The regional *BOLAM* model: some results from *MAP* and other projects

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BOLAM Main Features:

model dynamics (Buzzi et al, 1994)

- Primitive equations with u, v, θ, q, ps as dependent variables (+ 5 microphysical variables);
- Rotated Arakawa C grid; σ vertical coordinate (non uniform, staggered Lorenz grid);
- Original forward-backward 3-D advection scheme (FBAS - Malguzzi and Tartaglione, 1999) coupled with semi-lagrangian advection of hydrometeors;
- Split-explicit time scheme (FB for gravity modes);
- 4^{th} order horizontal diffusion and 2^{nd} order divergence diffusion;
- Davies-Kållberg-Lehmann relaxation scheme for lateral boundary conditions.

BOLAM Main Features

Physical aspects

- Radiation: infrared and solar, interacting with clouds (Ritter & Geleyn and ECMWF *RRTM* - Morcrette);
- Vertical diffusion (surface layer and PBL parameterization) depending on the Richardson number;
- Surface thermal and water balance; new soil and vegetation scheme under development (in coop. with the Hydrometeorological Institute of Russia – Pressman, 2002);
- Explicit microphysical scheme with 5 hydrometeors (cloud ice, cloud water, rain, snow, hail/graupel), modified from Schultz (1995) and Drofa (2001);
- Convective parameterization: Emanuel or Kain-Fritsch, the latter allowing interaction with the microphysical scheme and delayed downdraft (Spencer & Stensrud, 1998).

Interfacing with oceanic and hydrological models

- Two way coupling with *WAM* and *POM* (model *MIAO*, Lionello & Malguzzi, 2000).
- One way coupling with a distributed hydrological model (*DIMOSOP*, Univ. of Brescia) for MAP-SOP.

BOLAM mainly developed for research applications; but also operational, at the following sites:

Ufficio Centrale di Ecologia Agraria - UCEA, Rome (*DALAM*, since 1993) www.politicheagricole.it/UCEA/Dalam/Index.htm#

NATIONAL OBSERVATORY OF ATHENS

National Observatory of Athens - NOA (since 1999) www.noa.gr/~telefleu/bolam/index.htm

difi

Dept. of Physics, Univ. of Genoa (with Meteorological Centre of Liguria Region - CMIRL) (since 1999) www.cmirl.ge.infn.it/MAP/BOLAM/Bolamin.htm

CONSORZIO S.A.R.

Agrometeorological Service of Sardinia - SAR (since 2000) www.sar.sardegna.it

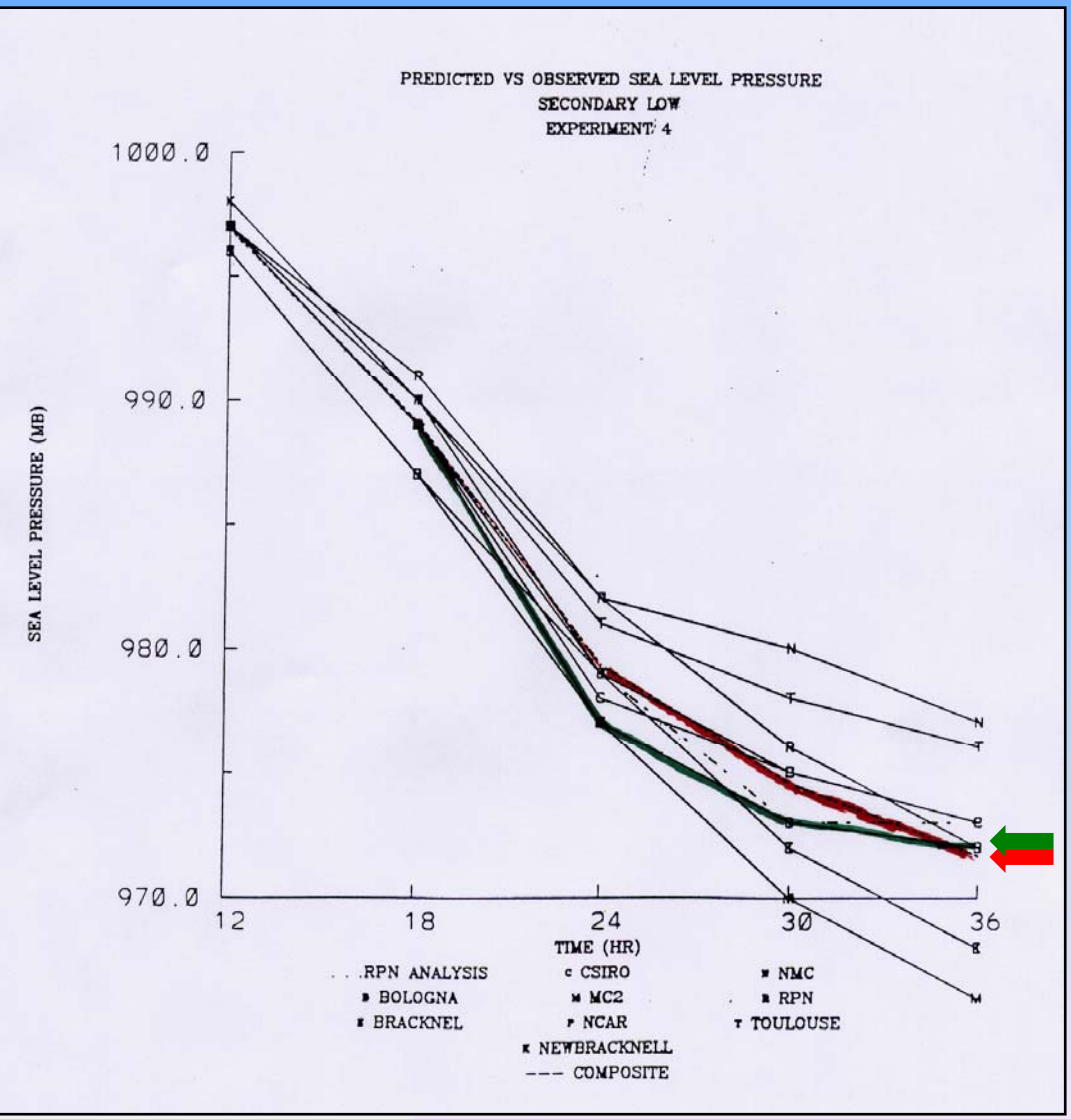
Presidenza del Consiglio dei Ministri DSTN Dipartimento per i Servizi Tecnici Nazionali

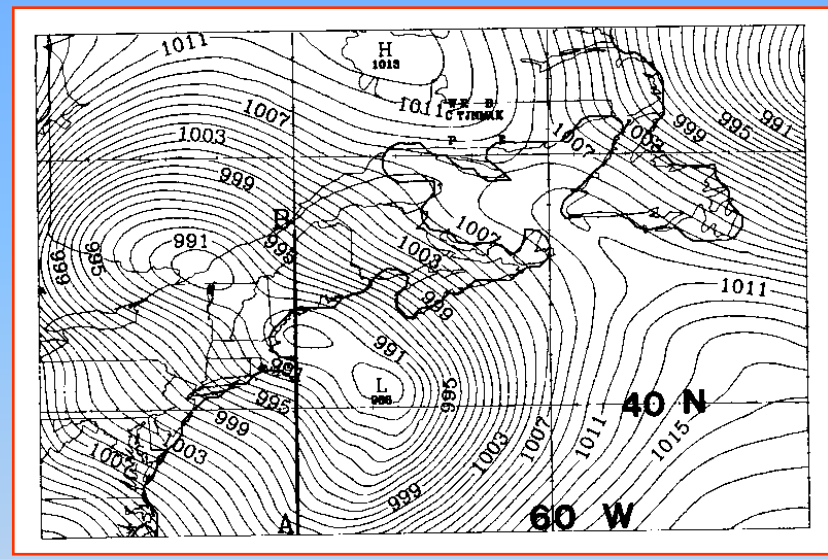
Department of Technical Services - DSTN, Rome (parallel *QBOLAM*, since 2001) www.dstn.it

Project COMPARE: The Comparison of Mesoscale Prediction and Research Experiments WMO-WGNE

- COMPARE I: The Canadian Atlantic Storms Project (1986) (Gyakum et al, Wea. and Forecasting, 1996)
- COMPARE II: The PYReanan EXperiment (PYREX, 1990) (Georgelin et al, Q. J. R. Meteorol. Soc., 2000)
- COMPARE III: The TYPOON-90 field experiment (TCM-90) (Nagata et al, J. Met. Soc. Japan, 2001)
- MAP (WMO-WWRP)

COMPARE 1:extra-tropical cyclone (Canada)





Green: BOLAM

Red: analysis

Predicted vs. observed MSLP, secondary low, experiment 4 (50 km res., nested, 35 lev.)

Precipitation scores

	MOD. FOREC. No	MOD. FOREC. Yes	
OBSERV.	a	b	No
	c	d	Yes

$$Bias\ (areal) = \frac{d+b}{d+c}$$

$$False\ A.R = \frac{b}{d+b}$$

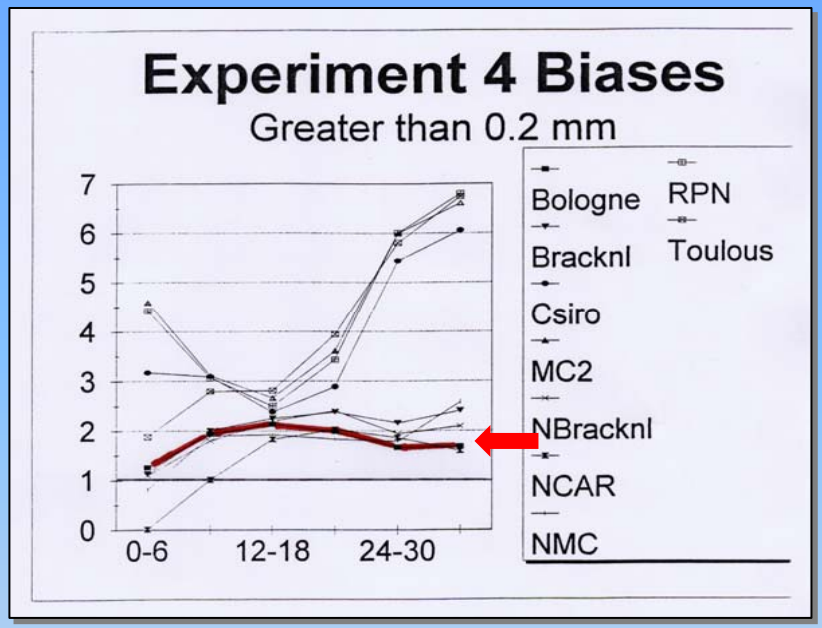
$$RN = \frac{(b+d)(c+d)}{a+b+c+d}$$

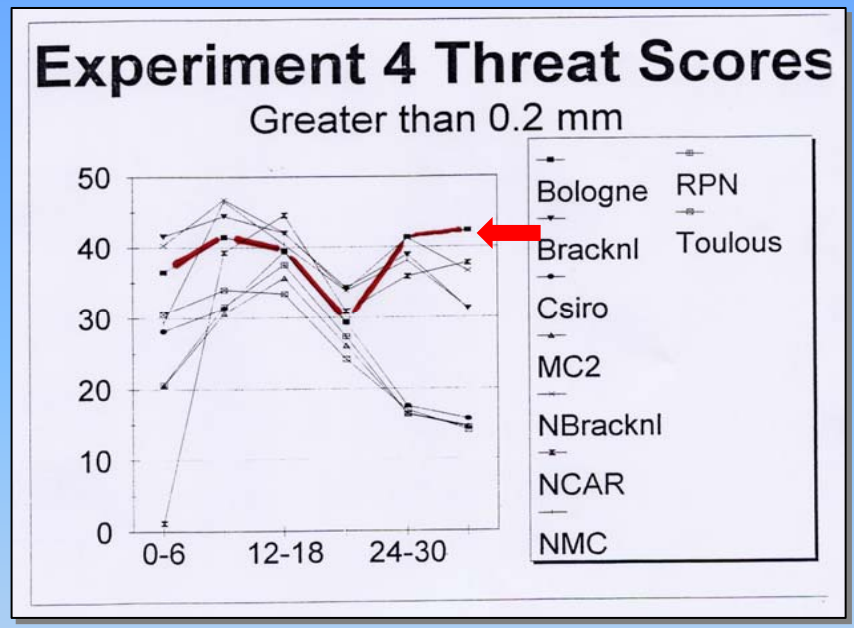
$$Equitable\ \ T.S. = \frac{d - RN}{b+c+d-RN}$$

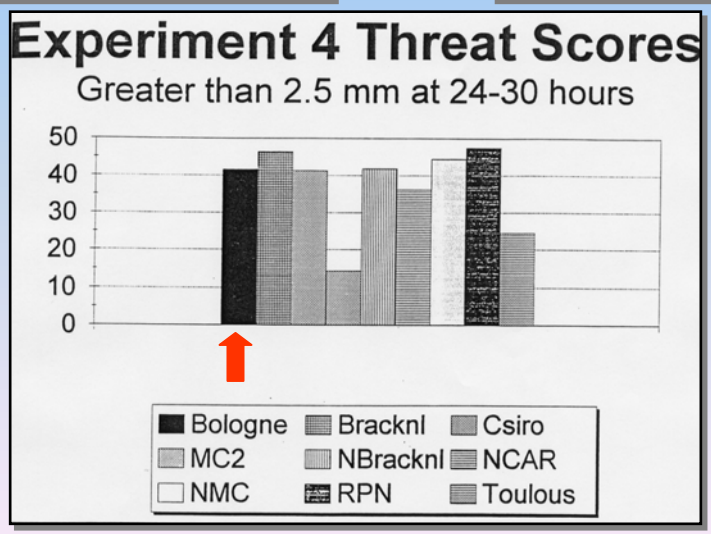
$$Threat\ \ Score = \frac{d}{d+b+c}$$

$$Heidke\ \ T.S. = \frac{2(ad-bc)}{(a+c)(c+d)+(a+b)(b+d)}$$

COMPARE 1: precipitation scores







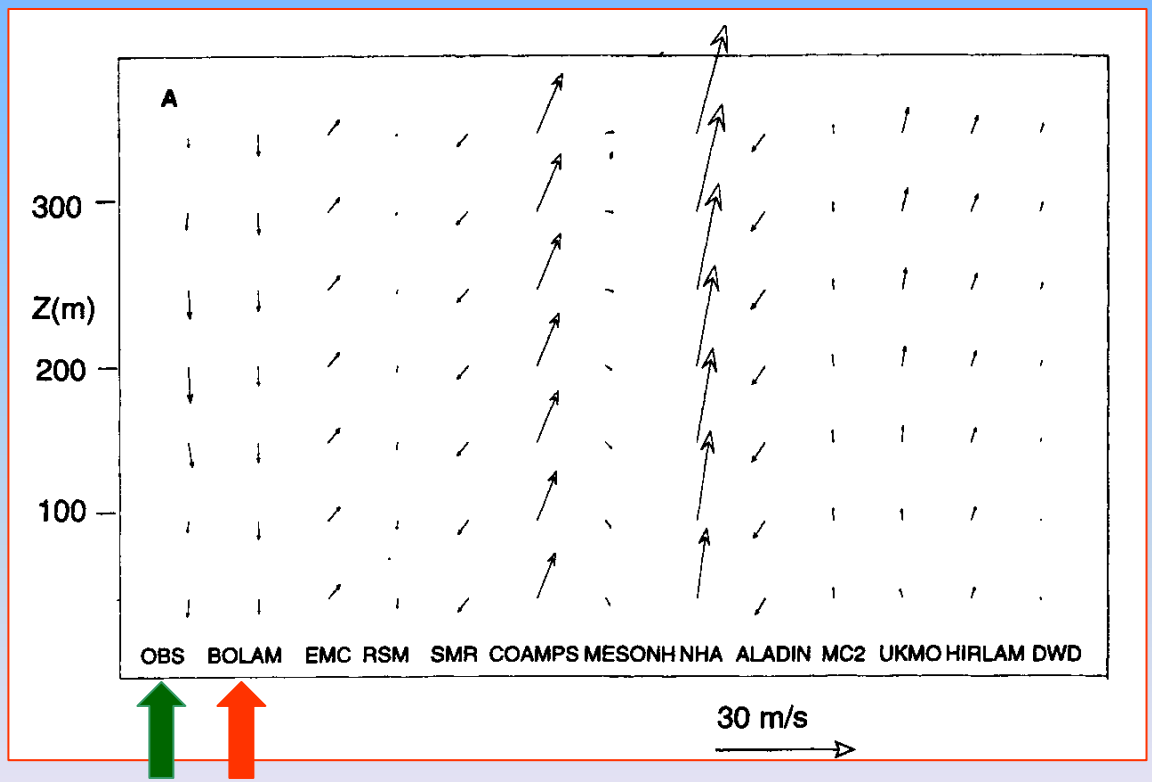
COMPARE 1:extra-tropical cyclone (Canada)

Ratio between worse/best scores against soundings

TABLE 5. Frequency of maximum/minimum scores from the soundings (parameters listed in Table 3).

