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On evaluating the applicability of CRA over small verification domains

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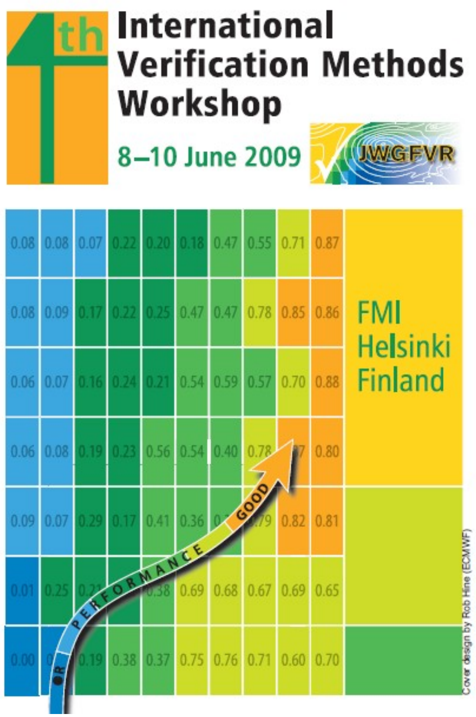
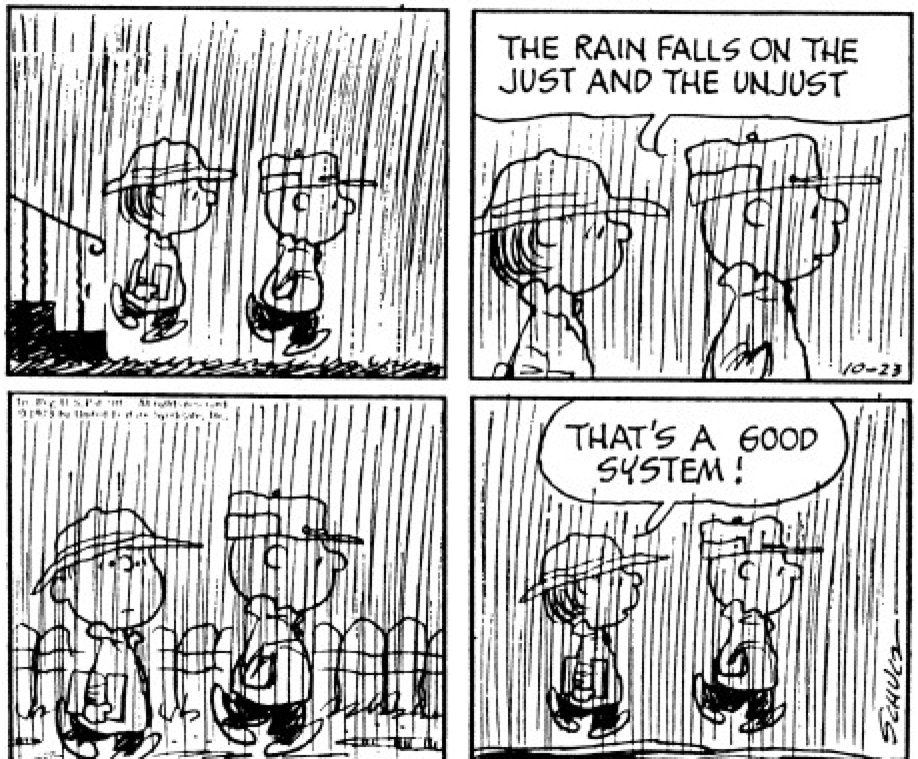


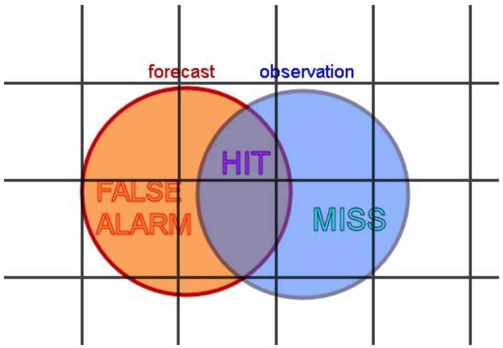


Motivation

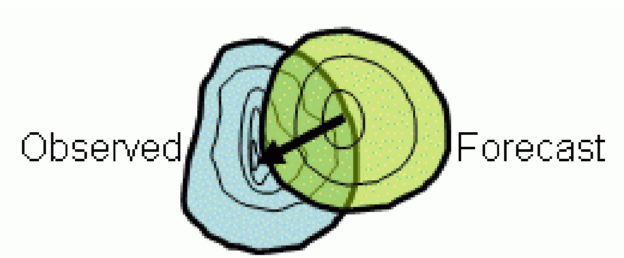
"[…] it is almost a platitude to say that a forecast not verified is a forecast not worth much […] There can be little doubt that this is a necessity, if we care about the quality of our output" **by Charles Doswell III (1996)**

Traditional categorical scores and skill scores are usually affected by the **double penalty effect**.

Object-oriented techniques provide instead a useful way to quantify and qualify – also in terms of error sources – the forecast spatial error.



In general, they give **quantitative** support to the standard "eyeball" verification, since they measure the spatial displacements perceived in the numerical forecasts.



After WWRP/WGNE website: http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html

The **contiguous rain area analysis** (**CRA**; Ebert and McBride 2000) is an object-oriented technique based on a pattern-matching of two contiguous areas delimited by a chosen isohyet.

Ebert, E. E. and J. L. McBride, *J. Hydrol.*, 239 (2000) 179–202

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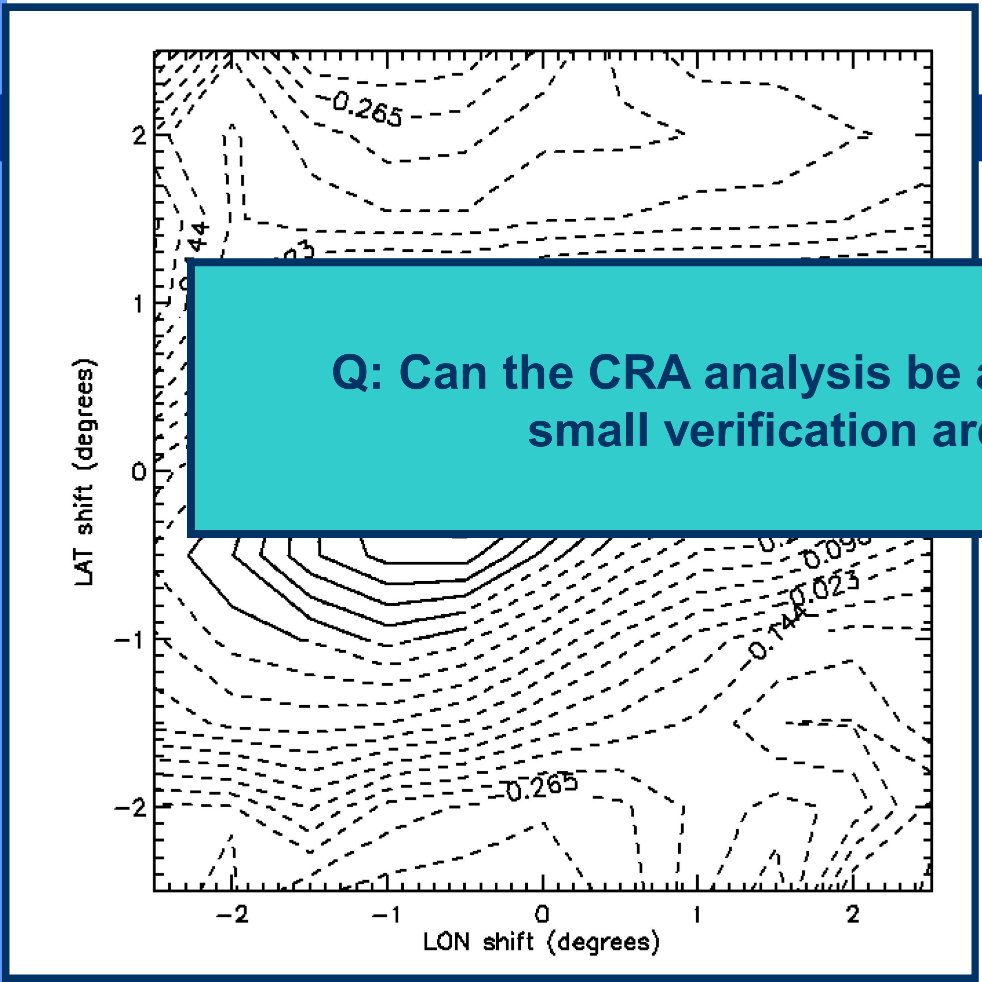
Contiguous rain area analysis for spatial verification

Pattern match is obtained by translating in lon. and lat. the forecast rainfall features over the observed ones, until a best-match criterion is satisfied.



