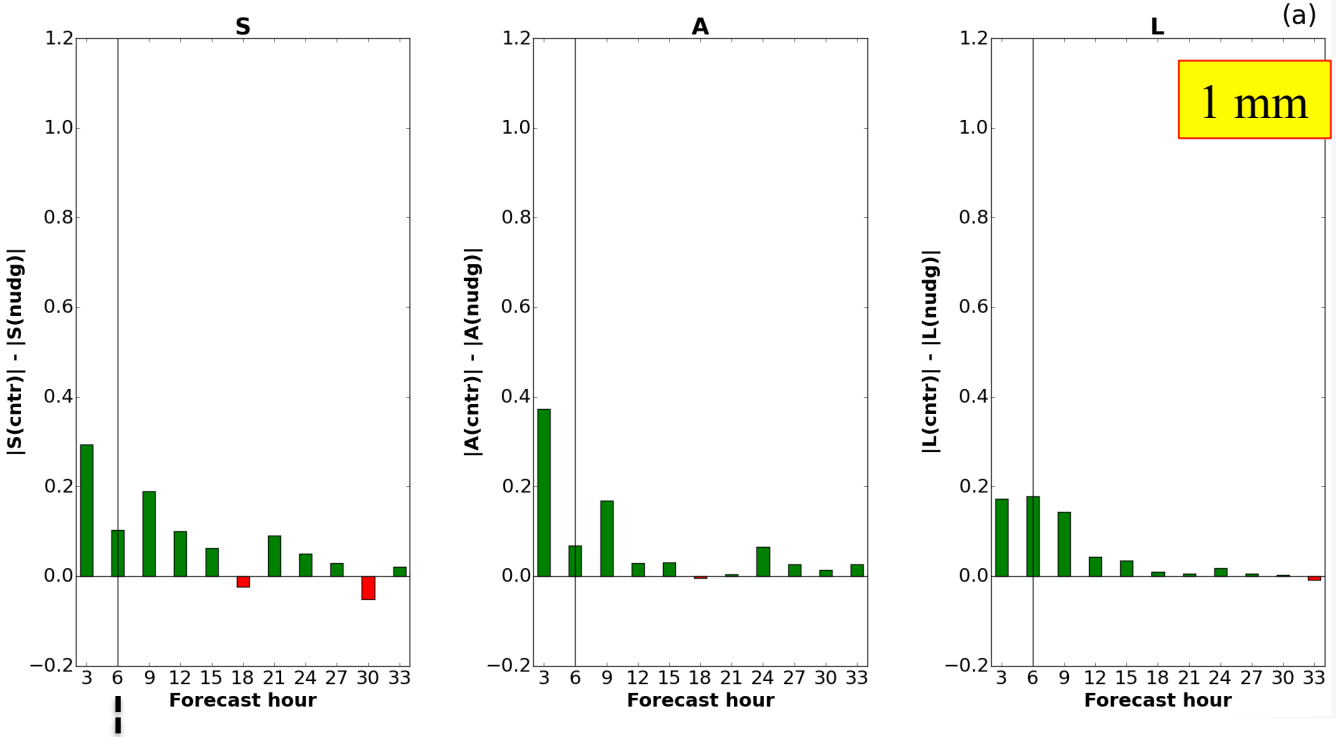
Results

SAL plot
3h accumulated precipitation range +6 to +9h, just after the assimilation period.