Forecast range (h)	12	12	24	24	36	36	
Experiment	1	3	1	3	1	3	
Horizontal resolution (km)	100	50	100	50	100	50	
Institution model (identifier)							Total
CSIRO LAM (C)	1/0	1/1	0/2	0/1	0/0	0/2	2/6
AES RFE (R)	0/2	1/0	1/2	0/0	0/2	0/3	2/9
AES MC2 (M)	1/0	0/0	0/0	1/1	1/2	0/0	3/3
Météo-France, Toulouse (T)	1/1	0/0	4/1	2/2	2/2	2/1	11/7
FISBAT, Italy (B)	0/2	0/2	0/3	0/3	1/1	1/1	2/12
JMA JLASM (J)	0/2	0/3	1/0	3/1	2/2	2/1	8/9
UKMO							
(E)	0/1	0/1	0/0	0/0	0/0	0/0	0/2
(K)	0/3	0/4	0/1	0/3	0/1	0/1	0/13
(A)	0/1	0/2	1/0	0/0	0/2	0/2	1/7
PSU–NCAR							
MM4 (P)	2/0	2/0	2/2	1/0	1/0	0/0	8/2
NCEP eta (N)	3/2	3/1	3/0	3/0	3/0	3/1	18/4
UW—NMS (W)	4/0	5/0	0/1	2/1	2/0	4/0	17/2

COMPARE 2: flow over the Pyrenees and formation of a low-level lee vortex



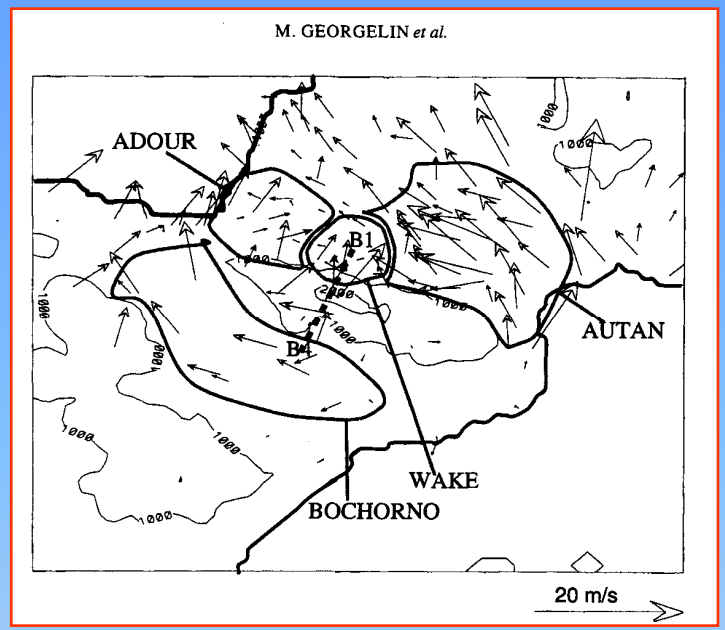


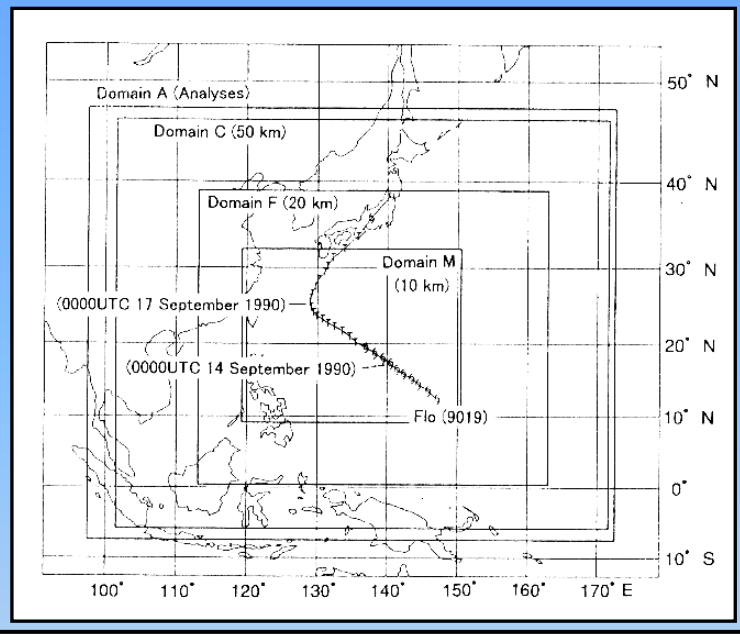
TABLE 1. LIST OF THE PARTICIPATING MODELS IN EACH EXPERIMENT

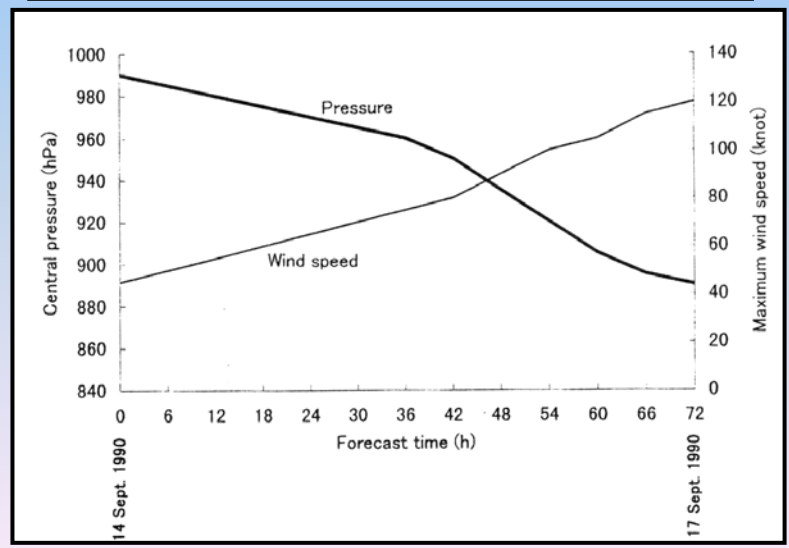
Institute	Model name	Non-hydrostatic	Experiments
JMA	JSM		3 5
FISBAT	BOLAM		3 4 5
CSIRO	DARLAM		3 5
CNRM	ALADIN		3 4
RPN	MC2	X	3 4 5
DWD	DM		3 4
UKMO	UKMO		3 4 5
NCEP	EMC		3 4 5
RPN	EFR		3 5
JMA	NHA	X	3 4
RER-SMR	LAMBO		3 4 5
INM	HIRLAM		3 4 5
CNRM and LA	MESONH	X	4
USNAVY	COAMPS	X	3 4 5
NCEP	RSM		3 4 5

COMPARE 3: super-typhoon over the Pacific

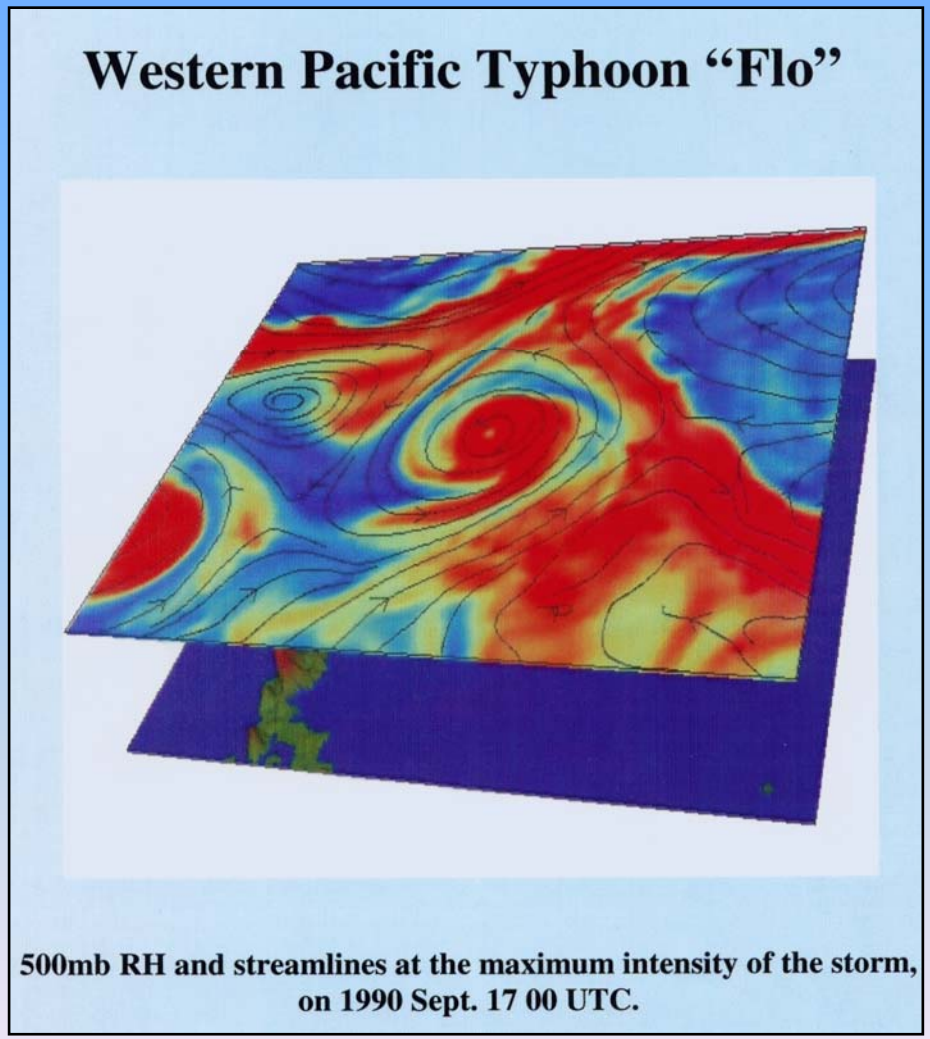
Table A1. Specifications of numerical models participating in Case III of COMPARE.

ID #	Institution	Model	Dynamics					
			Domain Map proj.	Equation	Grid	Resolution Horizontal	Vertical (in PBL) lowest at	Time integration
1	JMA (Japan)	TYM (RSM)	regional Mercator	hydrostatic	145x121 257x217	50 km 20 km	27 (9) 996.25 hPa	semi-implicit
2	UKMO (UK)	Unified Model	regional lat-lon	hydrostatic	160x110 280x220	.4425 deg .18 deg	27 (11) 996.25 hPa	foreward/ backward
3	FISBAT (Italy)	BOLAM	regional rot. lat-lon	hydrostatic	132x90 210x170	.48 deg .2 deg	27 (9) / 996 27 (7) / 997 996.0 hPa	foreward-backward
4	NCEP (USA)	RSM	regional Mercator	hydrostatic	145x122 257x218	50 km 20 km	27 (9) 995.0 hPa	semi-implicit
5	DWD (Germany)	EM10M	regional lat-lon	hydrostatic	145x109 201x151	.5 deg .25 deg	27 (9) 996.25 hPa	semi-implicit
6	RPN/EC (Canada)	MC2	regional Mercator	non-hydrostatic	144x120 256x216	50 km 20 km	29 (11) 36.6m/17.8m	semi-implicit
7	RPN/EC (Canada)	GEM	global stretched rot. lat-lon	hydrostatic	178x198 392x480	.5 deg .182 deg variable	29 (11) 997.5 hPa	semi-implicit
8	INM (Spain)	HIRLAM	regional rot. lat-lon	hydrostatic	146x110 252x194	47 km 22 km	27 996.25 hPa	semi-implicit
9	NCEP (USA)	Eta	regional rot. spheric	hydrostatic	145x175 151x305	50 km 20 km	27 (10) 10m	foreward-backward
A	CSIRO (Australia)	DARLAM	regional Mercator	hydrostatic	145x121 257x217	50 km 20 km	27 (9) 996.25 hPa	semi-implicit
B	CSIRO (Australia)	CSIRO-S	global stretched conformal cubic	hydrostatic	154x154 385x385	50 km 20 km	27 (9) 996.25 hPa	semi-implicit
C	MRI/JMA (Japan)	JSM	regional Mercator	hydrostatic	145x121 257x217	50 km 20 km	27 (9) 996.25 hPa	semi-implicit
D	NRL (USA)	COAMPS	regional Mercator	non-hydrostatic	91x91 100x100	50 km 20 km	30 (10) 10m	h: spl.-expl. v: spl.-impl.
E	NCMRWF (India)	RSM	regional Mercator	hydrostatic	97x84	50 km	18 (4) 995 hPa	semi-implicit

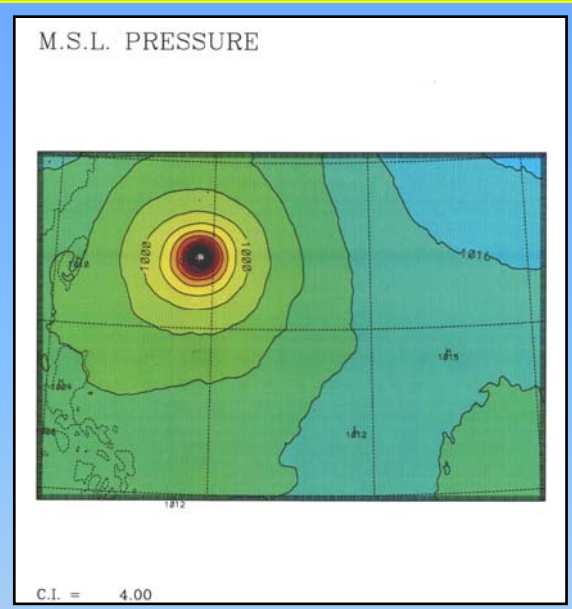


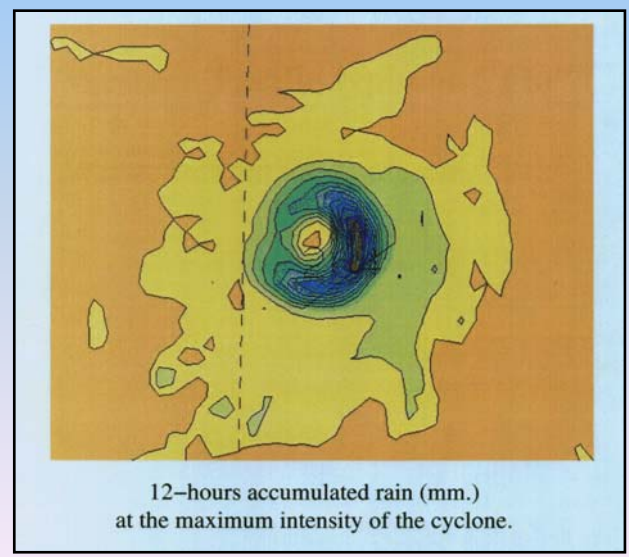


COMPARE 3: super-typhoon over the Pacific



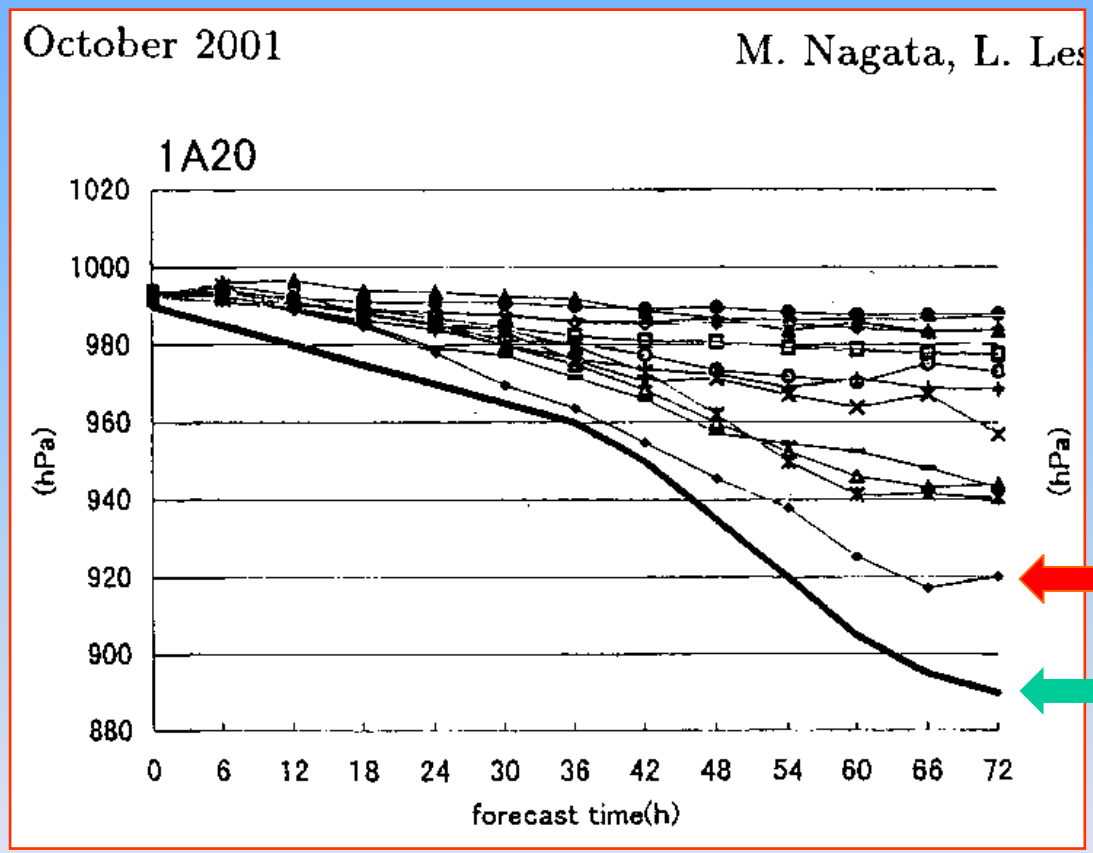
500mb RH and streamlines at the maximum intensity of the storm, on 1990 Sept. 17 00 UTC.