Q: Can the CRA analysis be applicable to small verification areas?

2-D CRA shift analysis

Imposing a maximum shifting
value and a CRA rain-rate
r.

btained by
e MSE or
correlation
between the forecast and the observed areas.

Total forecast error decomposed into **volume**, **pattern** and **displacement errors** – by following the approach proposed by Ebert and McBride (2000) or by Grams et al. (2006).

Grams, J. S. et al., *Wea. Forecasting,* 21 (2006) 288–306.

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The Montserrat-2000 event
HYDROPTIMET – INTERREG IIIB MEDOCC

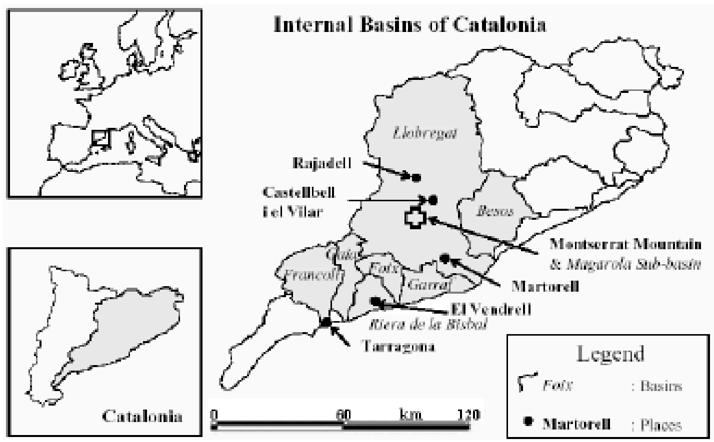

Fig. 1. Catalonia (Spain) internal basins (from Llasat et al., 2003).

The Spanish flash-flood event occurred over the internal basin of Catalonia on 9-10 June 2000 (Mariani et al., 2005).

Mariani, S. et al., *Nat. Hazards Earth Syst. Sci.,*, 5 (2005) 565–581.

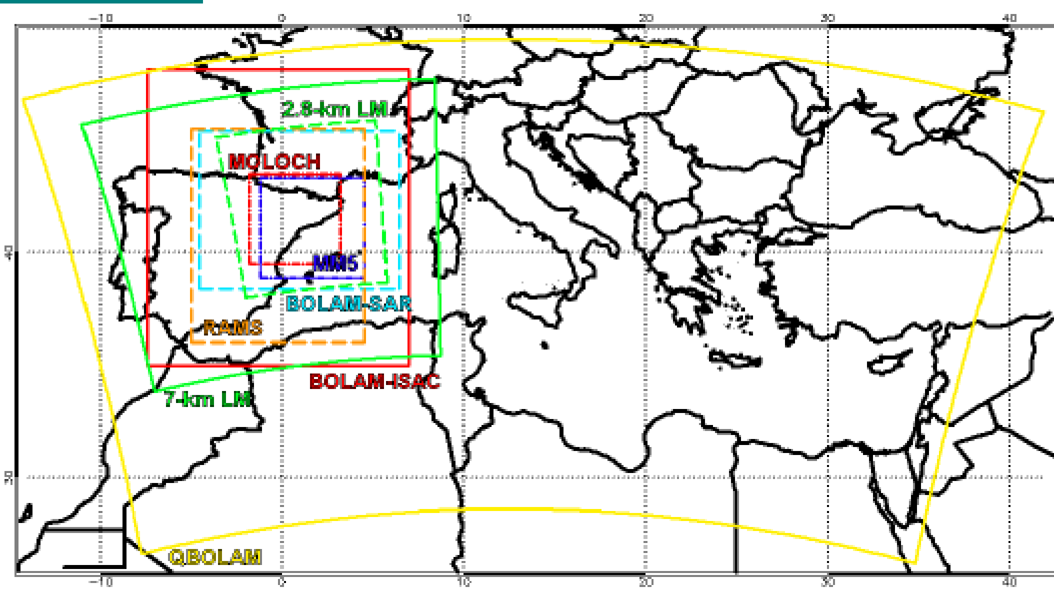

Fig. 2. Extension domains for the selected limited area models. Domains cover from entire Mediterranean Basin to Catalonia region. Solid yellow line: QBOLAM. Solid green line: 7-km LM. Solid red line: BOLAM from ISAC-CNR. Dashed sky-blue line: BOLAM from SAR. Dashed orange line: RAMS. Dashed green line: 2.8-km LM. Dash-dotted blue line: MM5. Dash-dotted red line: MOLOCH.

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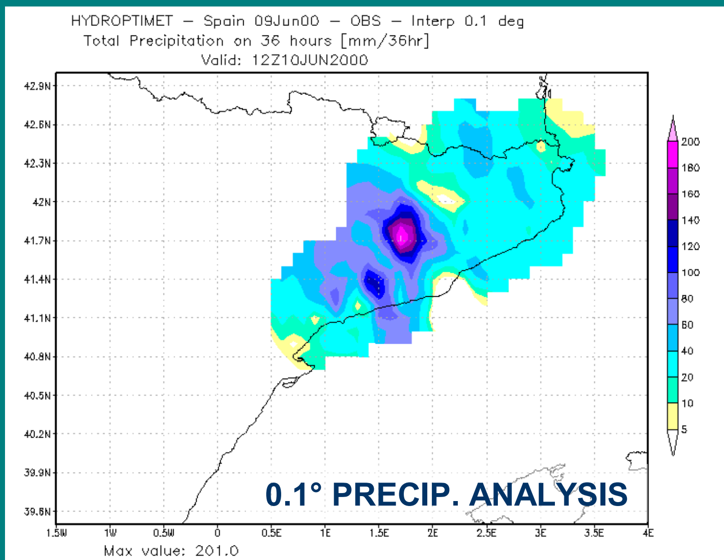
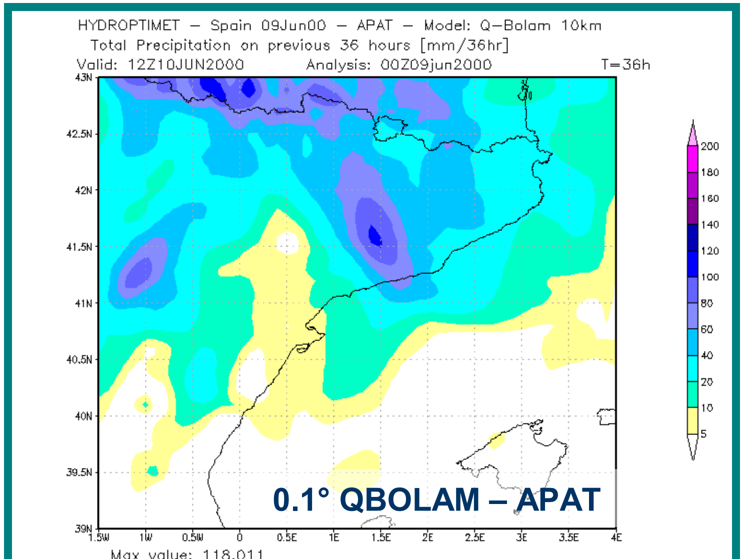
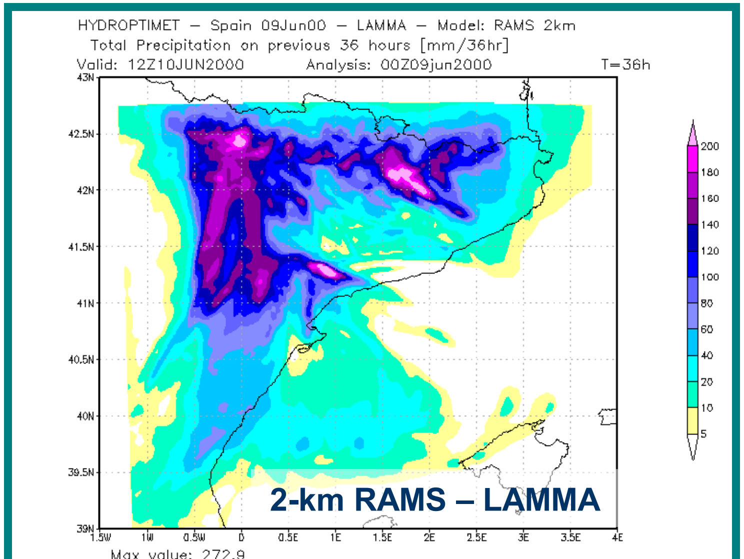