Perfect forecast:
red dot in the centre

Grey rectangle:
S & A interquartile range

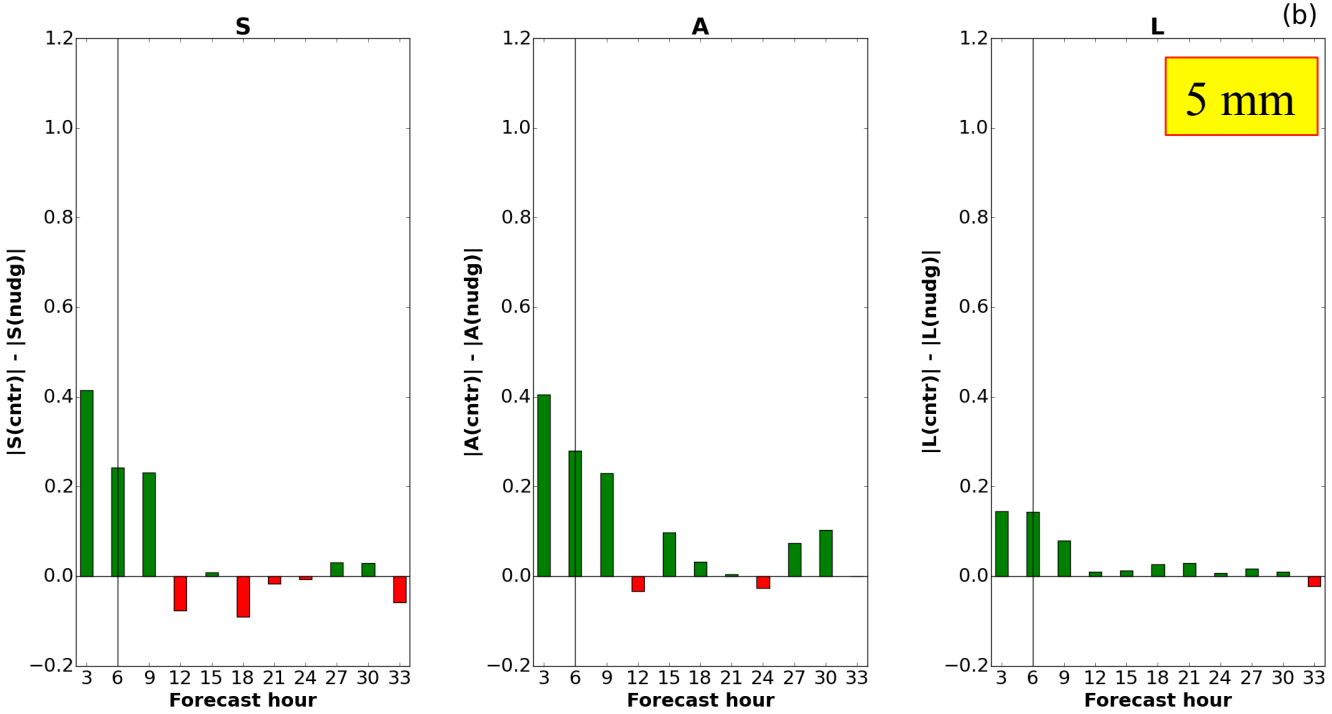




Evolution of SAL components with forecast range (3h rainfall).

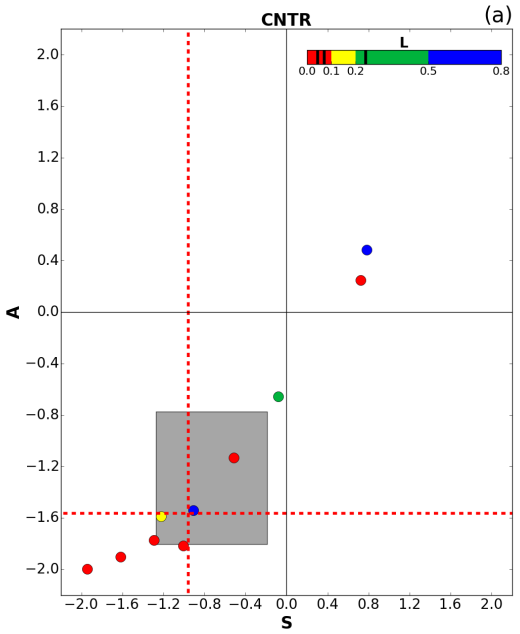
Difference between the absolute value of each SAL component.

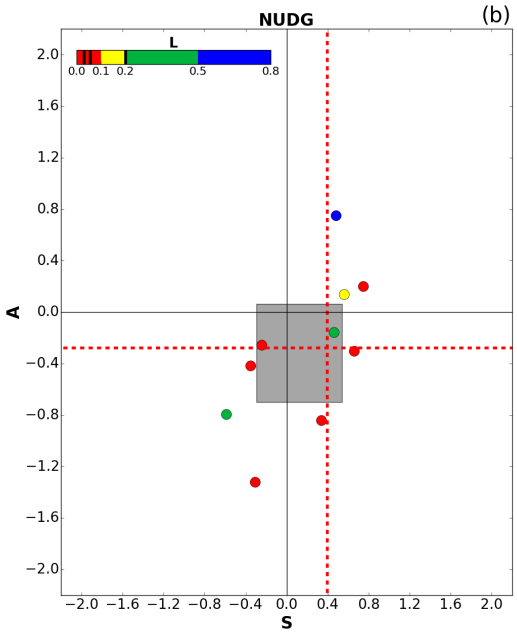
End of assimilation



POSITIVE VALUE → improvement due to assimilation

SAL plots for 3h accumulated precipitation after the assimilation period, threshold 5 mm
<u>October and November events are considered separately</u>