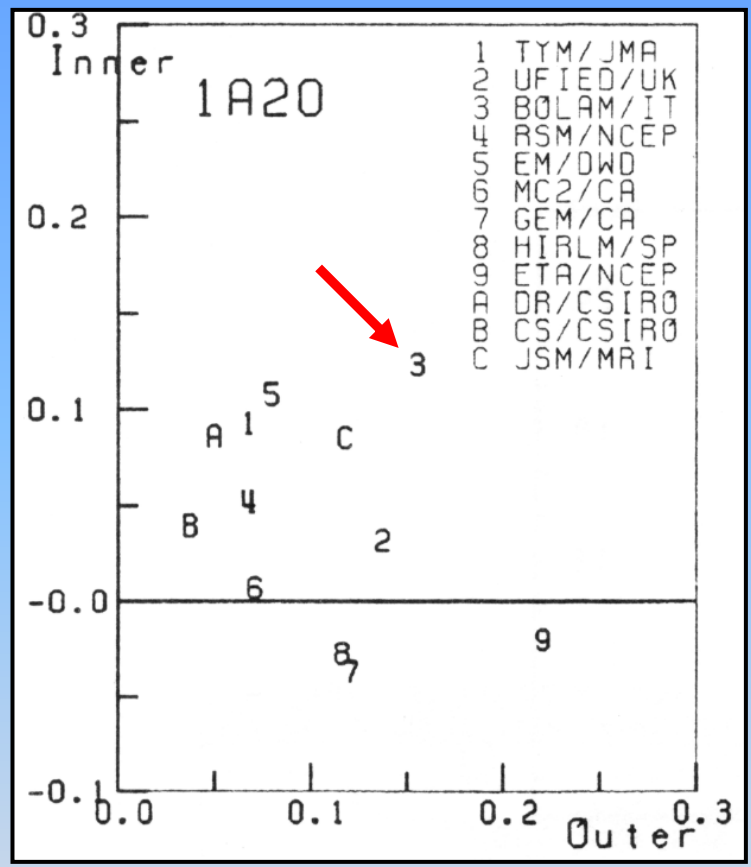




12–hours accumulated rain (mm.)
at the maximum intensity of the cyclone.

COMPARE 3: super-typhoon over the Pacific





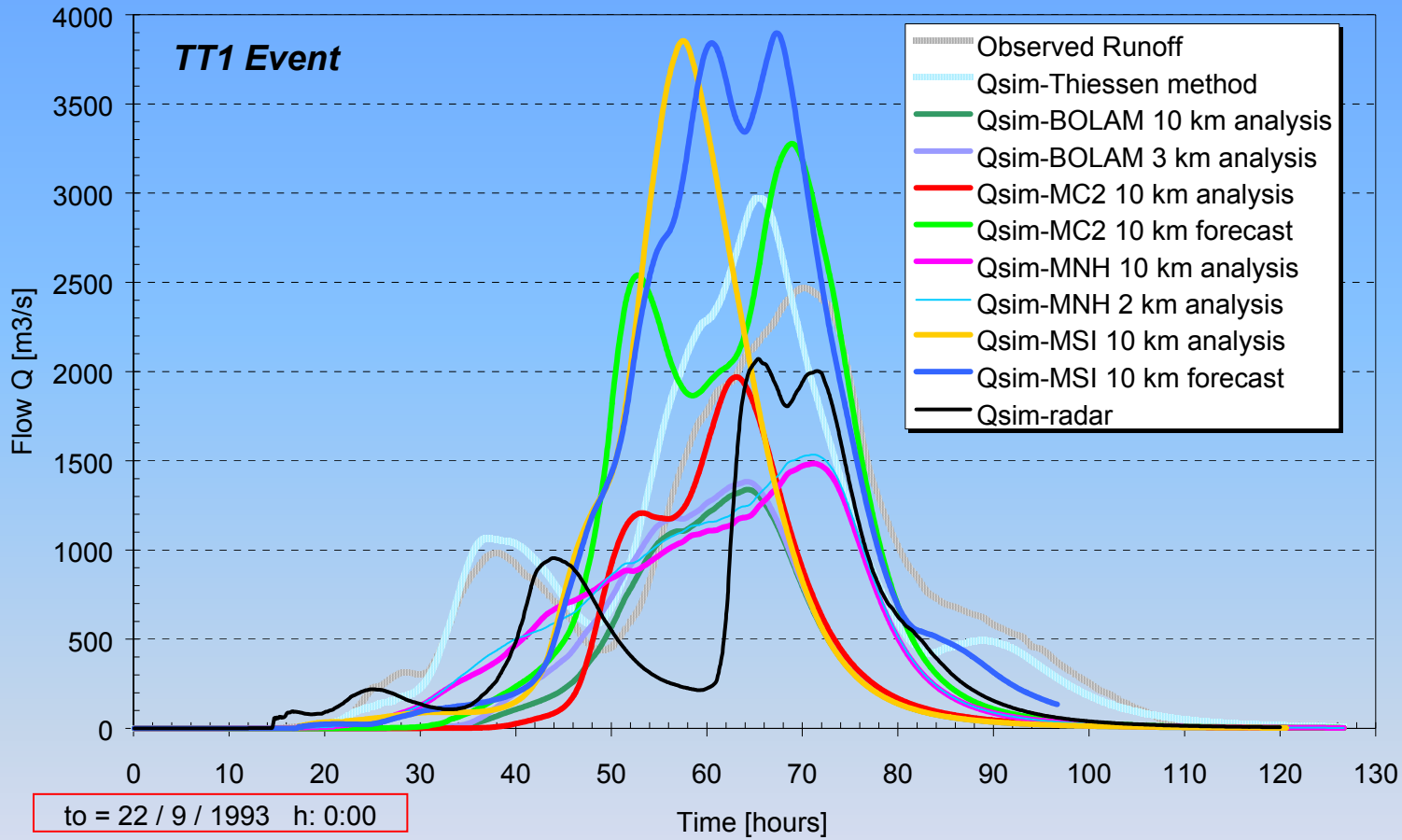
Time-mean equitable threat score of precipitation

The RAPHAEL EU project

(Bacchi, Ranzi et al, 1998-2000)

- The RAPHAEL project was designed in connection with MAP: the Mesoscale Alpine Programme
- Collected data and modelling were mainly based on case studies: episodes of heavy precipitation and flood in the Alps
- Demonstration in Alpine watersheds (Ticino-Toce, Ammer)
- Coupling of meteorological and hydrological models for flood forecasting in complex mountain areas

RAPHAEL



FEST98RS hydrological model (DIIAR, Politecnico MI)

RAPHAEL

TT1 Analysis mode	SM (EM analysis)	BOLAM (ECMWFanalysis)	MC2 (ECMWF analysis)	Meso-NH (ECMWF analysis)
P 24h	0.42	0.50	0.26	0.46
P 06h	0.14	0.21	0.16	0.20

TT3 Analysis mode	SM (EM analysis)	BOLAM (ECMWF analysis)	MC2 (ECMWF analysis)	Meso-NH (ECMWF analysis)
P 24h	0.57	0.62	0.52	0.38
P 06h	0.48	0.50	0.40	0.32

TT3 Forecast mode	SM (EM forecast)	BOLAM (ECMWF analysis)	MC2 (SM forecast)	Meso-NH (ECMWF forecast)
P 24h	0.48	0.58	0.55	0.41
P 06h	0.42	0.44	0.46	0.36

Table 2.2.8: Averaged Heidke skill scores.

The Mesoscale Alpine Programme (MAP)

Special Observing Period MAP-SOP

(7 Sept. - 15 Nov. 1999)

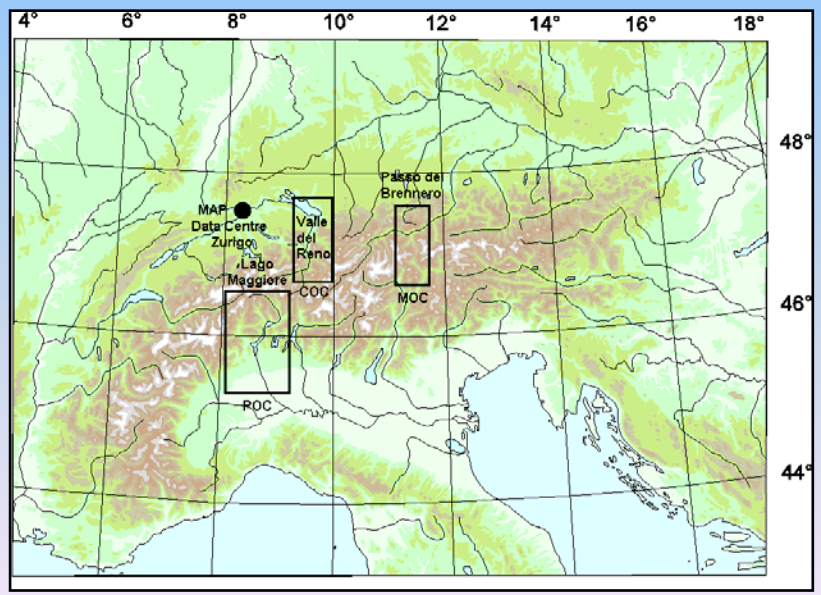
Among the MAP SOP scientific projects:

- Orographic precipitation
- Hydrological measurements and models

MAP SOP observations:

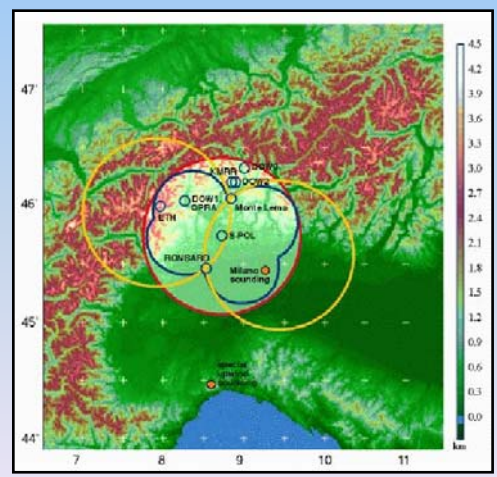
Three target areas:

- Lago Maggiore
- Brenner - Wipp Valley
- Rhine Valley



Main observing systems:

- Instrumented aircraft
- Doppler radars
- Wind profilers
- Lidars
- SODARs
- RASS
- Balloons etc.

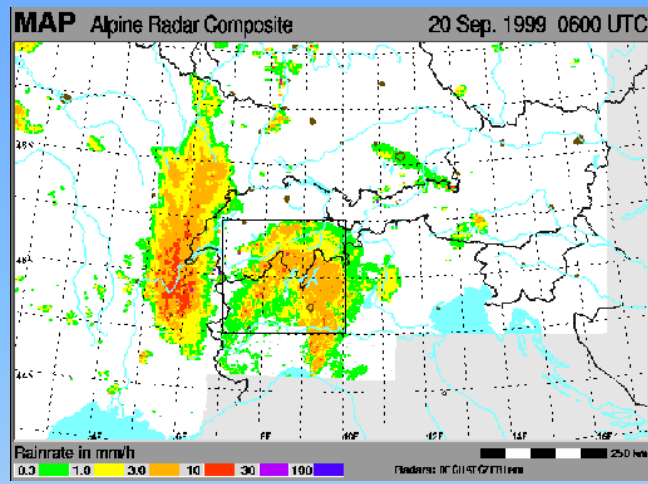


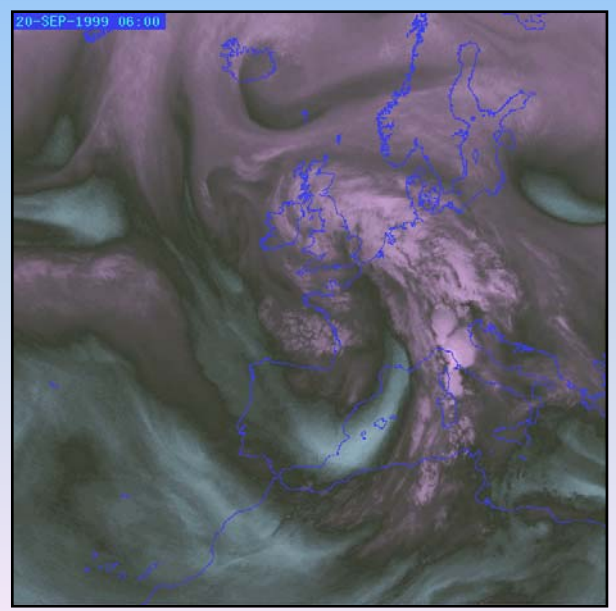
Other MAP SOP facilities:

- Radar composites
- METEOSAT rapid scans
- Meteorological visualisation products
- seven mesoscale model products

(up to 3 km horizontal resolution)

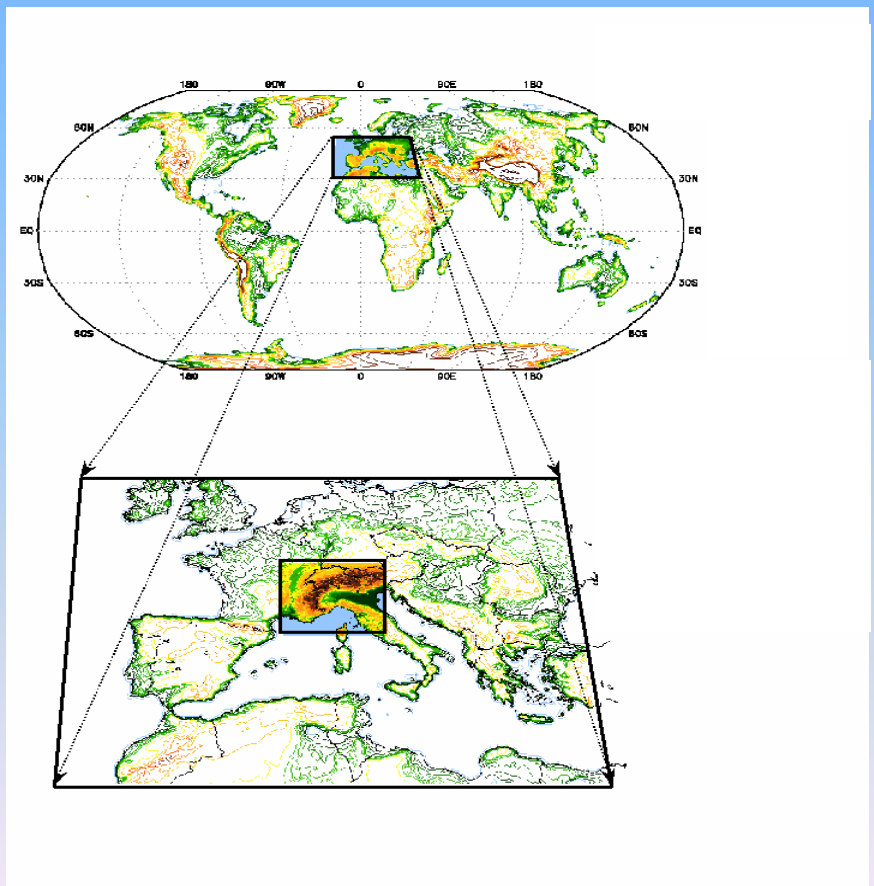
- Meteorological - hydrological real time coupled models: *MC2 - WATFLOOD; BOLAM - DIMOSOP*





Operational model chain Set up for BOLAM at CMIRL-DIFI Genoa since the MAP-SOP (Sept. 1999)