MSE used as pattern match criterion
CRA rain-rate contour = 0.5 mm $6h^{-1}$
0.1° verification grid
Focussing on 00 – 06 UTC of 10 June 2000

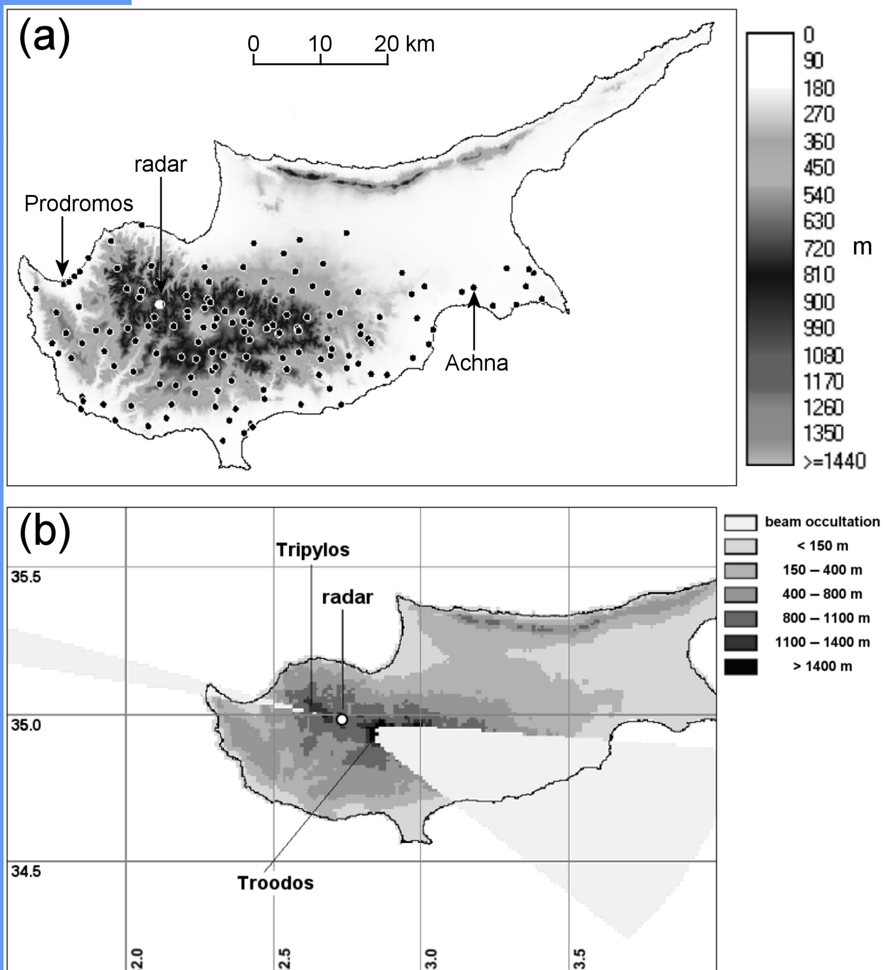
- QBOLAM: to be shifted 0°E and −0.4°N (MSE=**318.1 → 165.1** & Corr.=**0.82 → 0.90**)
- RAMS: to be shifted −0.5°E and −0.5°N (MSE=**2739.3 → 631.7** & Corr.=**−0.64 → 0.61**) ⇒possible unphysical result

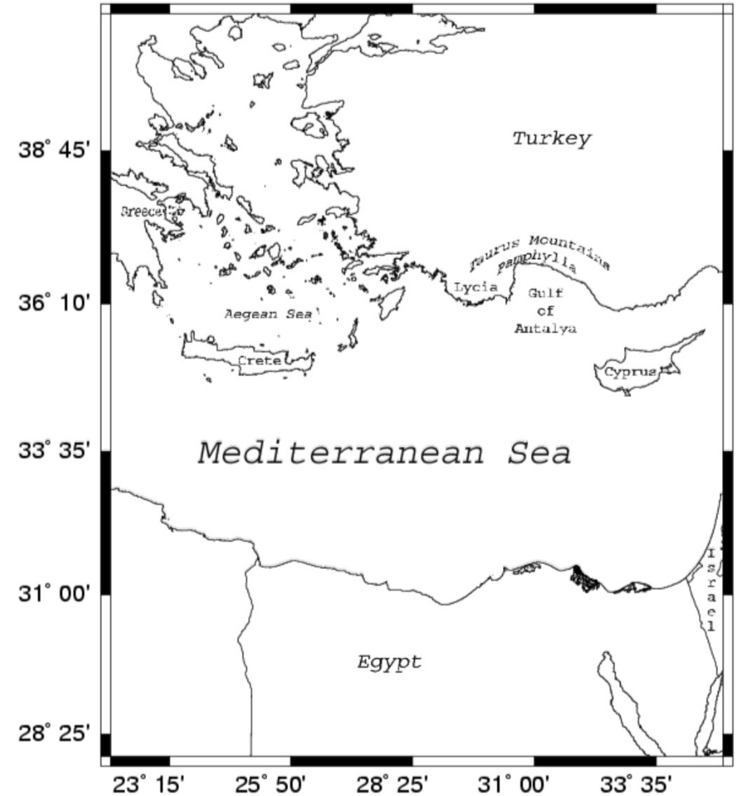




Multi-sensor spatial verification: the Cyprus case study on 5-6 March 2003

Cyprus is an optimal "test-bed": a dense rain gauge network – a weather radar – TRMM passage

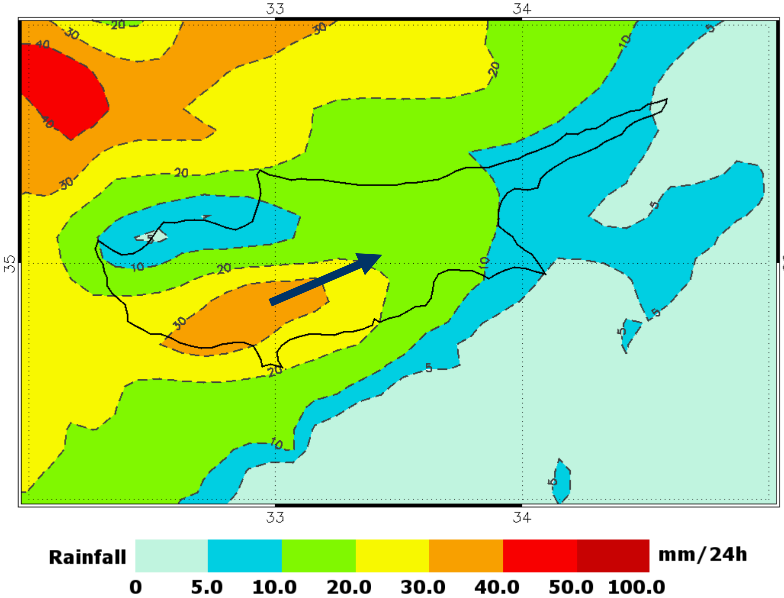




Within the **VOLTAIRE** project – **FP5**, the idea was to define a forecast verification methodology (Mariani et al., 2008) based on the assessment of the use of multi-sensor data and of the state-of-the-art verification techniques, in particular the CRA analysis.

Mariani, S. et al., *Wea. Forecasting,* 23 (2008) 674–701.