OCTOBER EVENTS

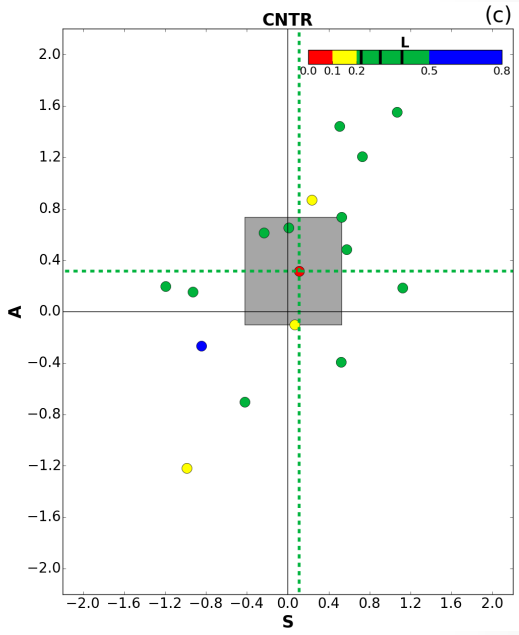
CNTR forecasts affected by a relevant uncertainty: large underestimation, small/sharp objects, location not bad.

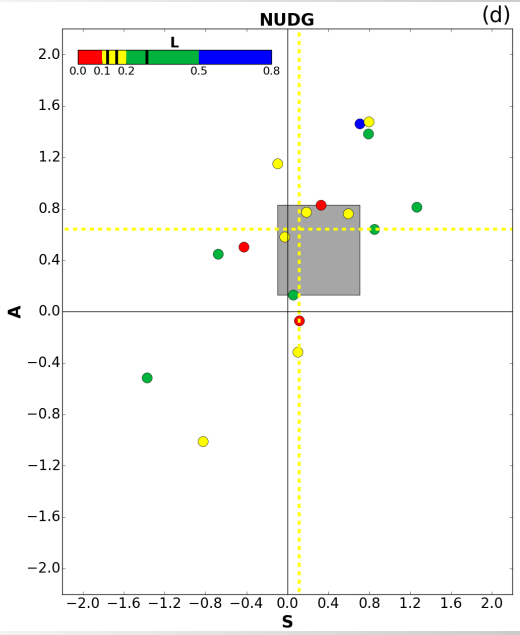
NUDG: large improvement of the forecasts due to nudging