ECMWF - BOLAM chain



ECMWF
~50 km resolution

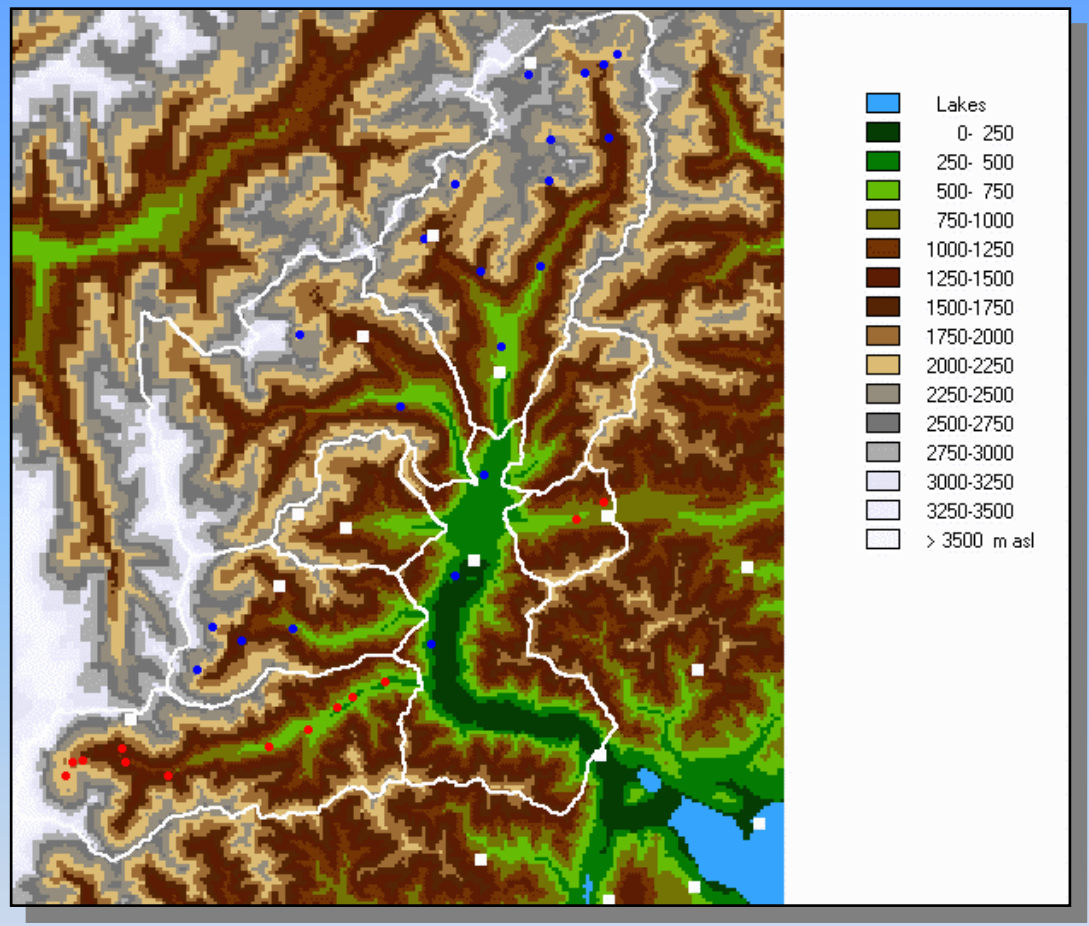
BOLAM
21.5 km resolution

BOLAM
6.5 km resolution

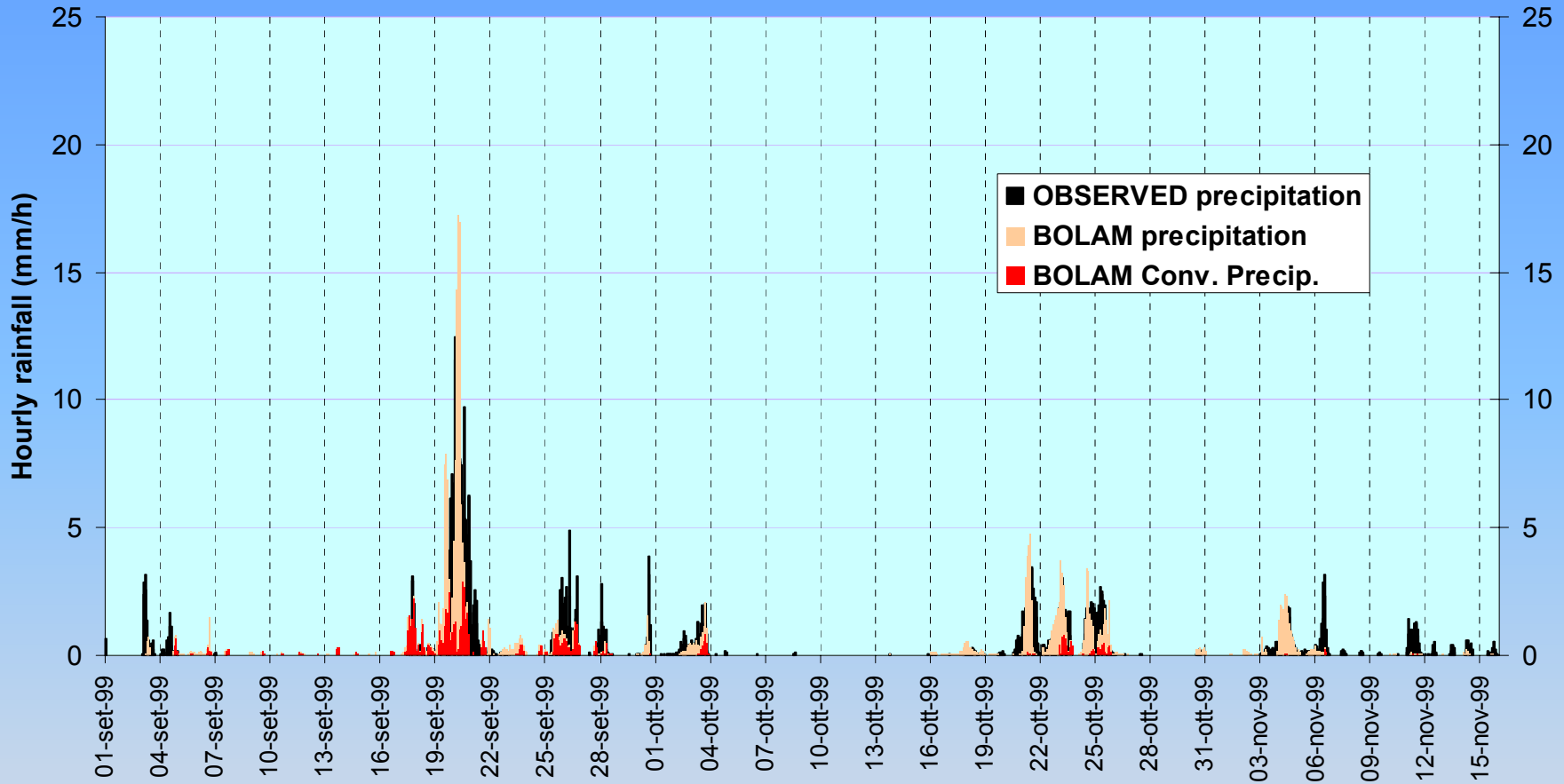
The Mesoscale Alpine Programme: testing of real-time meteo-hydrological coupled models

During the MAP-SOP (7 Sept. - 15 Nov. 1999), the BOLAM model (*ISAC-CNR*) was run at *DIFI-Univ. of Genoa* (in coop. with *CMIRL*) at 6.5 km resolution

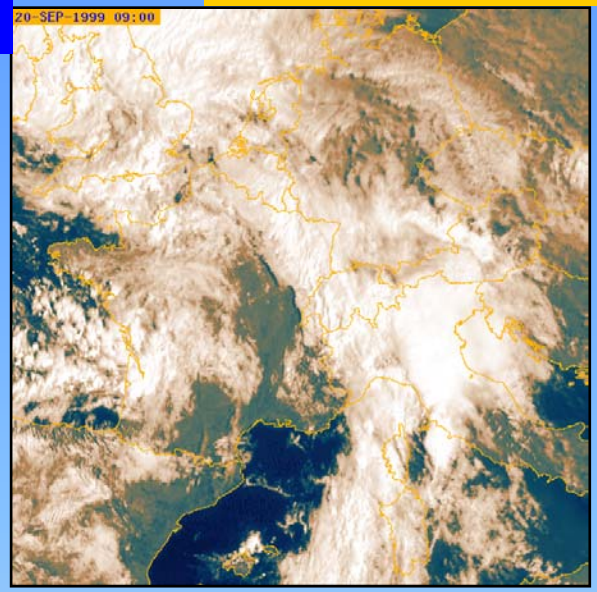
The QPF (up to 48 h) were used as input of a distributed hydrological model (DIMOSOP), operated by the Univ. of Brescia (Ranzi & Bacchi), applied to the Toce river basin (1532 km^2), in the 'Lago Maggiore Target Area'



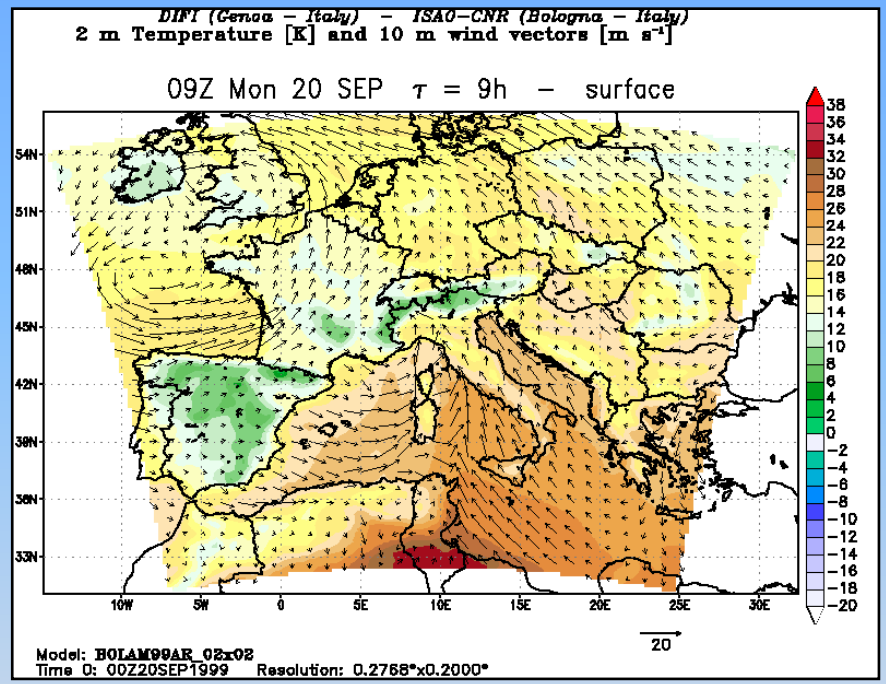
MAP SOP: 41 pluviometric stations in the catchment area (Regione Piemonte, ENEL S.p.A., Servizio Idrografico, + 14 deployed by the Univ. of Brescia) (R. Ranzi)



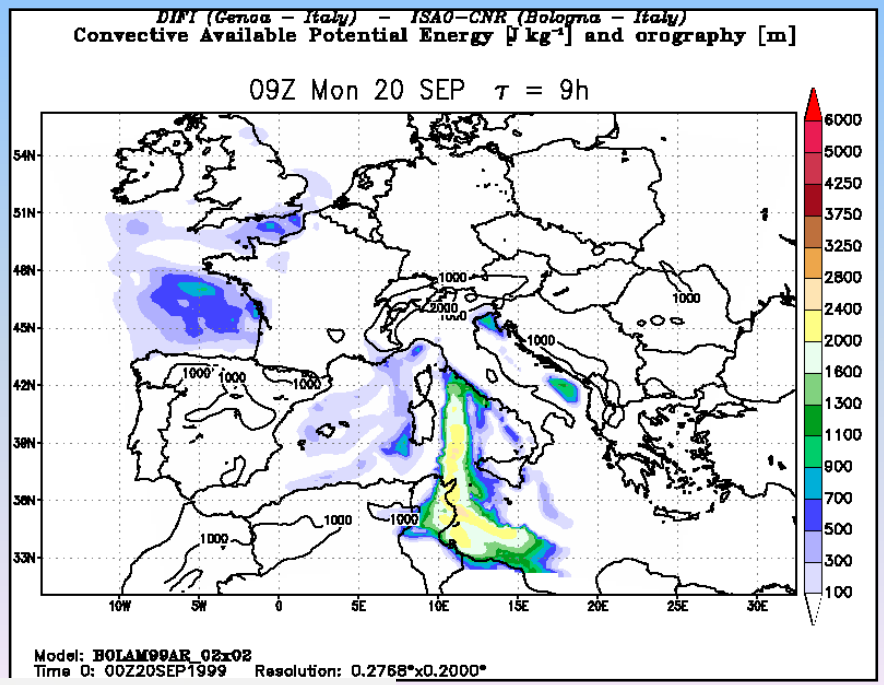
MAP-SOP: observed and forecasted precipitation over the entire Toce basin (R. Ranzi)