Model data and rain gauge-based analysis

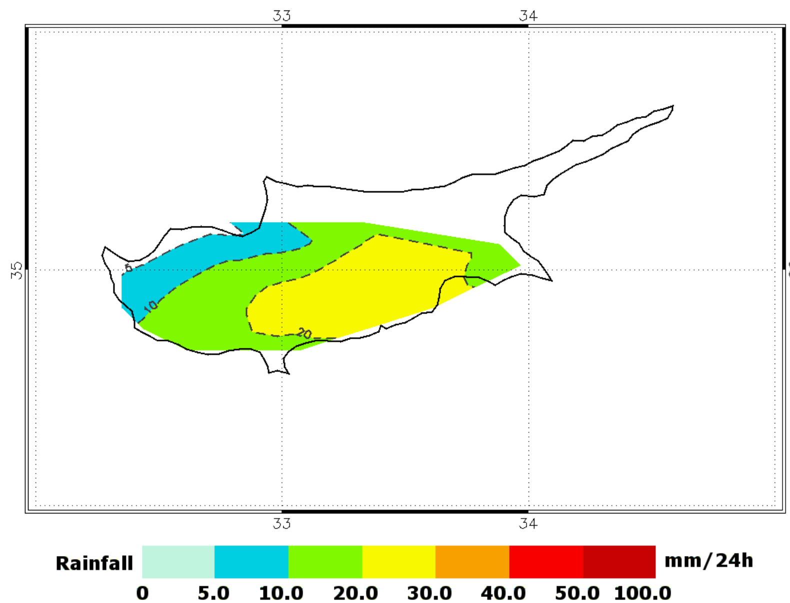


Precipitation modelled by the BOlogna Limited Area Model (BOLAM), accumulated on a daily basis from 06 UTC 5 March to 06 UTC 6 March 2003.

24-h Barnes precipitation analysis (using only rain gauges data):

- MSE-based results strongly depend to the maximum allowed shifting value (Tartaglione et al. 2005)
- Corr.-based results does not change as a function of the shifting value:0.27°E & 0.09°N.

Tartaglione, N. et al., *Atmos. Chem. Phys.*, 5 (2005) 2147–2154.



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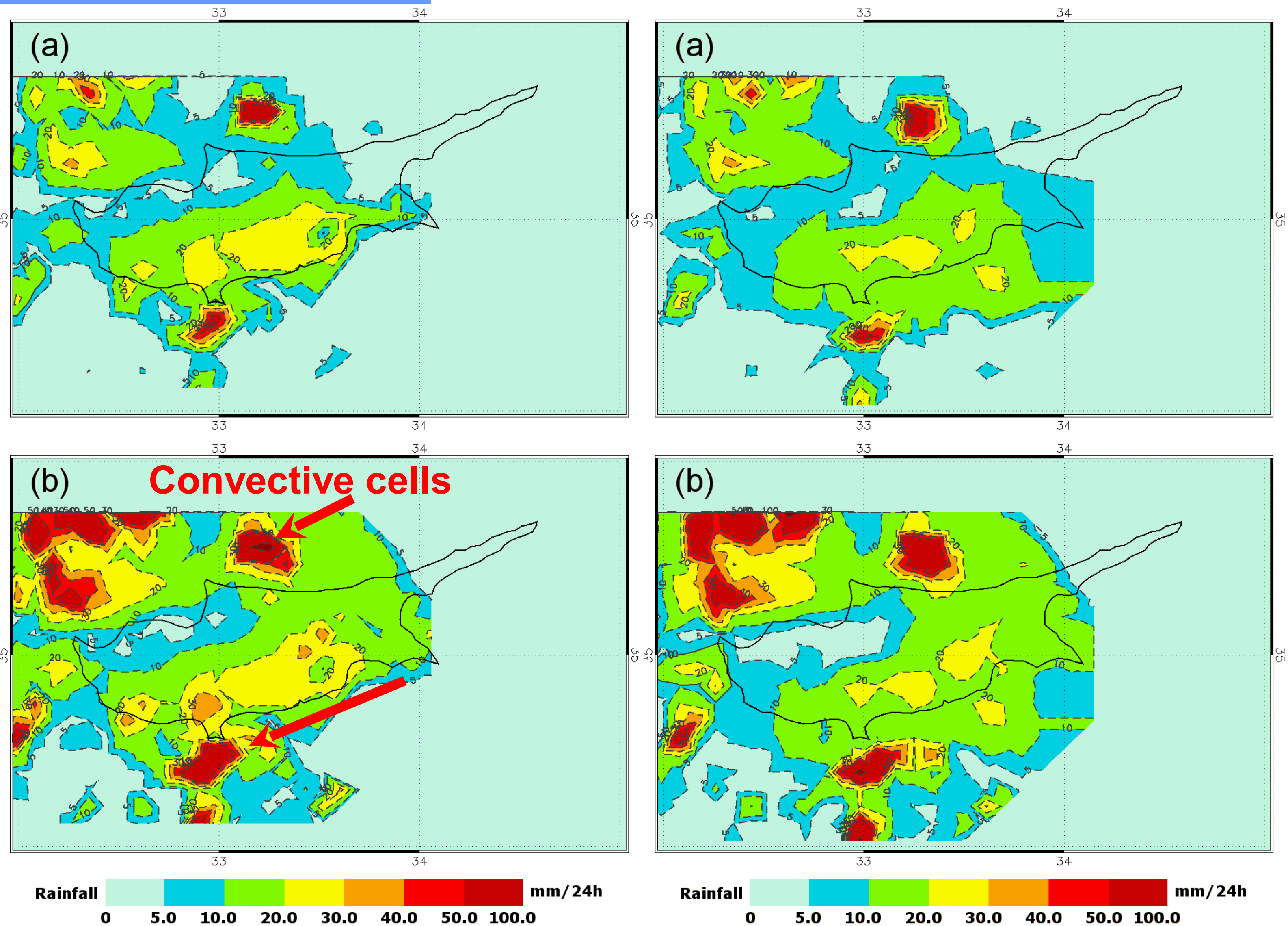
Radar-rain gauge composites



w. not-adj radar

w. adj radar

a simple weighted merge

a Bayesian-based merge (RainMusic)

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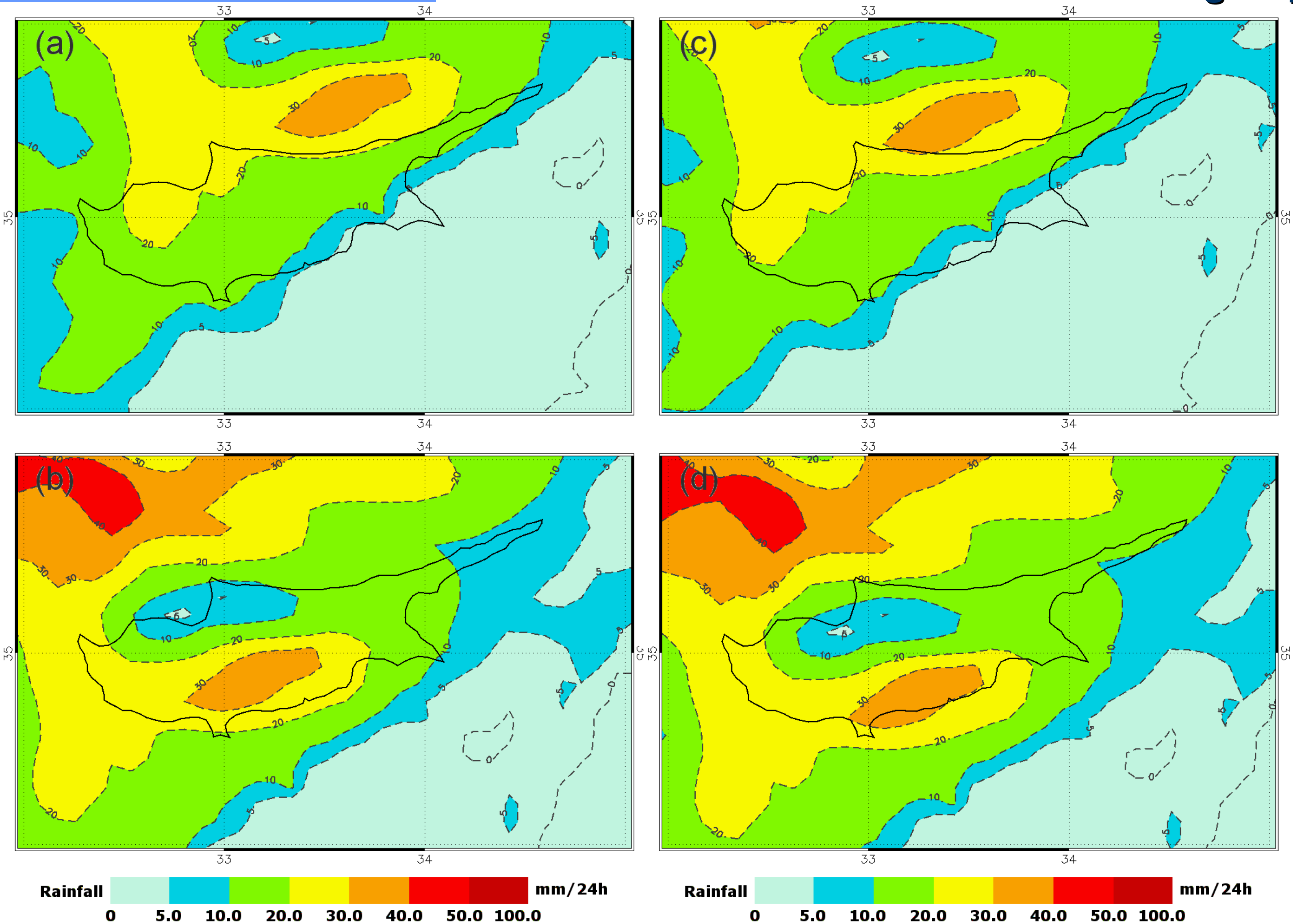
CRA results – MSE
CRA contour = 0.5 mm $24h^{-1}$ & sv = 9 grid points



w. not-adj radar

w. adj radar

a simple weighted merge

a Bayesian-based merge (RainMusic)