NOVEMBER EVENTS

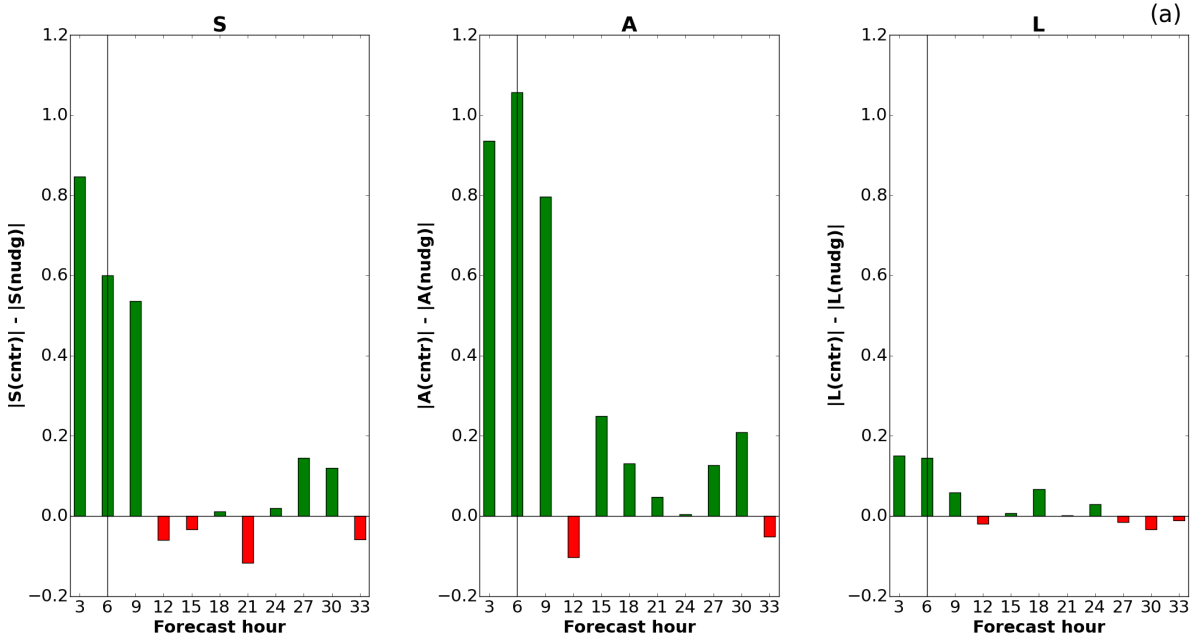
CNTR forecasts much more skilful, just slight overestimation

NUDG: no extraordinary effects; slightly accentuates overestimation, improves the location.





Evolution of SAL components with forecast range (3h prec) - October and November separately

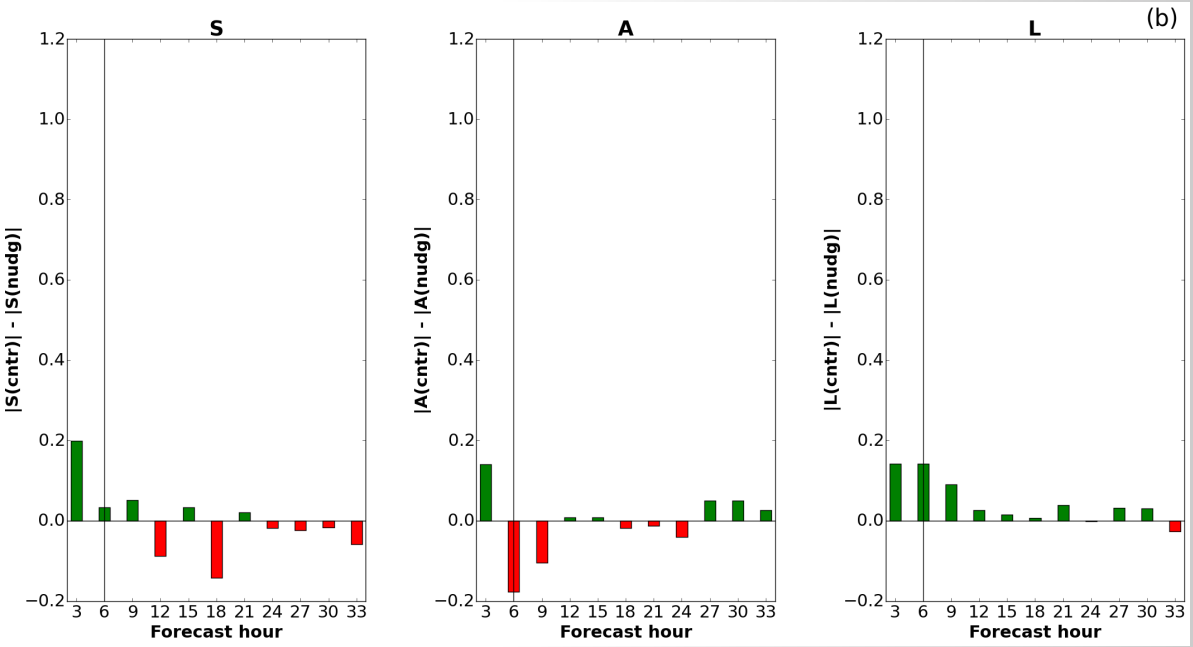


OCTOBER EVENTS

Rainfall assimilation greatly improves forecasts for S, A and L, during the assimilation period and for the first 3 hours of 4-6 free forecast.