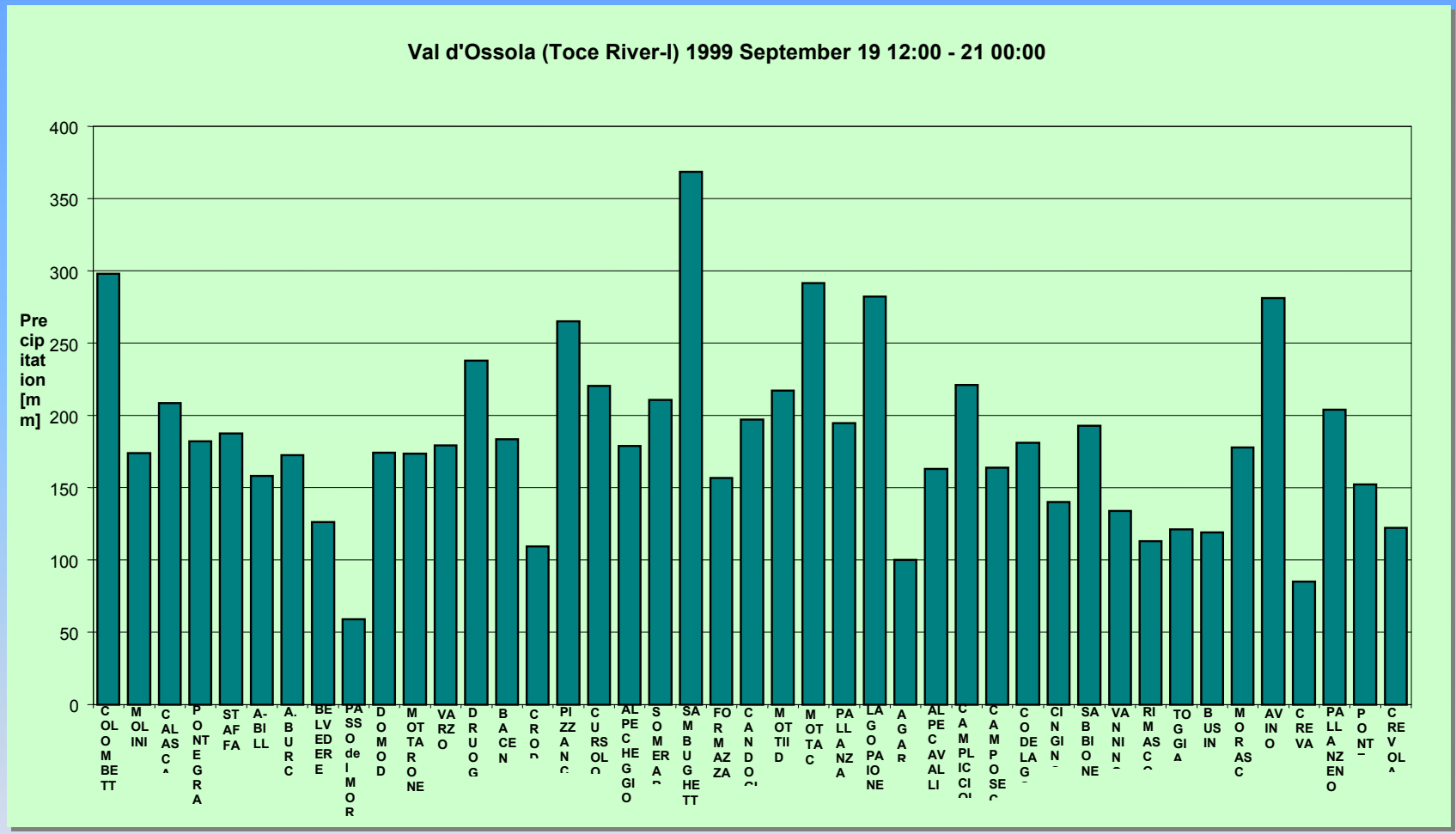
MAP IOP 2b, 20/09/1999, 09 UTC



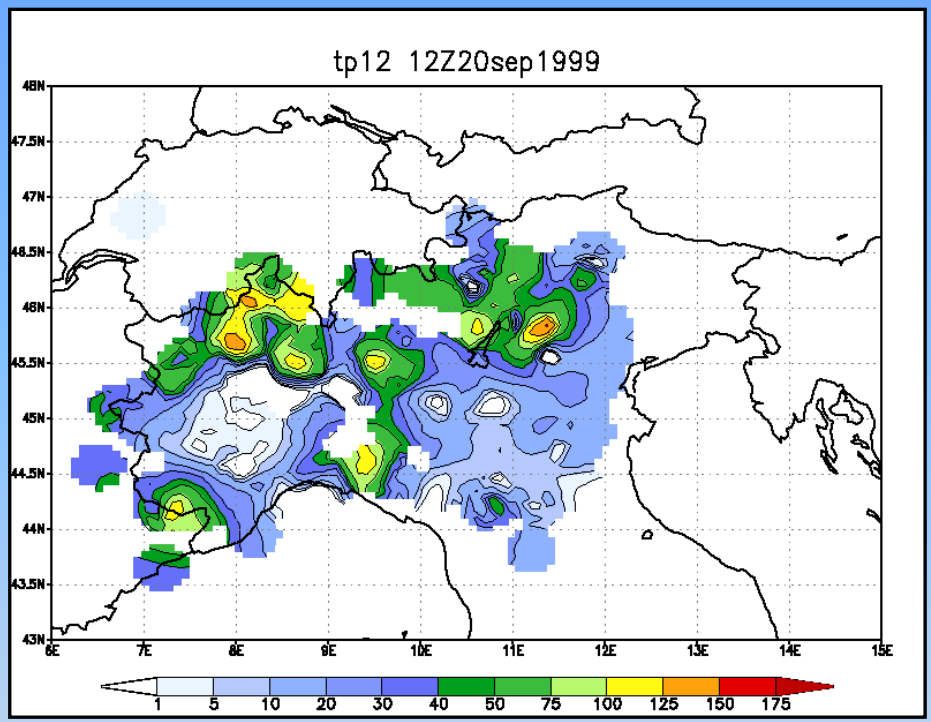
10 m wind and 2 m T

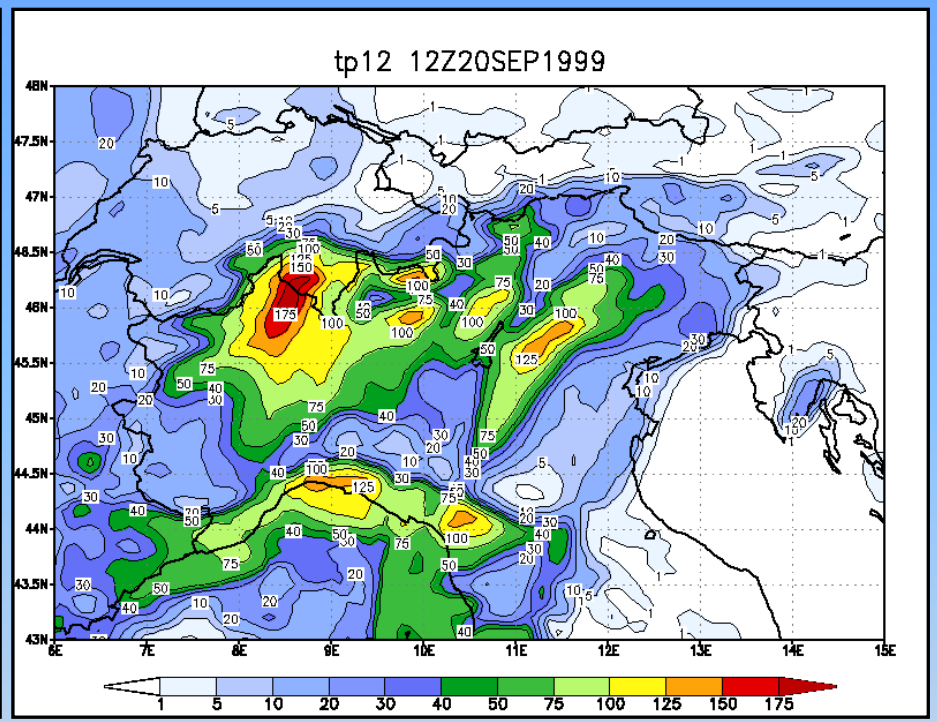


Convective Available Potential Energy

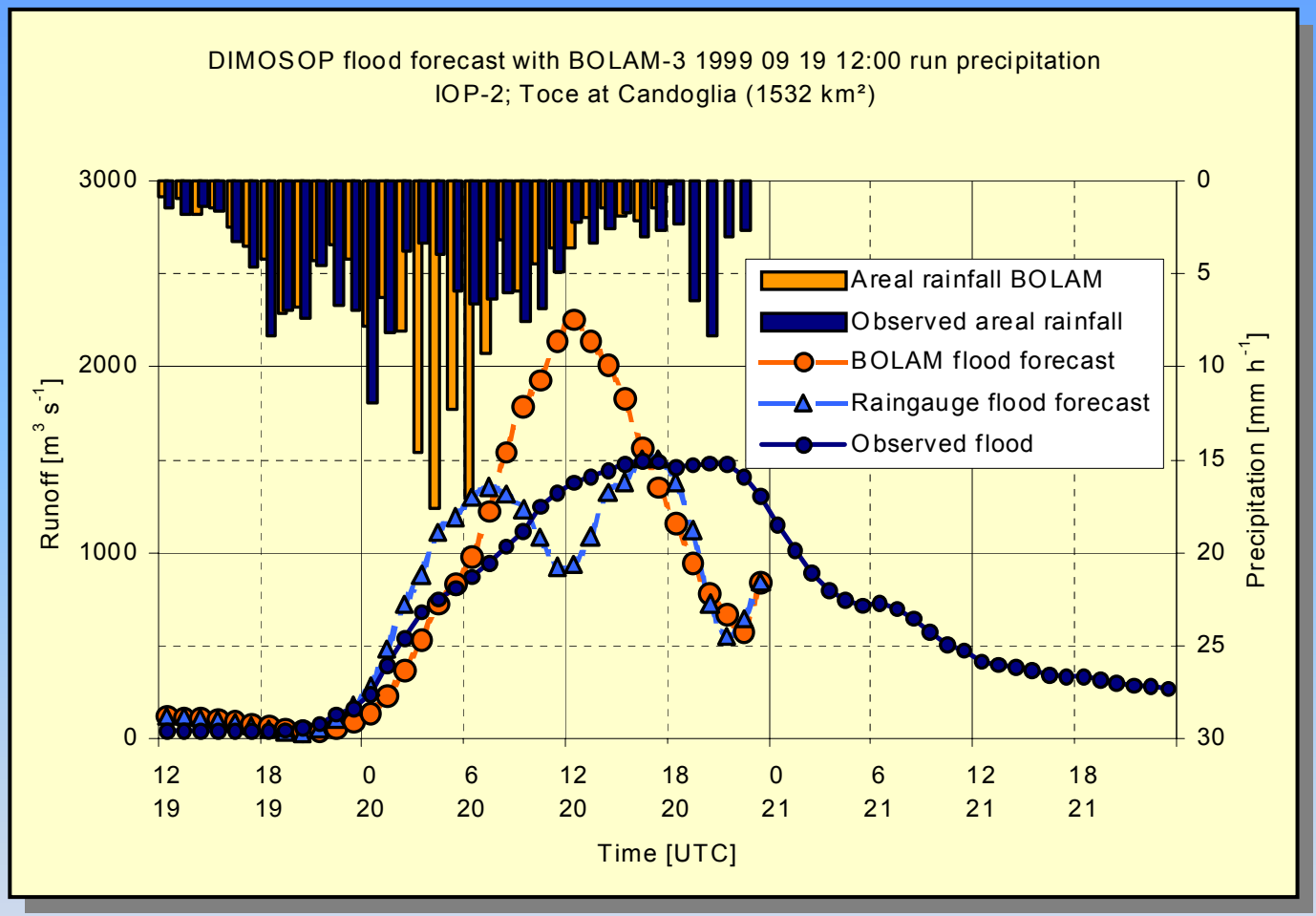


36 h accumulated precipitation during the IOP-2b event in the Toce valley (courtesy R. Ranzi)





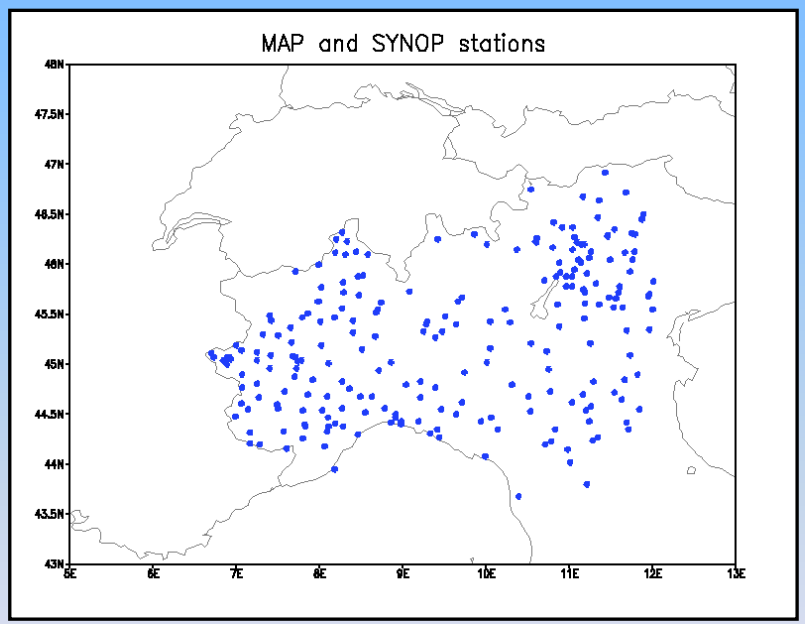
MAP-SOP: 12 h accumulated precip., observed (left) and forecasted with BOLAM (right) at t+24h, 20 Sept. 1999 (IOP 2b)

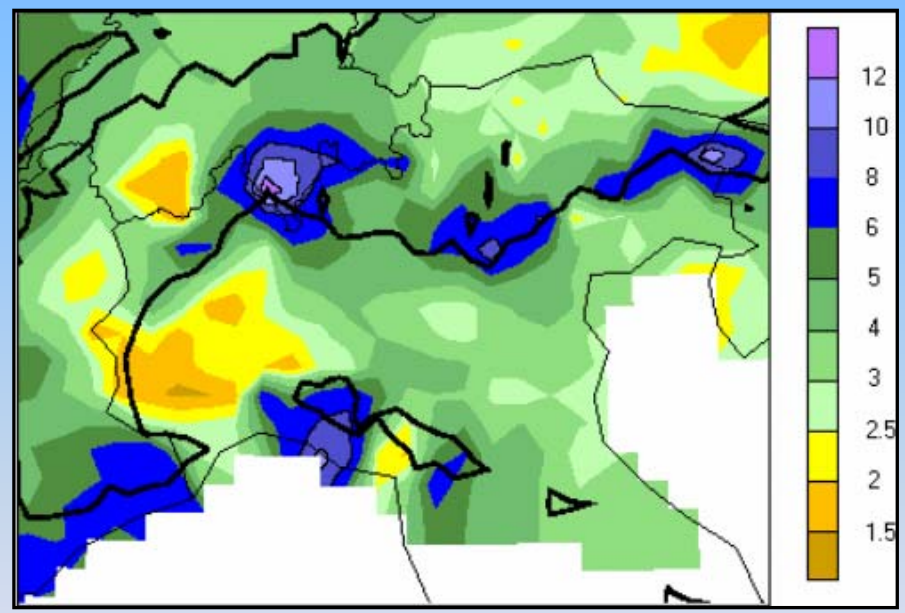


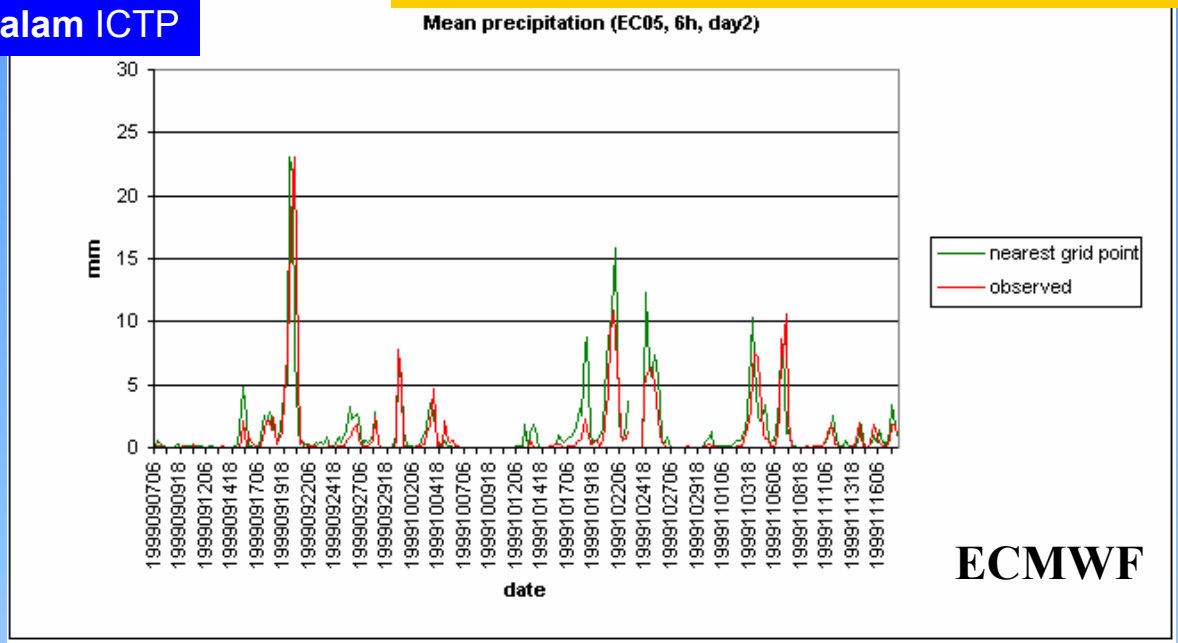
Runoff at Candoglia, observed and forecasted with DIMOSOP, based on BOLAM forecasts for the period 1999-09-19 12 UTC - 1999-09-21 00 UTC (MAP IOP 2b)

VERIFICATION OF PRECIPITATION IN LIMITED AREA MODELS OPERATING DURING THE MAP-SOP

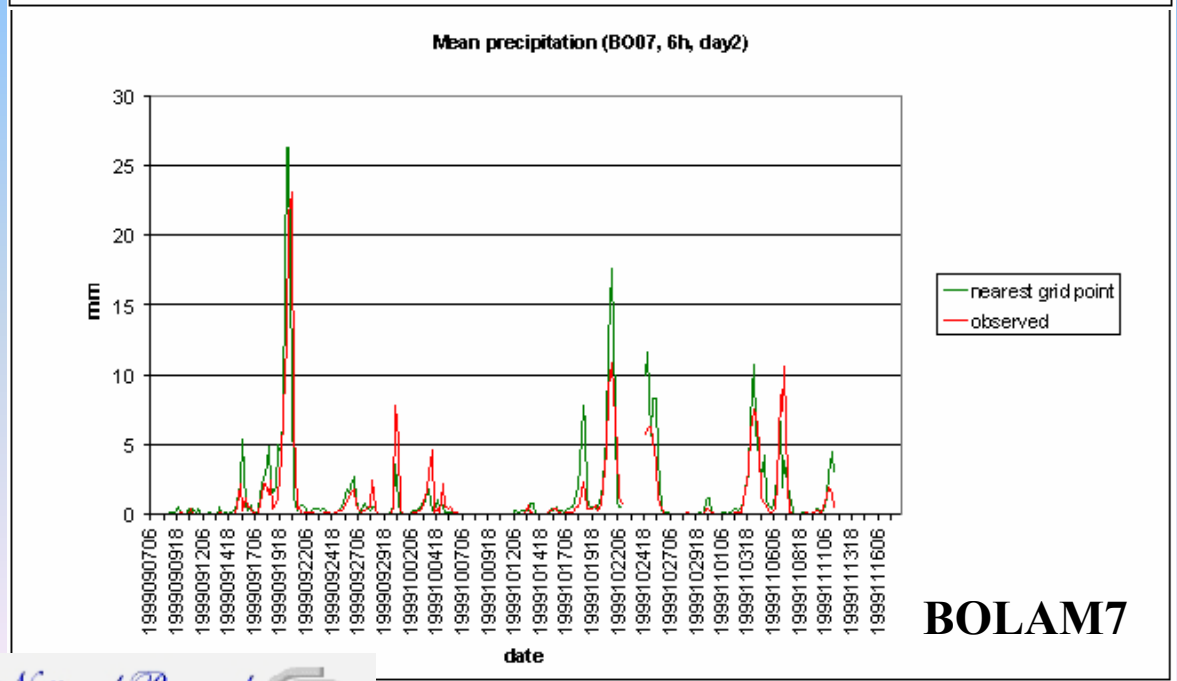
(Contri et al.)





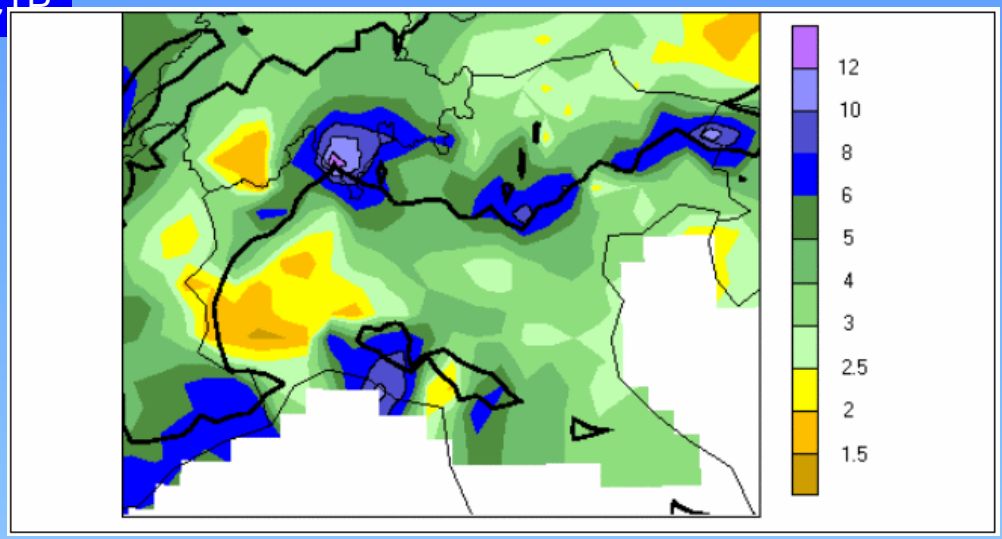


ECMWF

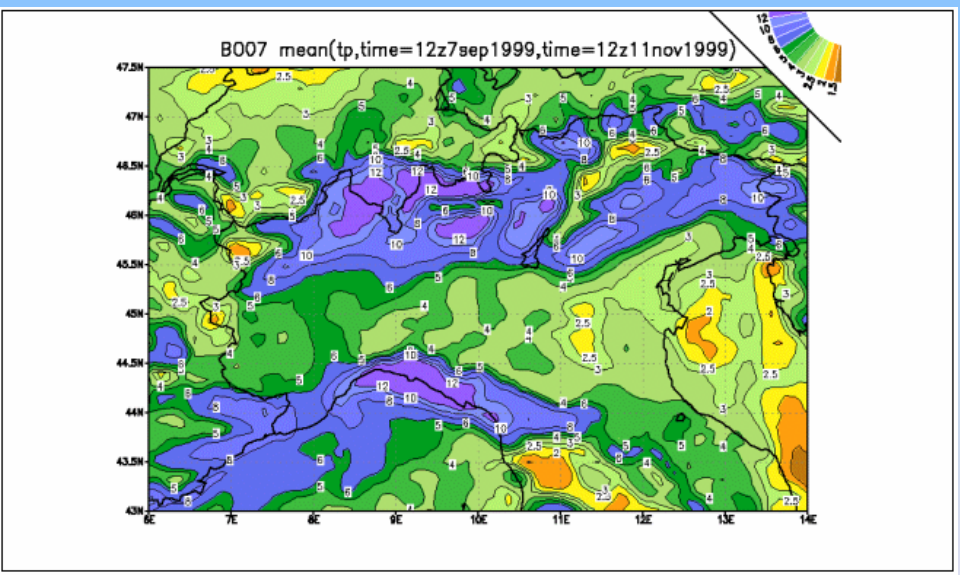


BOLAM7

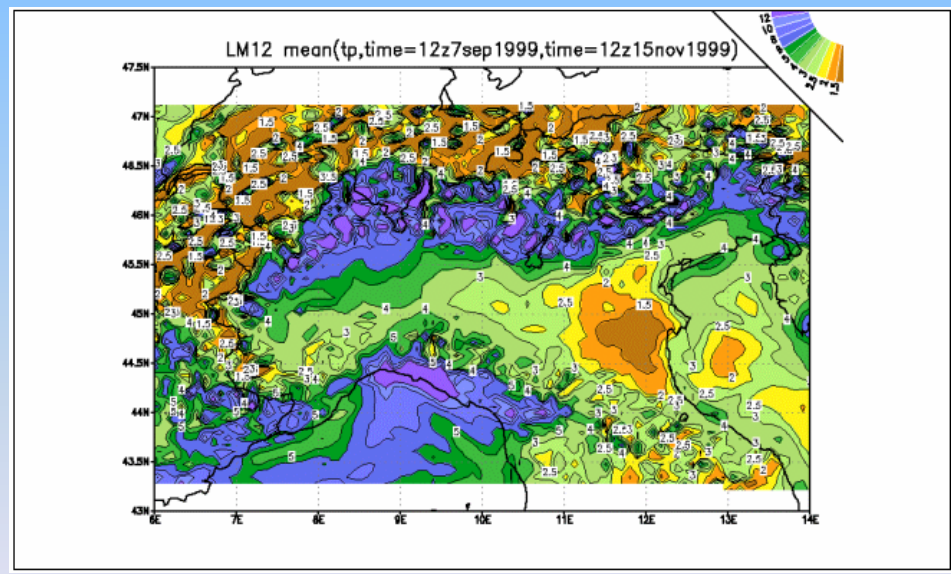
No major differences between the *ECMWF* global model and *BOLAM* in forecasting the precipitation averaged over the entire Northern Italy