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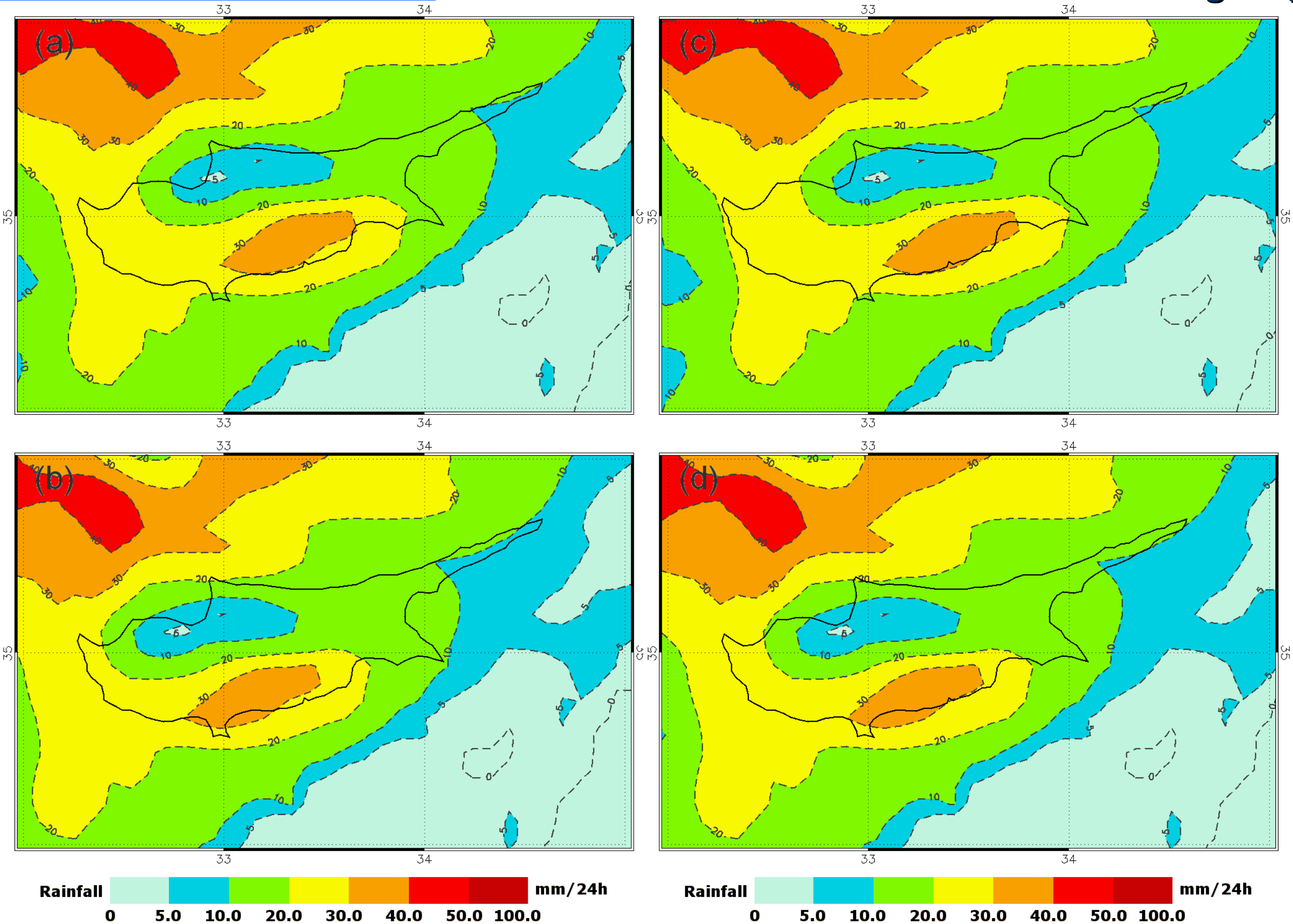
CRA results – Correlation
CRA contour = 0.5 mm 24h^{-1} & sv = 9 grid points



w. not-adj radar

w. adj radar

a simple weighted merge

a Bayesian-based merge (RainMusic)

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CRA results – Summary

Merging ground-based radar data to the observational analysis extends the area covered by observations and stabilizes the CRA results.

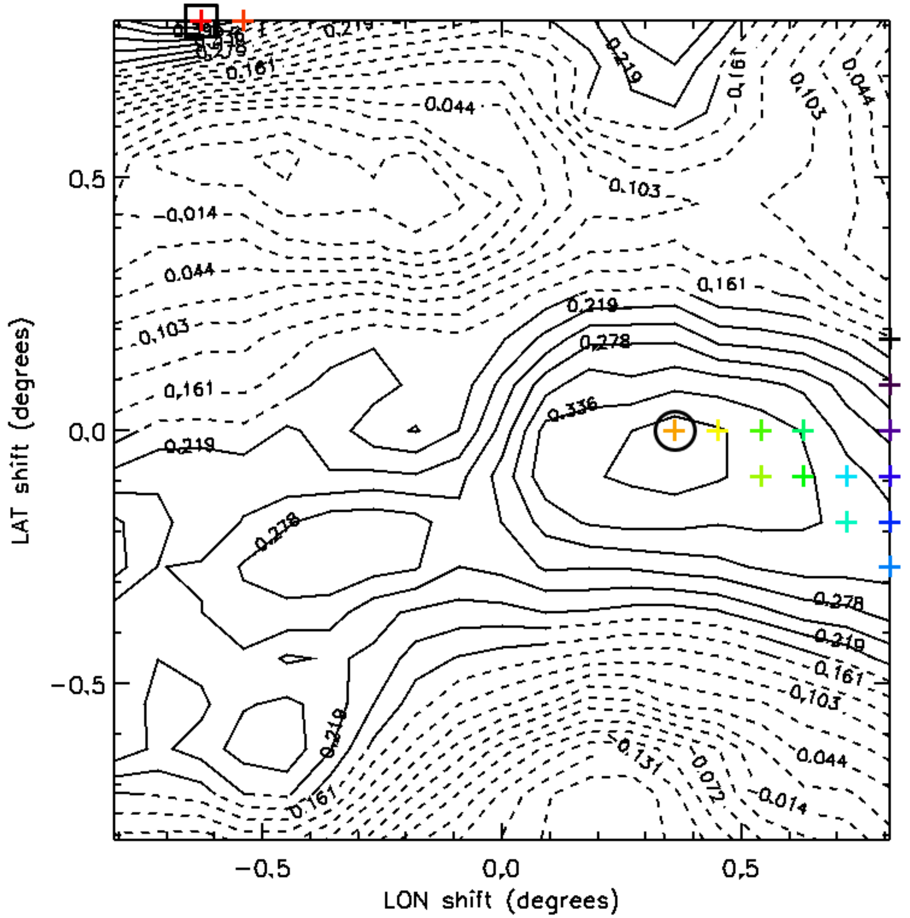
Obs. type	No. of grid points	MSE [mm^2]	Corr.	Bias ($\overline{o} - \overline{f}$) [mm]	CRA criterion	[E, N] shift	Shifted MSE [mm^2]	Shifted corr.	Shifted bias [mm]	MSE displ. [%]	MSE vol. [%]	MSE patt. [%]
P_{OGRD}	446	248.40	0.28	−10.75	MSE 5	[0.45°, 0.45°]	168.98	0.23	−6.95	31.97	19.43	48.60
					MSE 9	**[0.72°, 0.81°]**	**152.49**	**0.14**	**−4.58**	**38.61**	**8.44**	**52.95**
					MSE 13	**[1.17°, 1.17°]**	**101.43**	**0.21**	**−1.33**	**59.17**	**0.70**	**40.13**
					CORR	[0.45°, 0.09°]	215.42	0.42	−10.86	10.18	46.49	43.33
P_{RGRD}	454	273.87	0.36	−2.45	MSE	[0.27°, 0.09°]	252.10	0.41	−2.34	7.93	1.99	90.08
					CORR	[0.27°, 0.00°]	253.10	0.43	−3.39	9.13	2.18	88.69
RM_{OGRD}	502	230.41	0.18	−9.09	MSE 5	[0.45°, 0.45°]	154.63	0.18	−5.54	32.89	13.30	53.81
					MSE 9	**[0.54°, 0.72°]**	**138.21**	**0.19**	**−3.77**	**40.01**	**6.17**	**53.82**
					MSE 13	**[0.45°, 1.17°]**	**105.14**	**0.15**	**0.66**	**54.37**	**0.19**	**45.44**
					CORR 5	[0.45°, 0.00°]	222.30	0.39	−11.08	16.50	35.82	47.68
					CORR 9/13	[0.54°, 0.09°]	193.01	0.41	−10.06	17.52	35.82	46.66
RM_{RGRD}	514	313.40	0.27	−2.12	MSE	[0.36°, 0.00°]	264.10	0.43	−3.74	15.73	4.45	79.81
					CORR 5/9	[0.36°, 0.00°]	264.10	0.43	−3.74	17.69	1.43	80.87
					CORR 13	**[−0.81°, 0.99°]**	**379.60**	**0.44**	**10.62**	**19.21**	**1.43**	**79.36**