NOVEMBER EVENTS

The positive impact of assimilation is much smaller; some degradation in terms of amplitude. Location is improved.



Characteristics of the meteorological environment

Convective equilibrium (Emanuel, 1994)

$$\tau_c = \frac{CAPE}{\frac{dCAPE}{dt}} = \frac{1}{2}\frac{c_p \rho T_0}{L_v g}\frac{CAPE}{P}$$

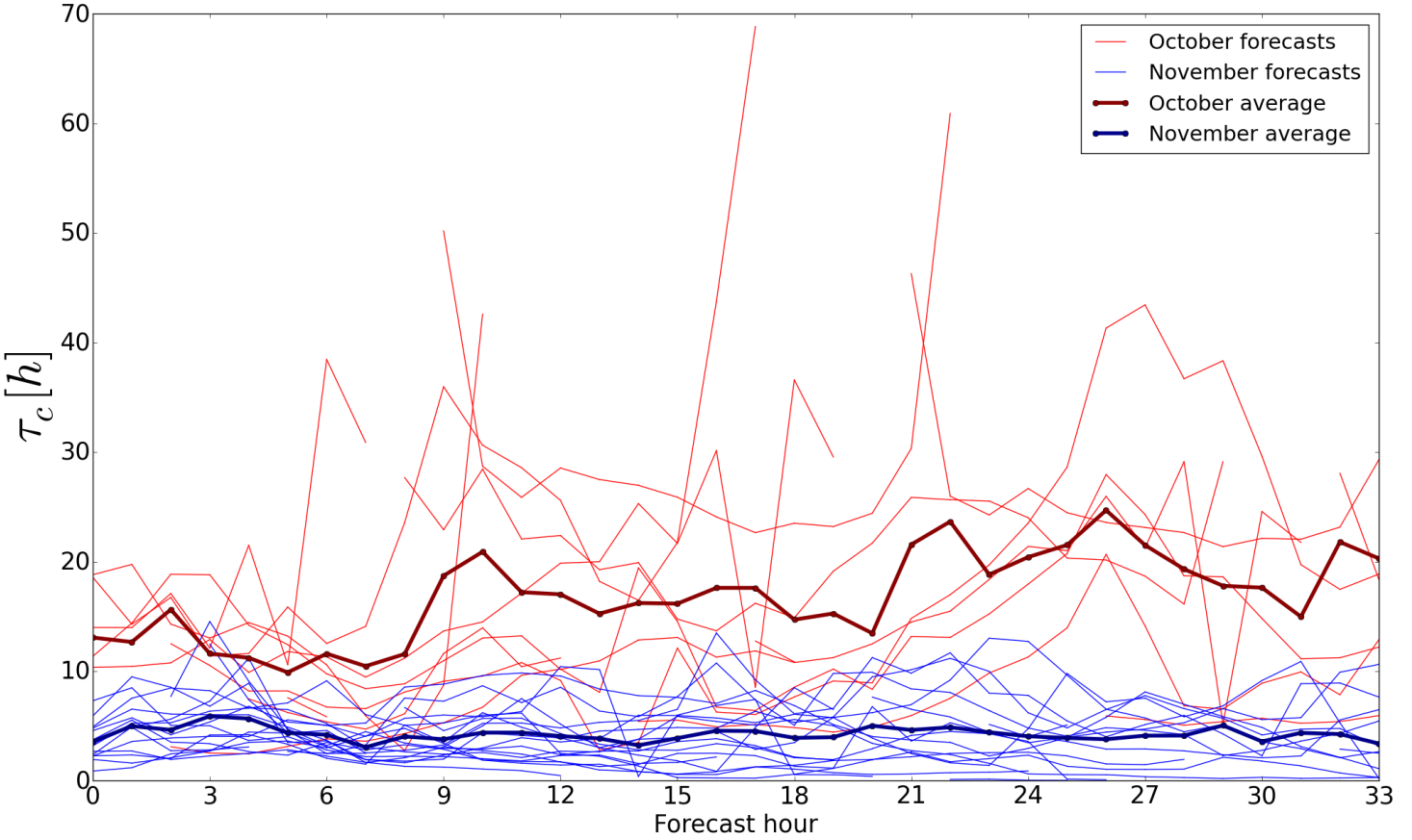
Equilibrium convection: convection is in equilibrium with large-scale forcing, the instability is consumed at the same rate it is produced by the large-scale forcing. Convection and rainfall are determined by the large-scale flow, CIN is almost zero. τ_c is small.