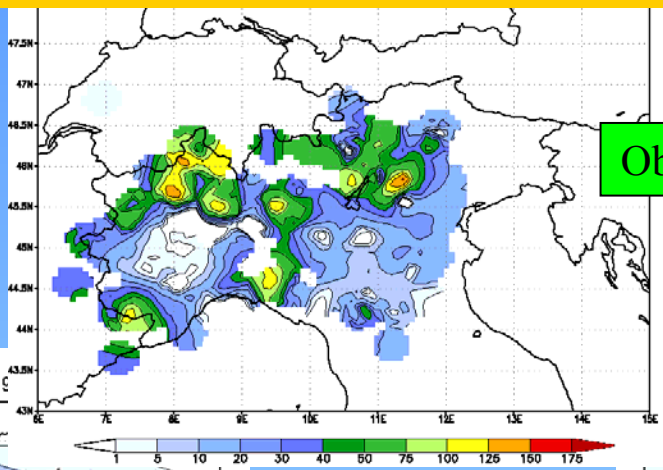
Observed precip., MAP SOP



Forecast. precip., *BOLAM*, MAP SOP

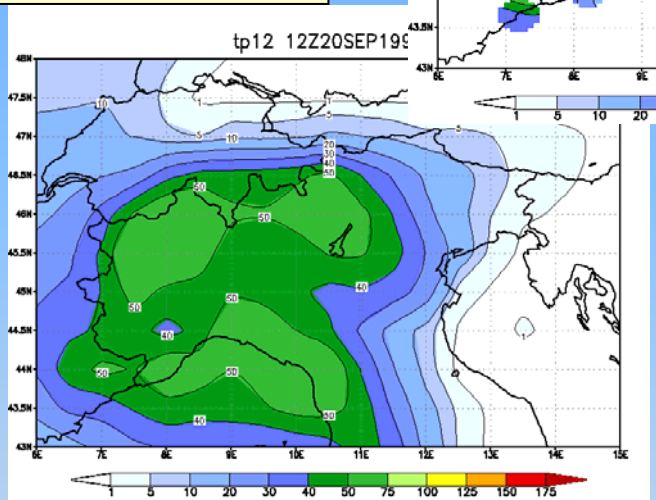


Forecast. precip., *LM*, MAP SOP

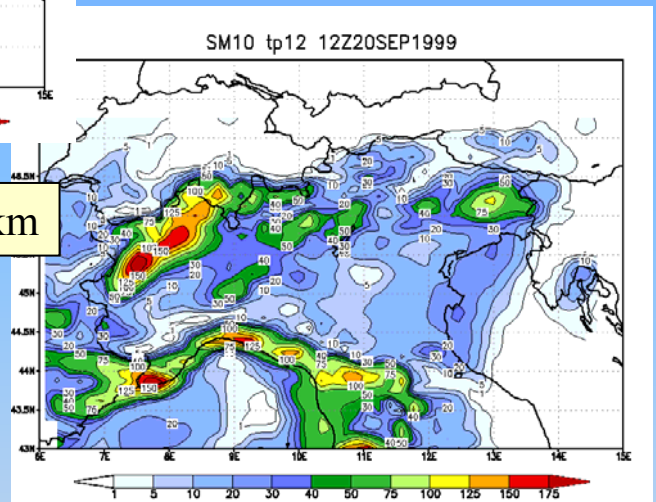


Observed, IOP 2b

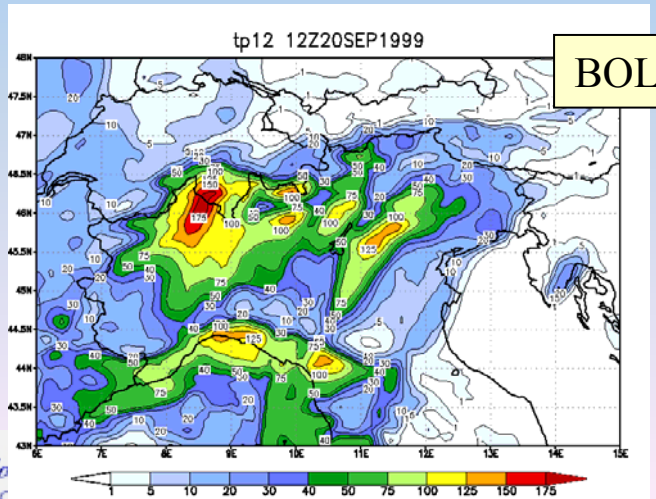
ECMWF, ~ 60 km



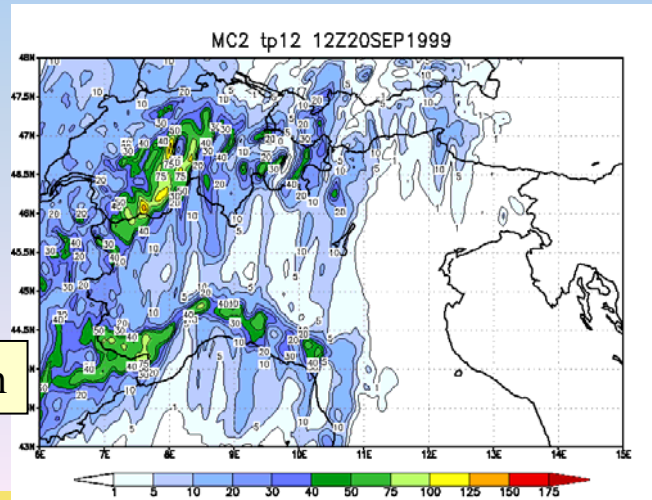
SWISS M., 14 km



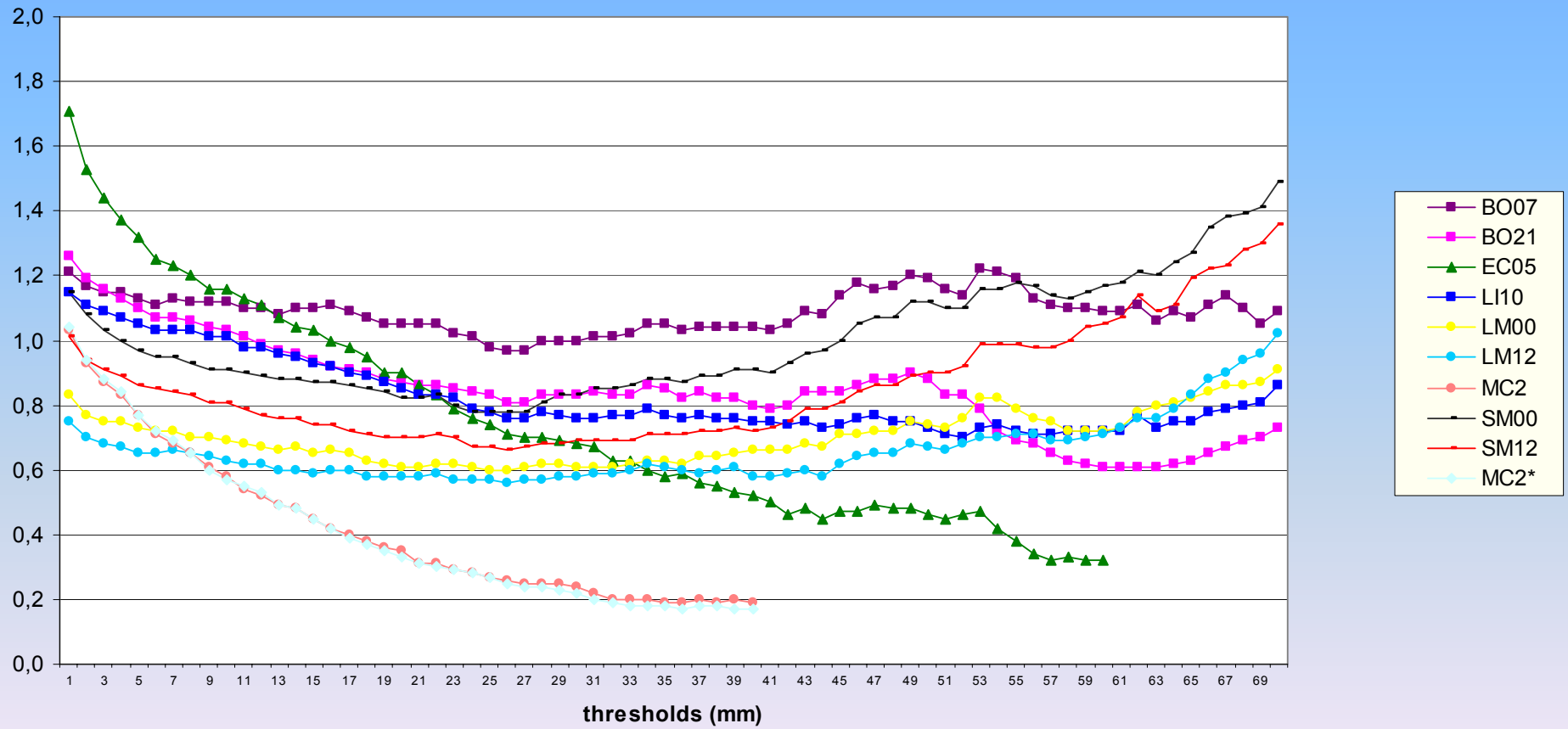
BOLAM, 6.5 km



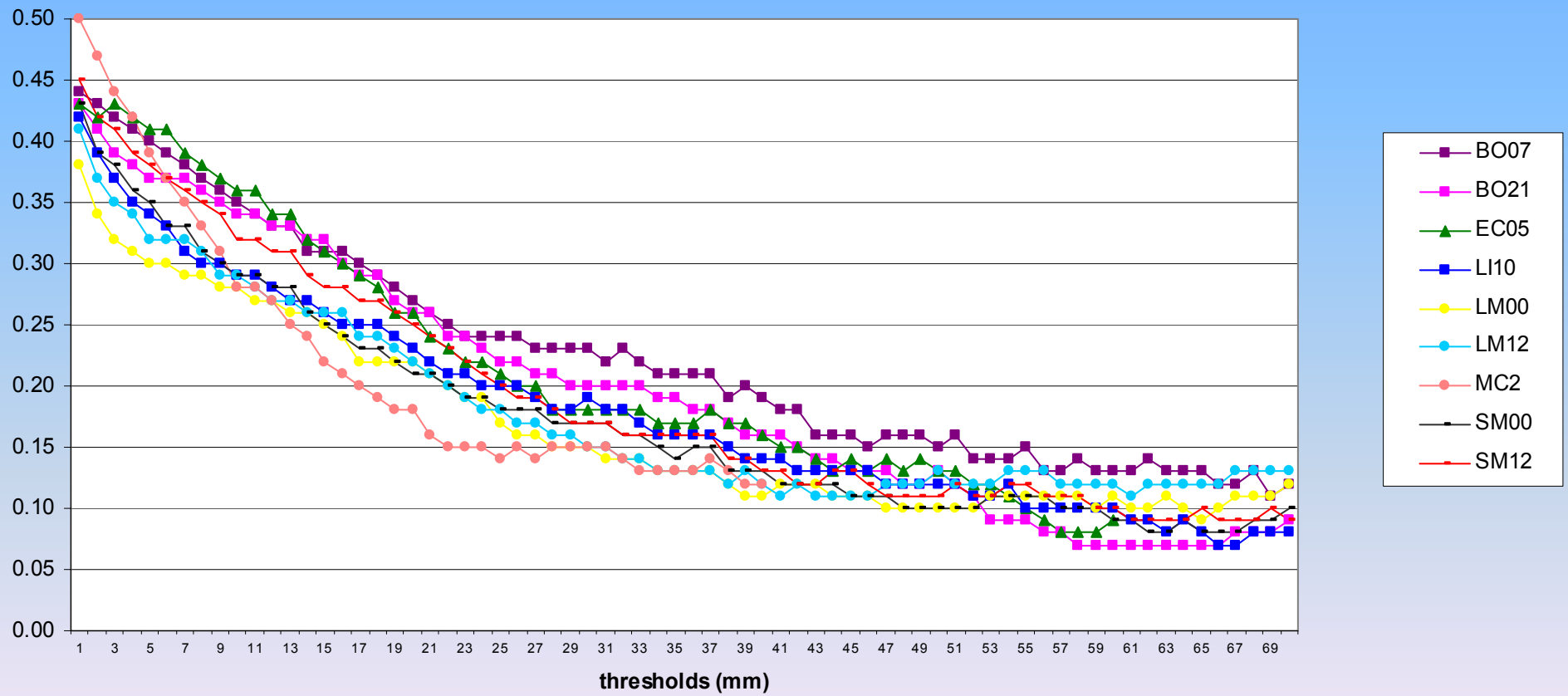
MC2, 3 km



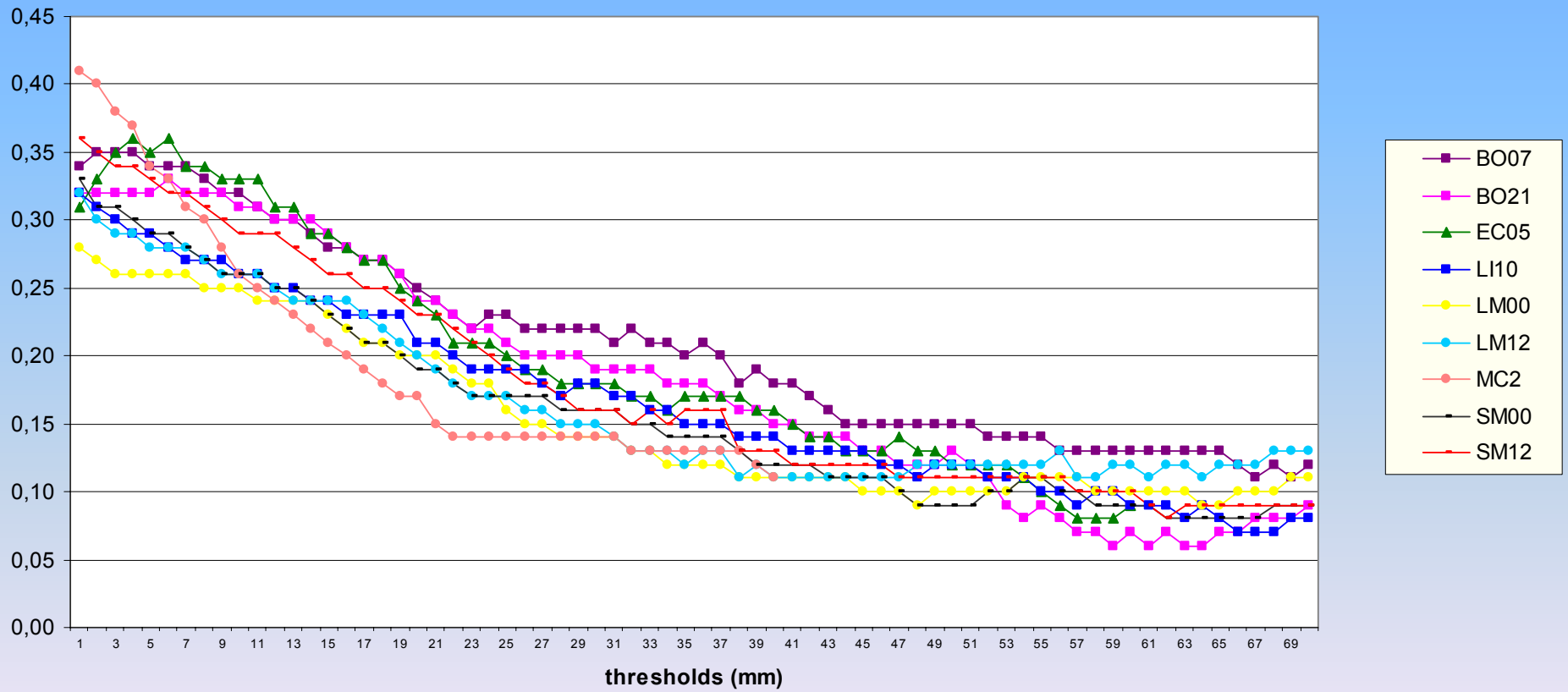
Precipitation (12 h) scores:
Bias



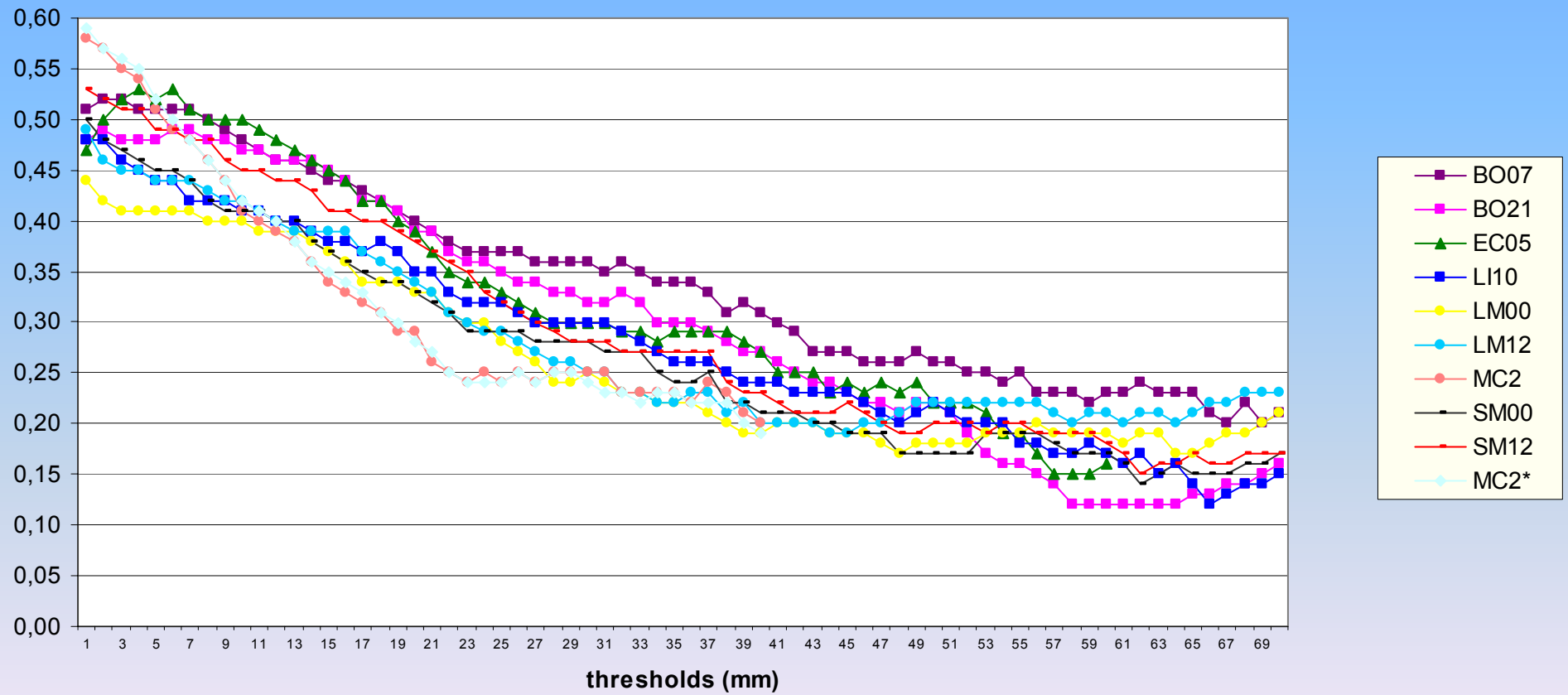
Precipitation (12 h) scores:
Threat score



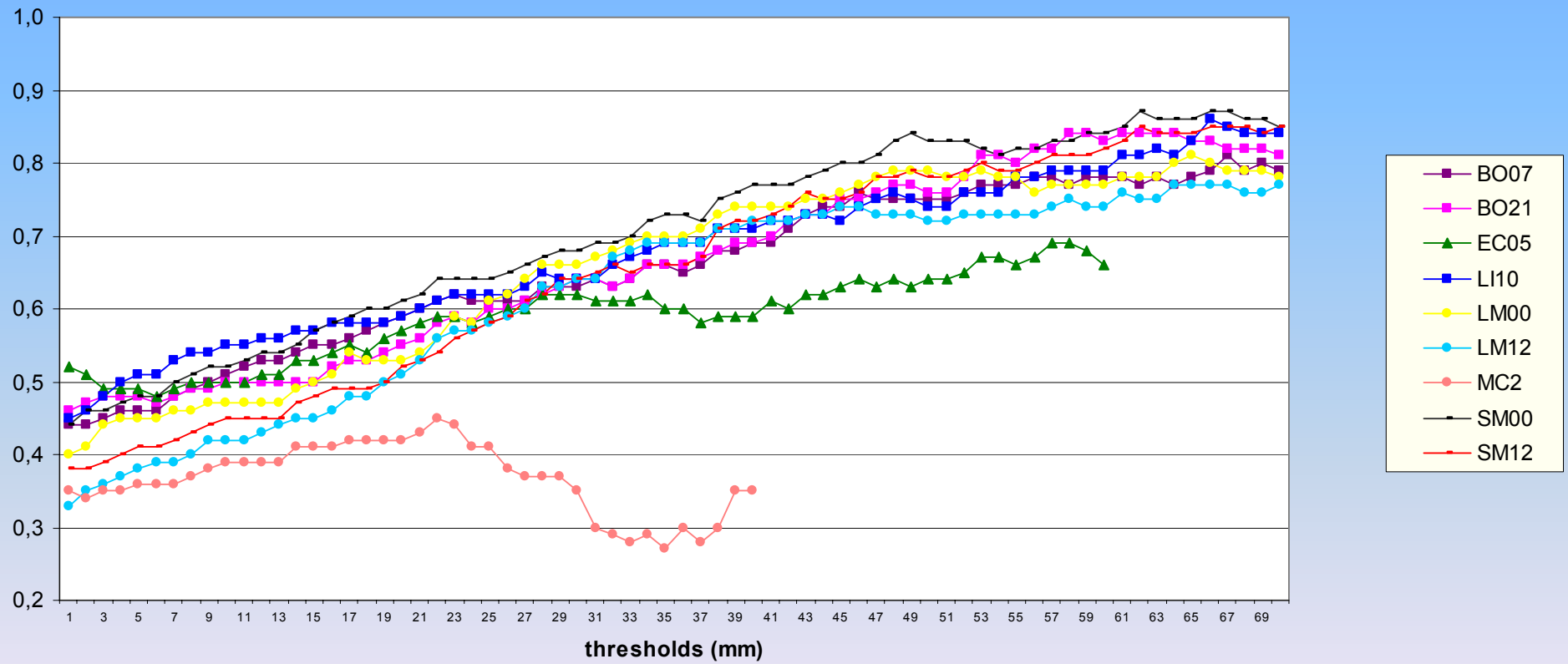