Suspicious unphysical results may be found if CRA is applied in an automatic, unsupervised way (figures in bold), usually linked to the shift of the higher rain values present in the forecast out of the verification domain.

This is more evident when using a CRA rain-rate contour equal to 5.0 mm $24h^{-1}$.

CRA results – Summary

Quality tests can be applied to verify whether the best-match found is obtained by chance (not reliable) or it is the result of a reasonable match.



2-D CRA shift analysis maximizing correlation for BOLAM vs. RM_{RGRD} (isohyet=5.0 mm $24h^{-1}$).

→ Plotting over the 2-D CRA analysis the maximum corr. values found during CRA.

← The suspicious final shift in the top-left corner is a localized isolated corr. max, whereas the relative second max in the middle-right side is a more robust result.

← A more complex matching procedure based on the corr. maximization conditioned to the MSE minimization, is able to automatically select the secondary maximum.

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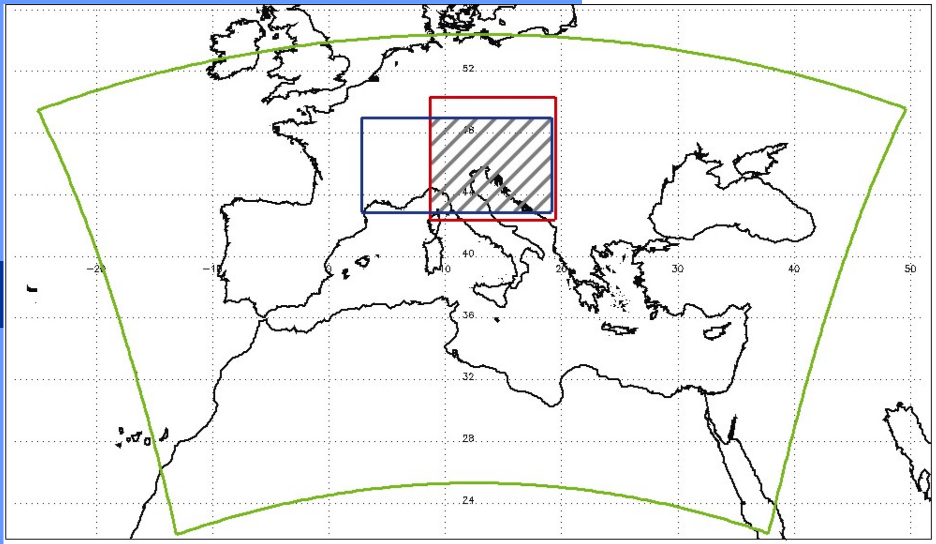
FORALPS – INTERREG IIIB Alpine Space



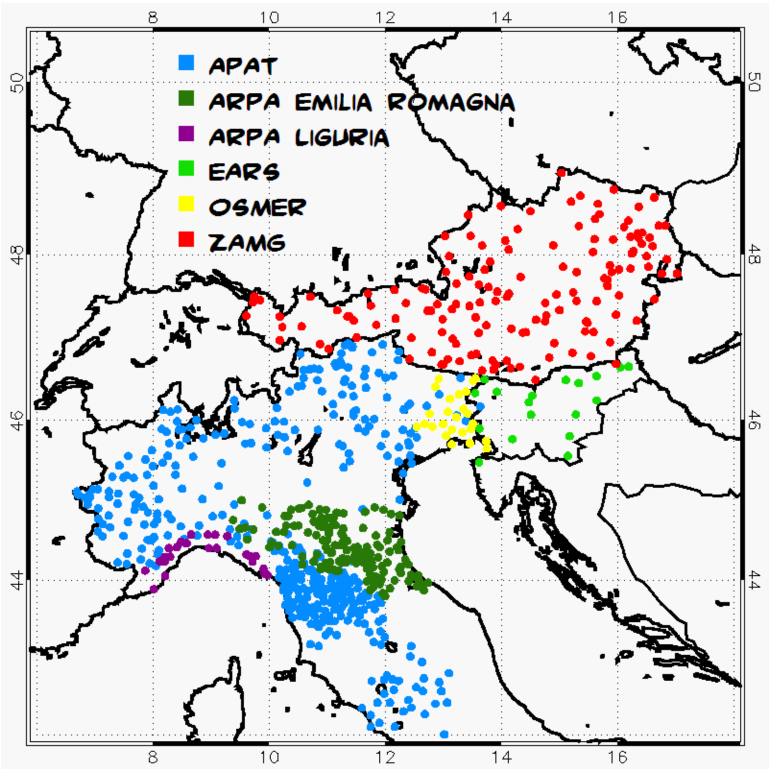
LAMs domains: ALADIN (red), QBOLAM (green), and WRF (blue). The grey shaded area is the verification area.

Within the **FORALPS** project, the idea is to assess the performance of the NWP models by applying a **combined approach** – multi-scale, objective (incl. CRA) and subjective – to the QPF verification (Mariani et al. 2009).

Selected events with significant rainfall over the eastern Alpine range (Friuli Venezia Giulia region, Italy), which was connected with the passage of a depression over the Mediterranean region, have been investigated.

Mariani, S. et al., ICAM 2007 special issue on *Met. Atmos. Phys.* (2009).