Non-equilibrium convection: weak synoptic forcing and strong inhibition to the release of instability (capping inversion) favour large values of CAPE. When/where CIN threshold is overcome (triggering) CAPE is rapidly exhausted and rainfall occurs. Less predictable, strongly depends upon exact prediction of local triggering. τ_c is large.

τ_c 6÷12 threshold between the two regimes (lot of literature).

Craig et al. (2012) related predictability and rainfall assimilation impact with convection equilibrium regime (using 3 case studies over Germany and ensemble forecasting).

CONVECTIVE TIME SCALE

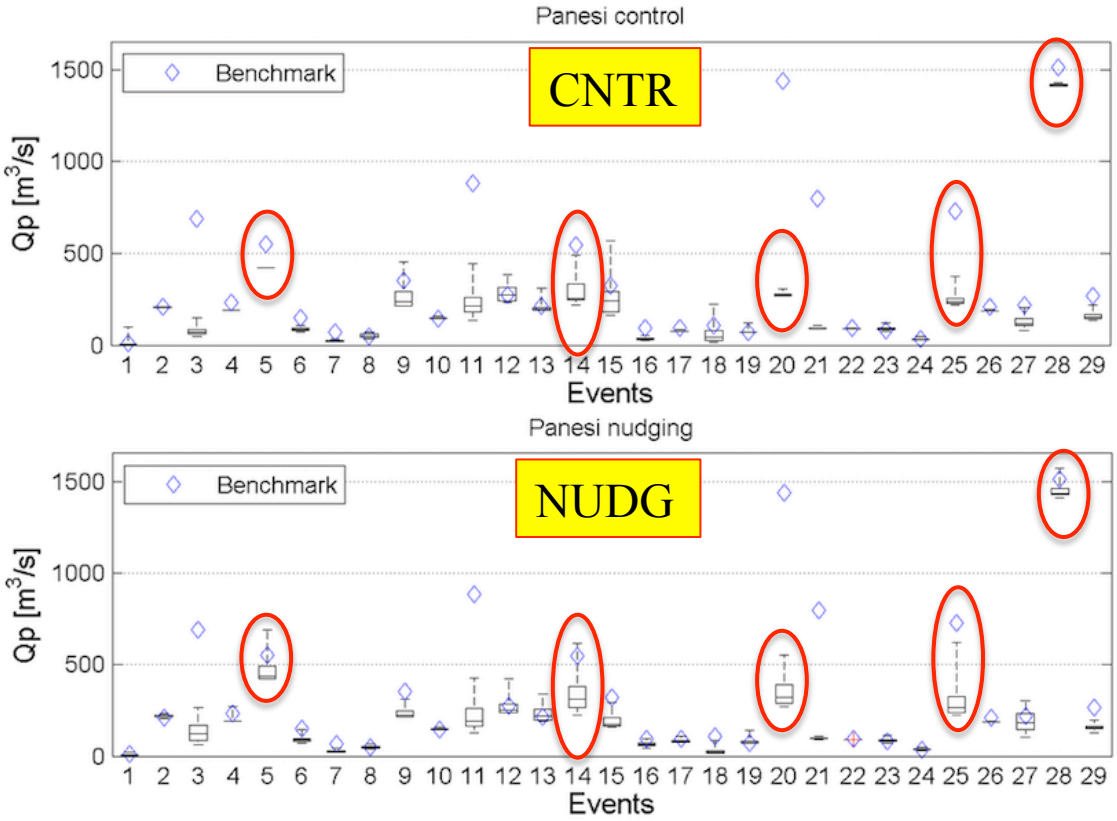


τ_c is larger in October, which was characterized by several MCSs and by a lower predictability. The impact of assimilation is larger in October, associated with non-equilibrium convection. The assimilation allows to correctly simulate timing and location of local convection triggering.