Precipitation (12 h) scores: Equitable threat score



Precipitation (12 h) scores: Heidke score



Precipitation (12 h) scores: False alarm score



OPERATIONAL USE OF THE METEOROLOGICAL MODEL BOLAM AT THE NATIONAL OBSERVATORY OF ATHENS

K. Lagouvardos, V. Kotroni, A. Koussis and C. Feidas

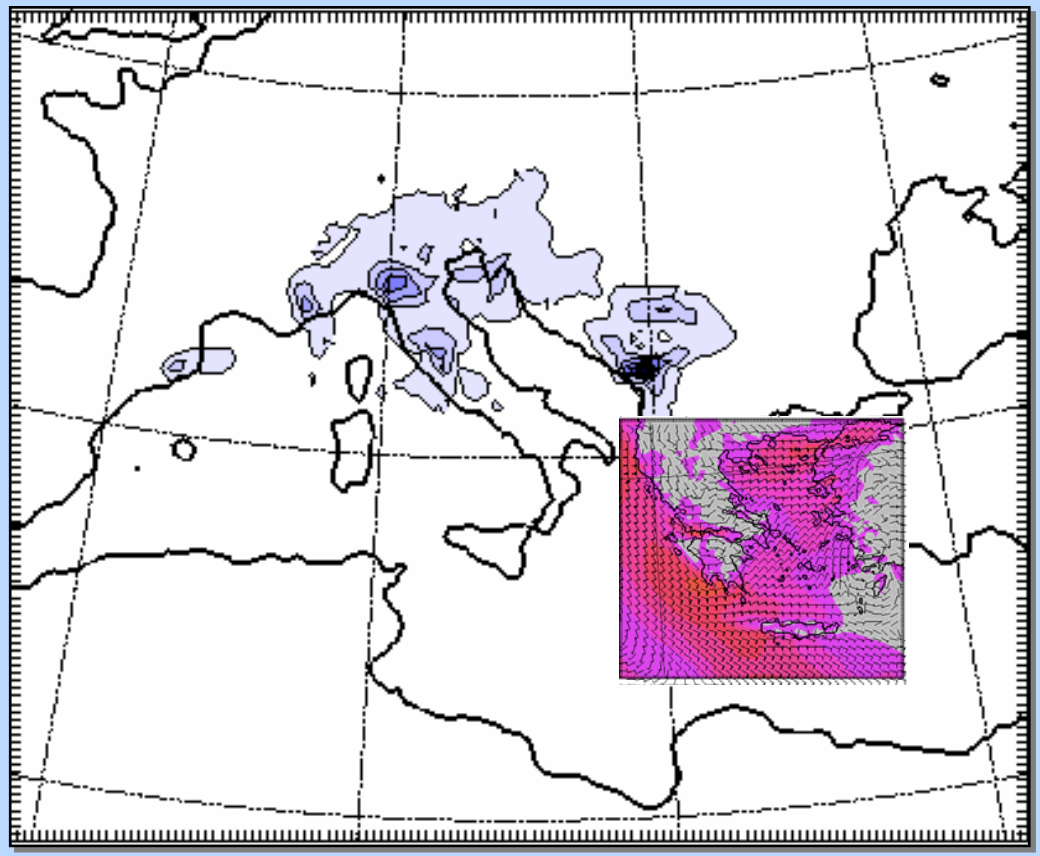
National Observatory of Athens

A. Buzzi, P. Malguzzi

Institute of Atmospheric Sciences and Climate-CNR, Bologna

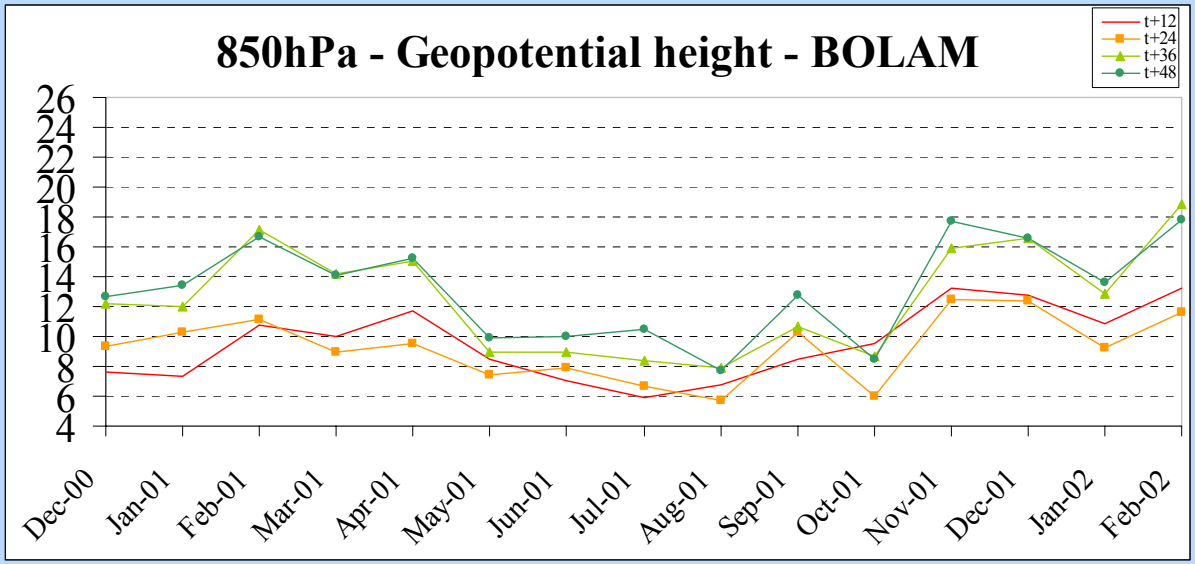
NESTED SIMULATIONS
(2 years of operation)

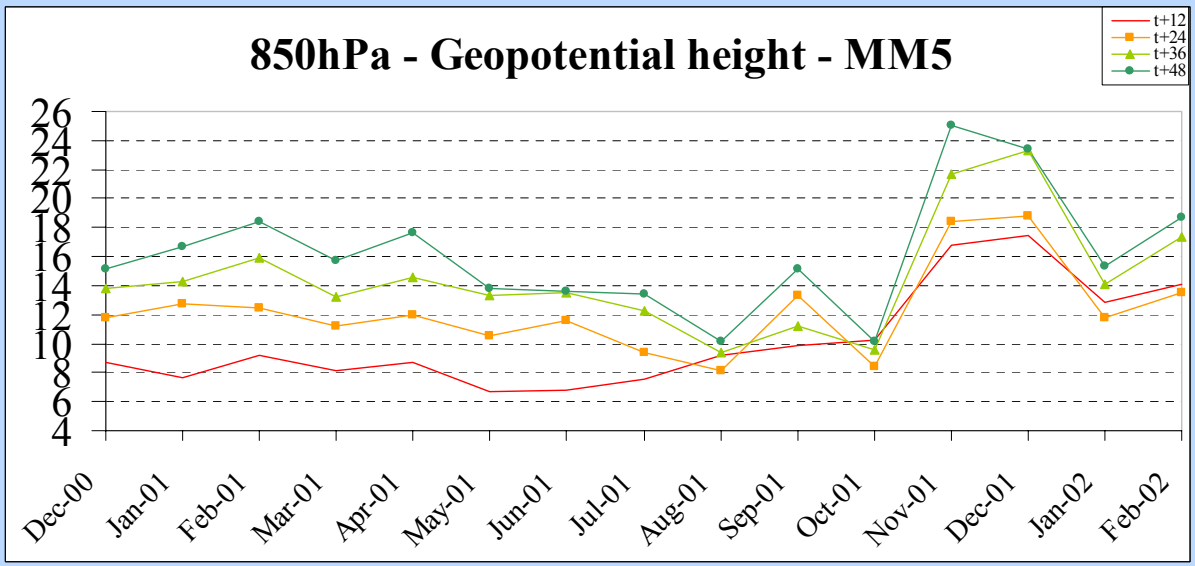
- Coarse grid:
  0.21 deg resolution, 30 levels
- Inner grid:
  0.06 deg resolution, 40 levels