NOVEMBER 2002 EVENT



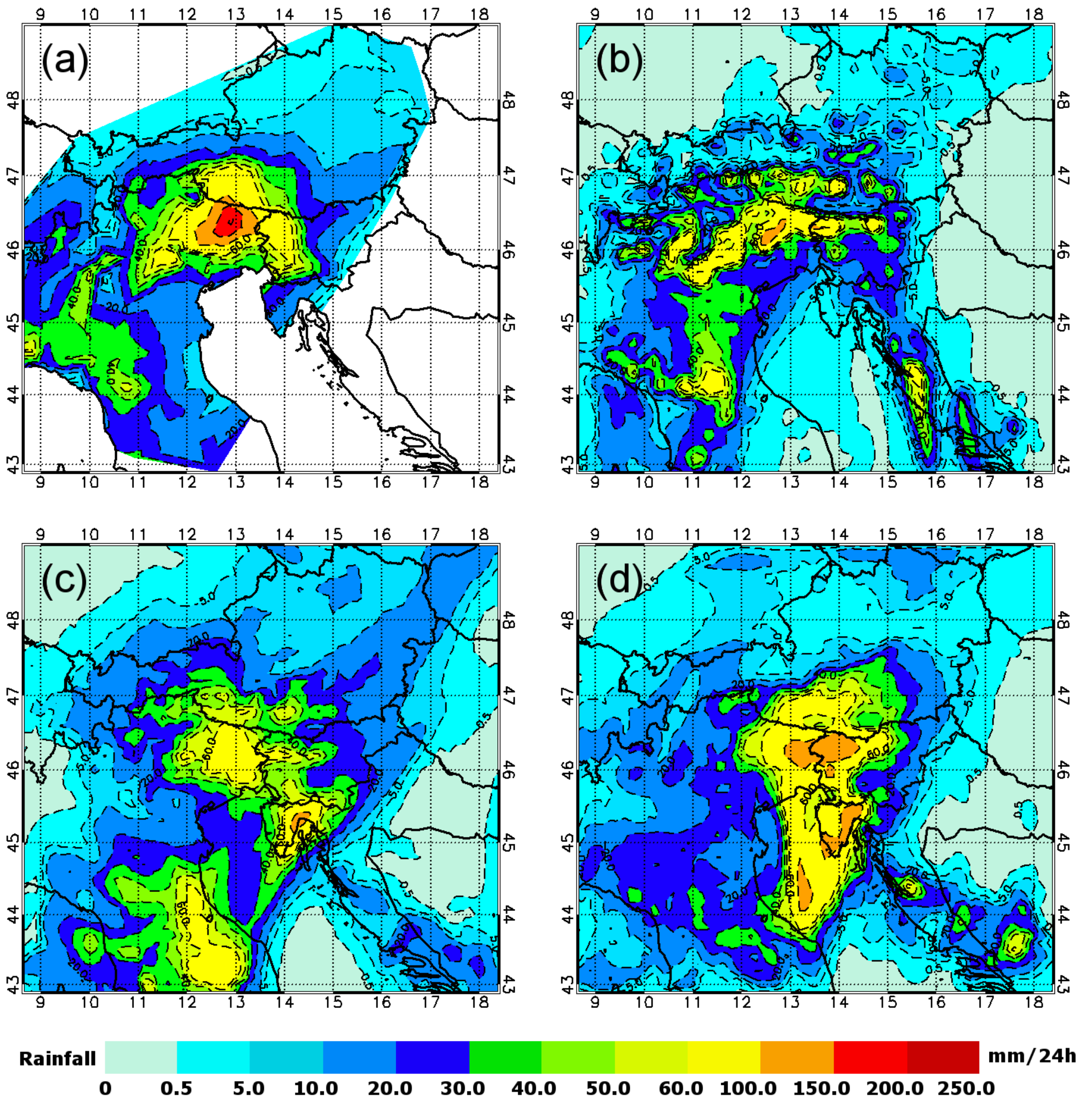
Subject verification

Precipitation contours of observed (a) and forecast by ALADIN (b), QBOLAM (c) and WRF (d) remapped on the 0.1° grid.

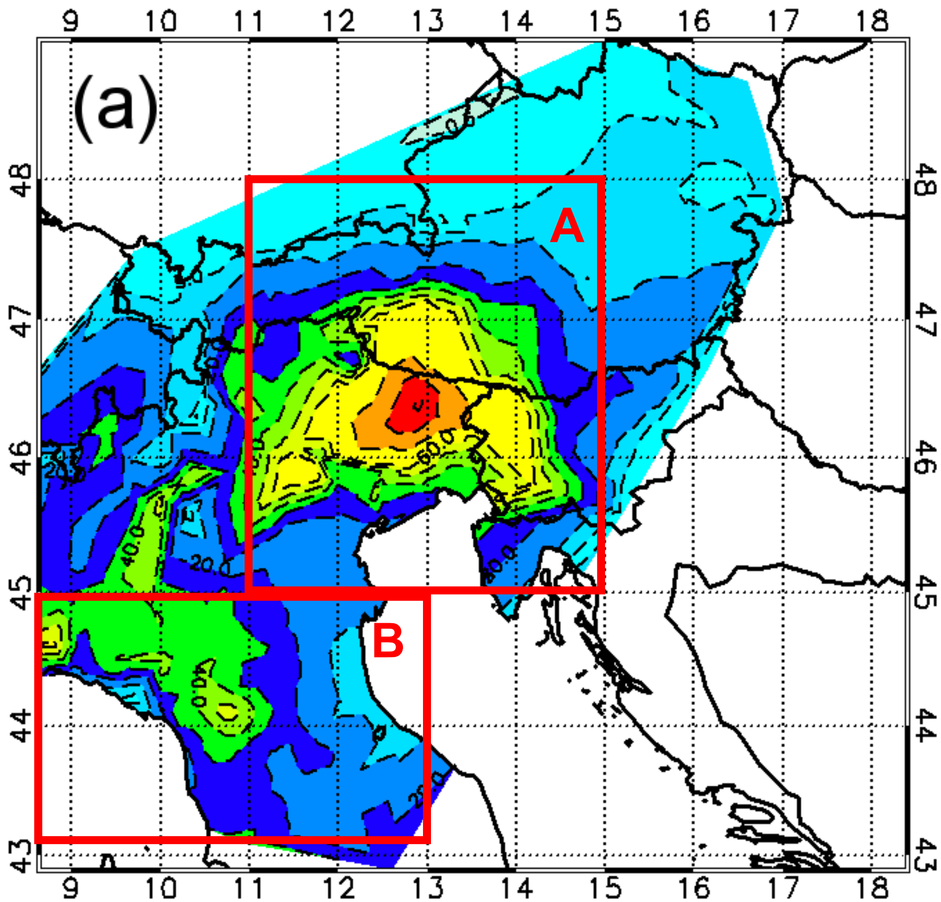
18 November 2002

- ALADIN seems to have the best overall match
- Absolute maximum is better caught by WRF
- Differences can be partly described in terms of shifting errors (due to the incorrect forecast of the trajectory of the depression)

In terms of CRA?



CRA results
CRA contour = 10.0 mm $24h^{-1}$



- Entire domain
- Sub-domain A: 45.0°–48.0°N; 11.0°–15.0°E
- Sub-domain B: 42.9°–45.0°N; 8.7°–13.0°E

CRA results show that the WRF forecast is slightly shifted eastwards (and a bit southwards); whereas the ALADIN and QBOLAM forecasts' displacement is quite small.

Coherently with the eyeball verification, provided that only the main peak over the Friuli Venezia Giulia region is considered.

But, what happen if we considered the CRA analysis over two sub-domains encompassing the two precipitation peaks?

→ We can correctly detect the magnitude of the displacement of both major rainfall peaks.

CRA results

ALADIN and QBOLAM: CRA analysis for the sub-domain B correctly detects the shift of the secondary peak; whereas for the sub-domain A the shift is negligible.

WRF: CRA result for the sub-domain A provides a larger westward displacement, more coherent with the subjective analysis. No realistic result has been obtained for the sub-domain B (not able to match the predicted rain band over the Adriatic Sea with the one observed over the Apennines, also due to their different orientation).

Date (Area)	Model	(E, N) shift	No. of comparing grid points	Corr.	Shifted Corr.	MSE displ. (%)	MSE vol. (%)	MSE patt. (%)
18 Nov. 2002 (entire domain)	ALADIN	(–0.10°, 0.00°)	317	0.521	0.526	0.96	1.39	97.65
	QBOLAM	(0.10°, 0.10°)	359	0.434	0.510	10.58	0.02	89.40
	WRF	(–0.40°, 0.10°)	367	0.619	0.672	12.98	4.27	82.75
18 Nov. 2002 (sub-domain A)	ALADIN	(0.00°, 0.00°)	109	0.712	0.712	0.00	25.56	74.44
	QBOLAM	(0.00°, 0.10°)	129	0.704	0.767	9.48	14.96	75.56
	WRF	(–1.00°, 0.00°)	127	0.561	0.731	36.59	1.13	62.28
18 Nov. 2002 (sub-domain B)	ALADIN	(–0.70°, 0.00°)	163	0.088	0.584	45.10	8.40	46.50
	QBOLAM	(–2.00°, 0.90°)	165	–0.495	0.610	65.59	9.32	25.09