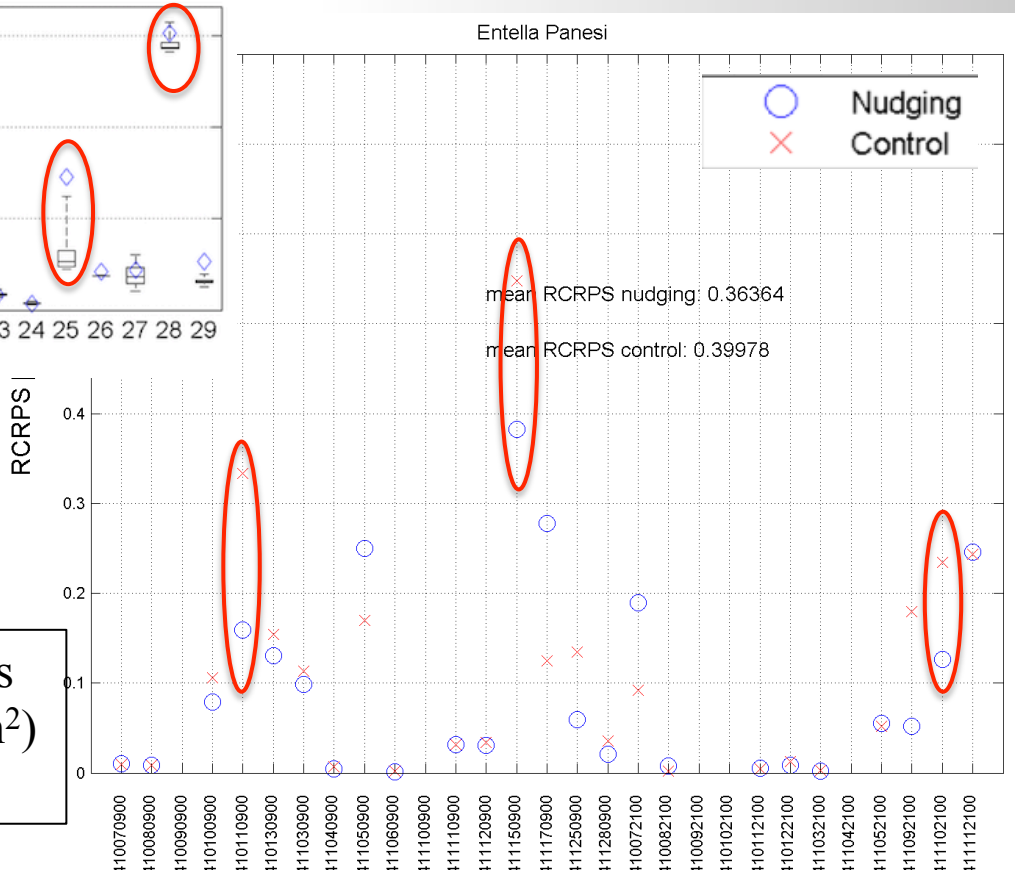
In November, strong large-scale forcing rapidly removes the assimilation adjustment, data assimilation impact last shorter.

Hydrological results: example

Peak flows are compared in a time window that starts at the end of the assimilation and lasts for 18h.