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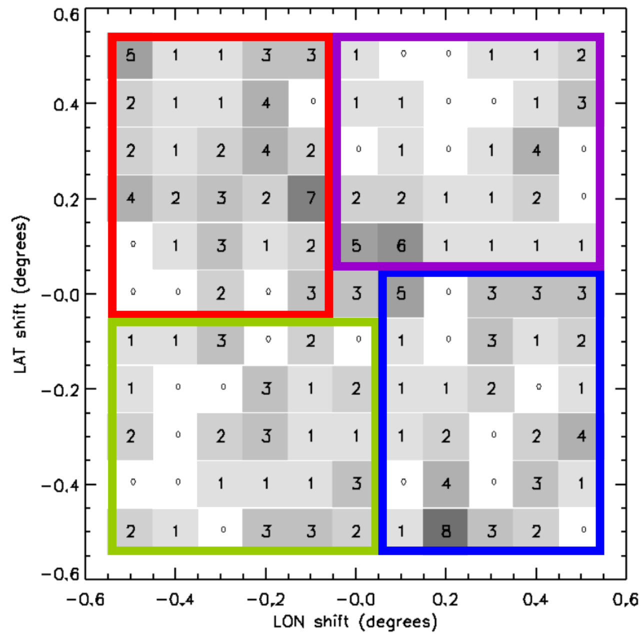
A statistical approach…



To diagnose systematic spatial forecast errors, the CRA analysis should be used on a series of case studies, or on a long time series.

$$
\begin{cases}
i_t > 0, & \text{forecast needs to be moved } i_t\text{-points eastward;}\\
i_t < 0, & \text{forecast needs to be moved } i_t\text{-points westward;}\\
i_t = 0, & \text{forecast does not need to be moved in longitude;}\\
j_t > 0, & \text{forecast needs to be moved } j_t\text{-points northward;}\\
j_t < 0, & \text{forecast needs to be moved } j_t\text{-points southward;}\\
j_t = 0, & \text{forecast does not need to be moved in latitude.}
\end{cases}
$$

$$\text{CMS} = \sum_{i=-N}^{N} \sum_{j=-N}^{N} f_{i,j} \cdot w_{i,j} \in \left[0, N\sqrt{2}\right]$$

where :

- N is the maximum shift value (in this case $N = 5$);
- $f_{i,j}$ is the shift frequency in i, j obtained by dividing the number of shift in i, j with the total number of shift (in this case 202);
- $w_{i,j} = \sqrt{i^2 + j^2}$ measures the distance of the CRA best shift in i, j.

Each point of the CRA shift summary table $ns(i,j)$ represents the number of times in which the gridded forecast entity need to be shifted i-points E and j-points N.

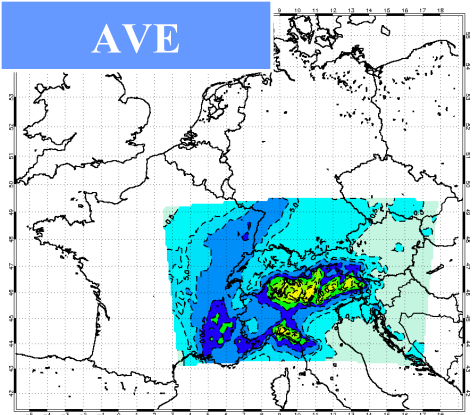
When performed as post-analysis, automatic procedures should be applied to detect correctly the spatial displacement.

Q: Can the CRA analysis be applicable to small verification areas?
A: Yes it can, but quality checks should be performed to detect possible suspicious results and more complex pattern match should be applied to quantify correctly the displacement.

Future works

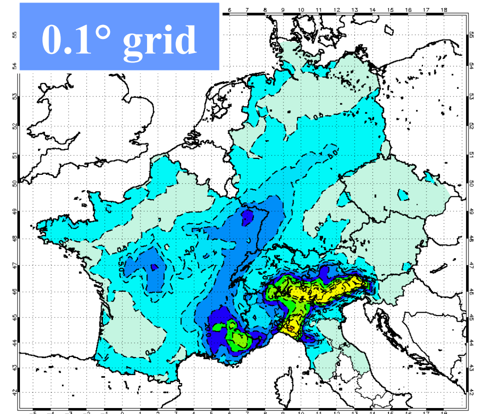
Within the MAP D-PHASE project – WMO WWRP – investigate the performance by means of CRA of selected deterministic models with respect to two meteorological events (25–28 Sep. 2007 & 22–25 Nov. 2007):

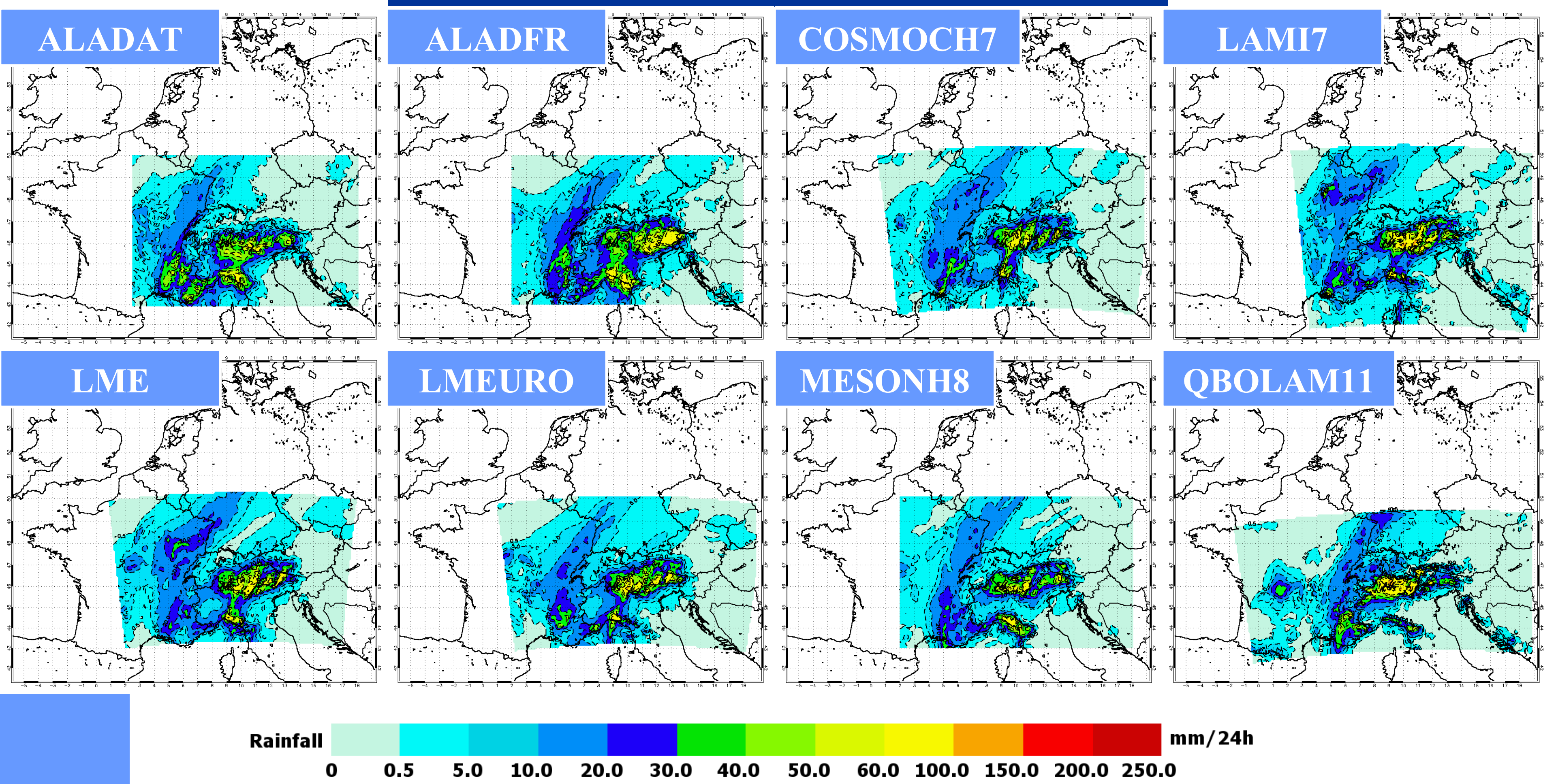
- ✓ by considering the Barnes analysis applied to the available no-GTS observations;
- ✓ by applying a bayesian-based method (RAINMUSIC code by ProGeA – Univ. Bologna, Italy) to produce observational analyses by merging rain-gauge data with precipitation retrieved by radar. Radar data requested to OSMER – ARPA Friuli Venezia Giulia, ARPA Veneto and MeteoSwiss;
- ✓ by including the 8-km VERA analyses (by Theresa Gorgas and Manfred Dorninger, Univ. Vienna, Austria).



23 November 2007

HR forecasts remapped on the 0.1° verification grid





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Thank you

for your attention!

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