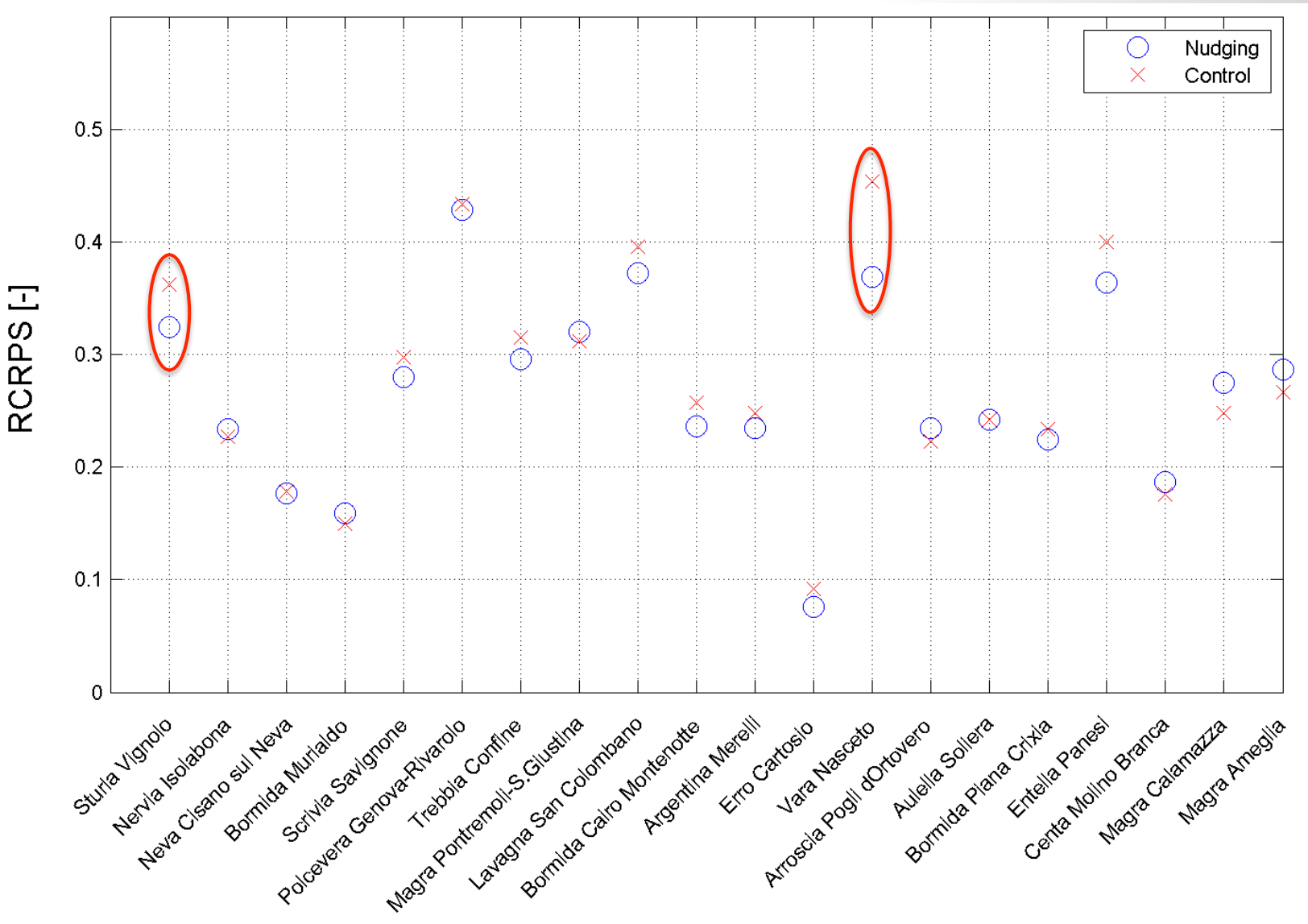
Peak flows (m^3/s)
Entella basin (364 km^2)
All 29 forecasts



RCRPS for discharges
Entella basin (364 km^2)
All 29 forecasts

Hydrological results: summary for the 20 basins

Mean RCRPS computed over all the events in order to evaluate the overall impact of data assimilation on a large number of simulations.



Conclusions

Assimilation scheme implemented in order to be feasible for hydro-meteorological operational activities; evaluated not only in terms of QPF but also considering the hydrological response.

SAL shows a systematic positive impact on QPF, although limited to the first hours of free forecast. Nudging removes misplaced rainfall and it is able to trigger precipitation in the correct place/time, associated with the activation of vertical motions due to latent heat release.

Although assimilation impact on rainfall does not last for many hours (nowcasting application), it can improve the hydrological prediction, especially in case of high flow.

The impact of assimilation is related to the environment characteristics (convective equilibrium). This support Craig et al (2012) results, being obtained with a different model, nudging procedure and on a large sample of heavy precipitation forecasts.

Sensitivity experiments provided indications on

- observation frequency (10' vs 1h)
- length of the assimilation window (3 vs 6 hours).

THANK YOU

Journal of Hydrometeorology

Impact of rainfall assimilation on high-resolution hydro-meteorological forecasts over Liguria (Italy)

--Manuscript Draft--

Manuscript Number:	JHM-D-17-0073
Full Title:	Impact of rainfall assimilation on high-resolution hydro-meteorological forecasts over Liguria (Italy)
Article Type:	Article