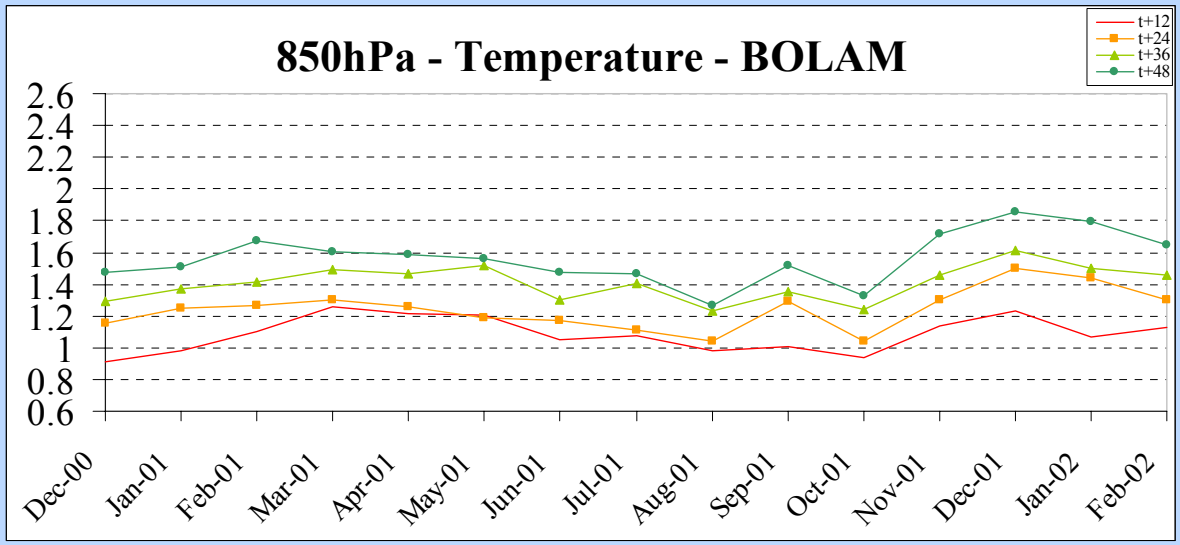
http://www.noa.gr/~telefleu

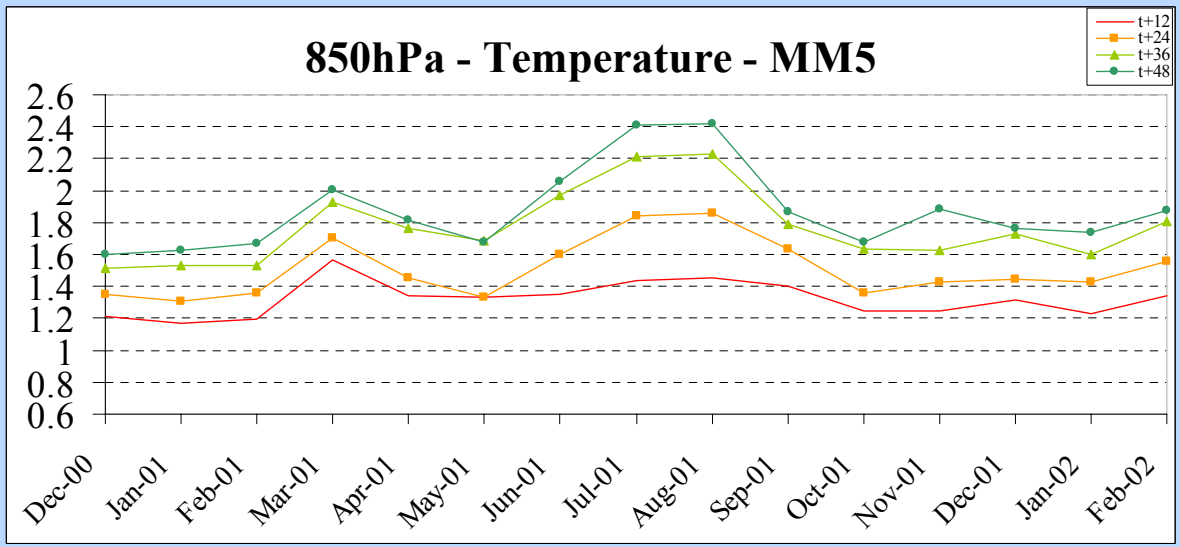
Verification against AVN-NCEP analyses



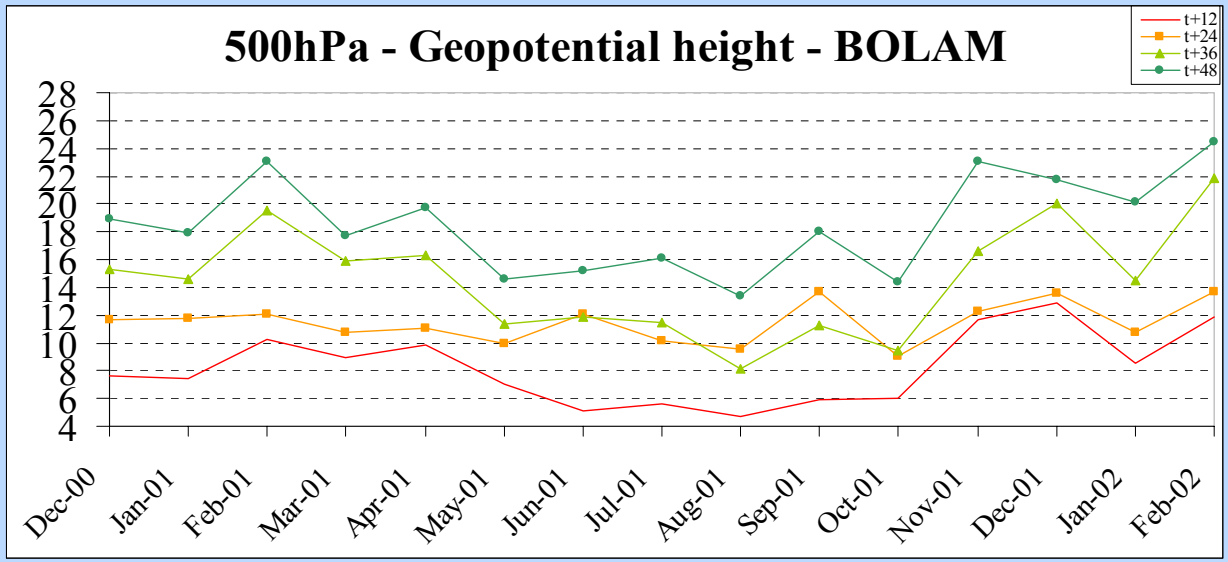


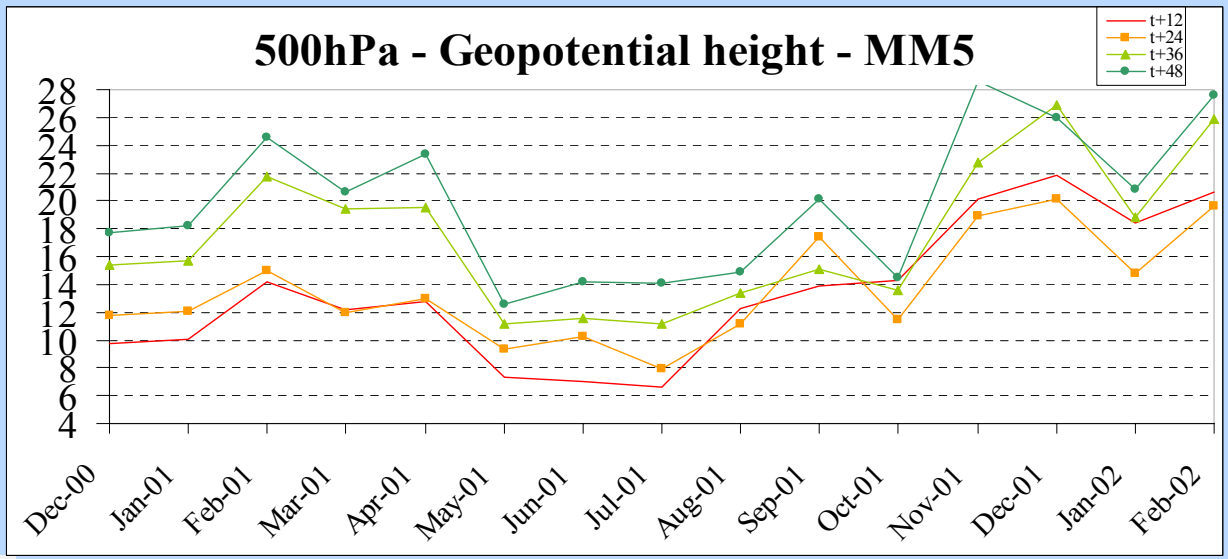
Verification against AVN-NCEP analyses



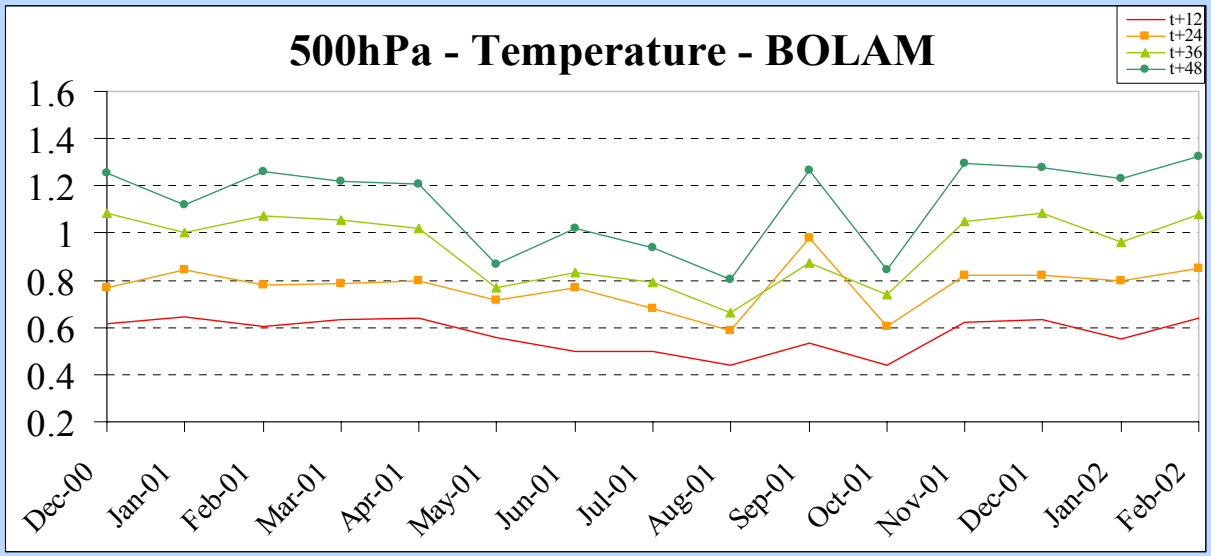


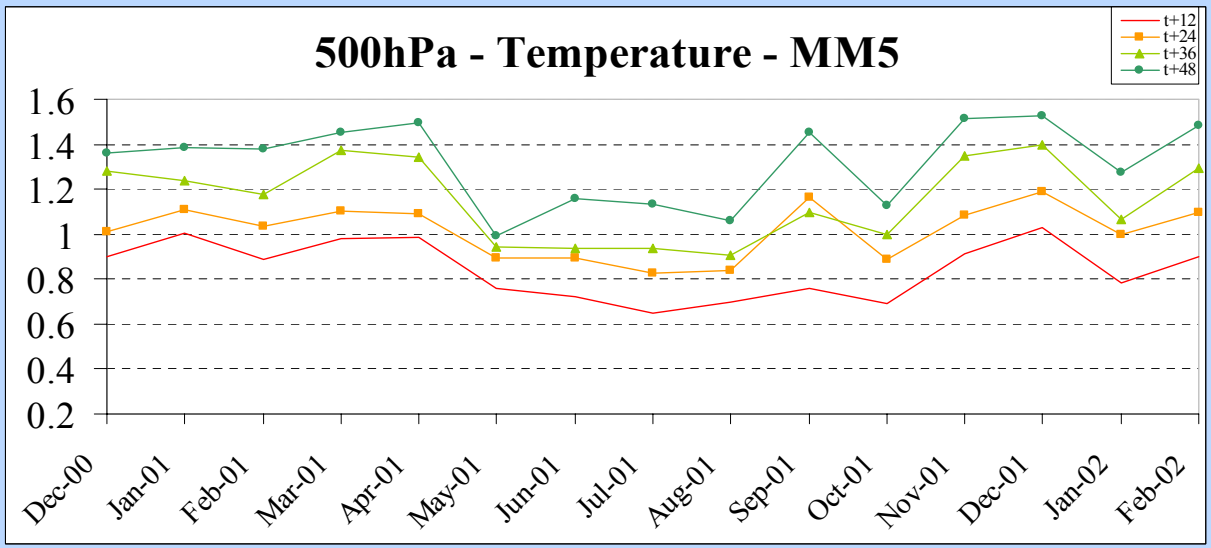
Verification against AVN-NCEP analyses





Verification against AVN-NCEP analyses

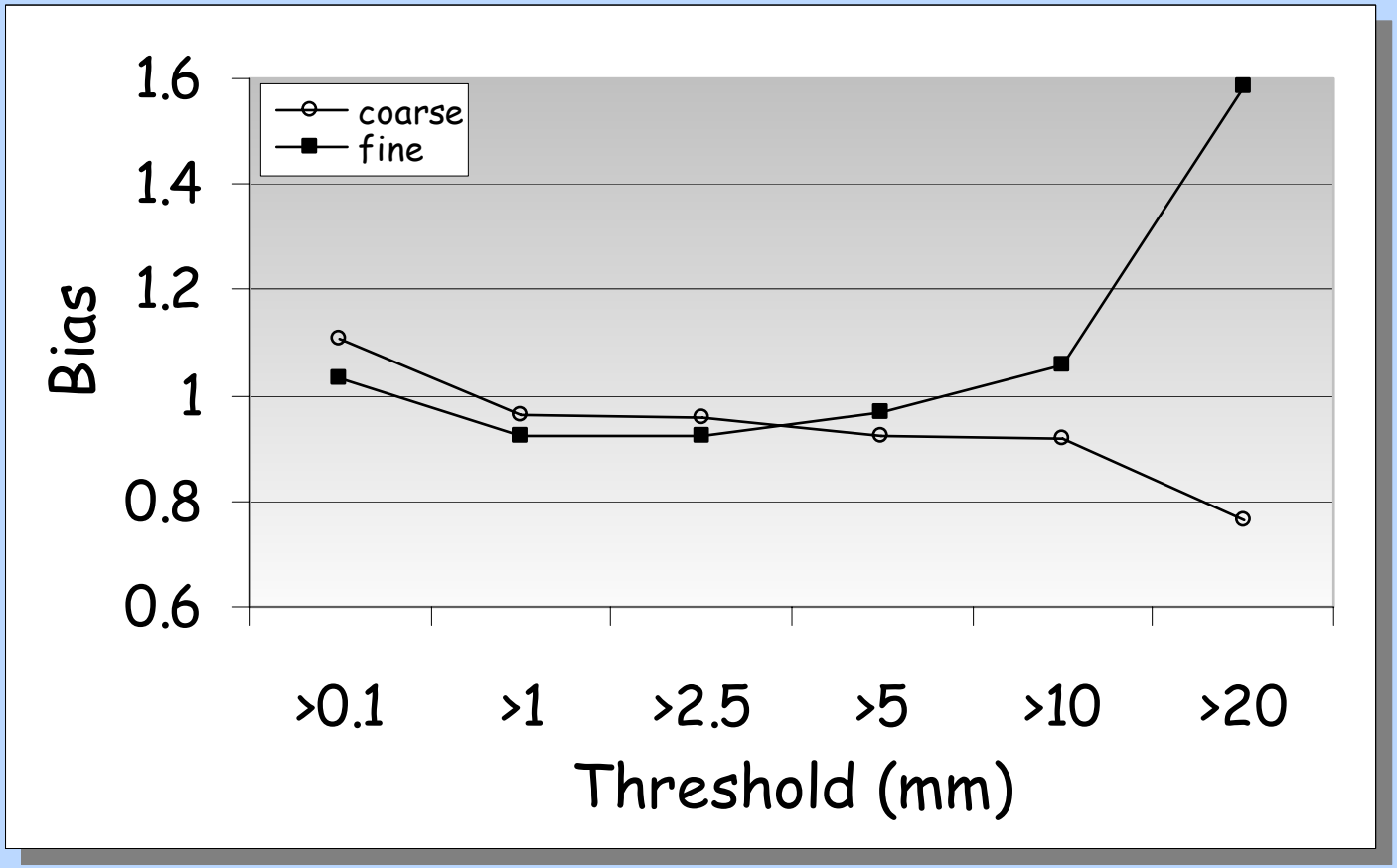




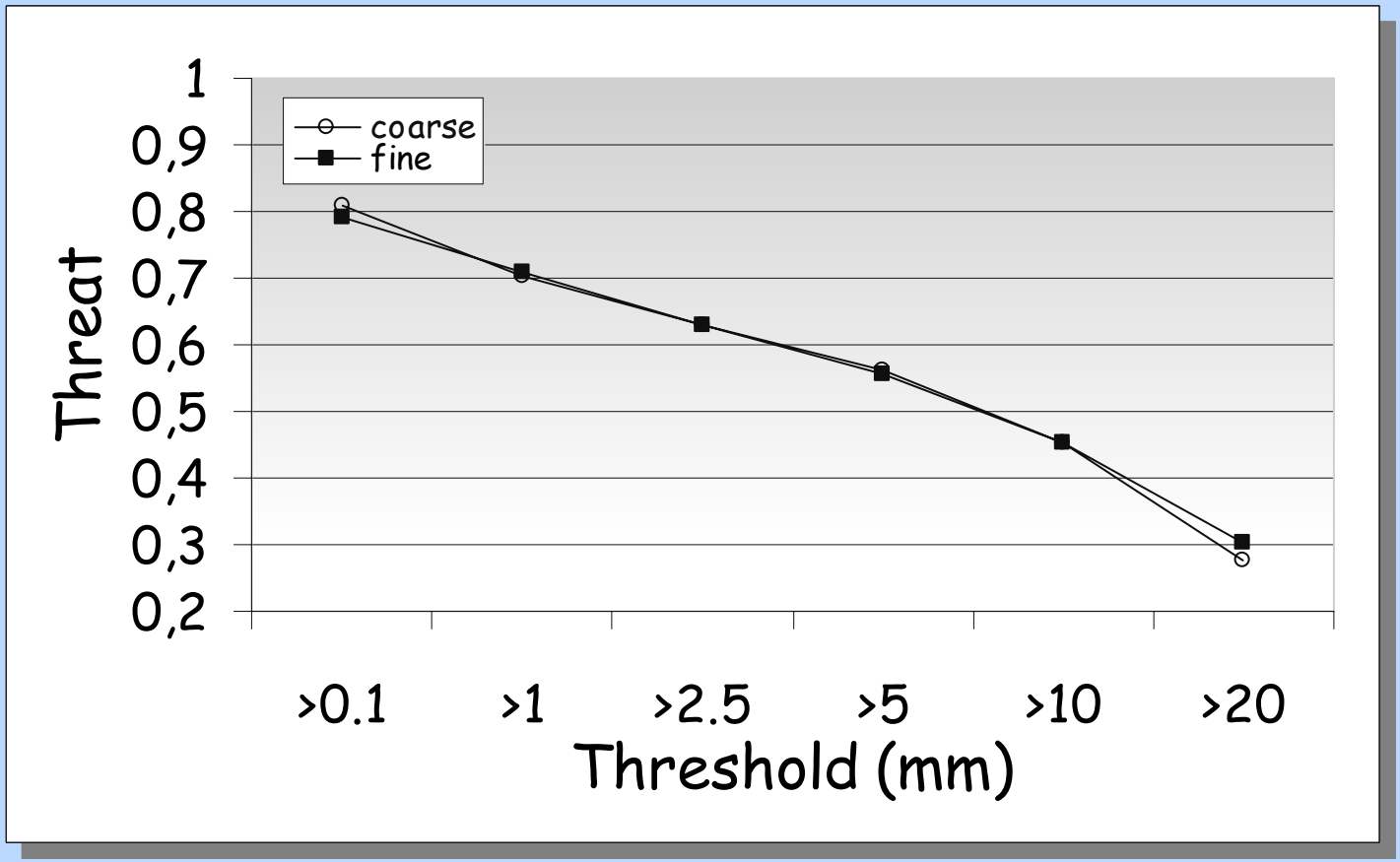
Verification of model quantitative precipitation forecasts

- 11 cases of significant precipitation over Greece during the cold periods of 1999 and 2000 are verified.
- The verification of accumulated precipitation has been performed for a 24-h period
- The observed precipitation (from the network of raingauges of the Hellenic Meteorological Service) is verified against *BOLAM* model coarse (~21 km) and the fine (~6.5 km) grid precipitation, accumulated between t+18 and t+42 forecast hours.

Verification of model QPF

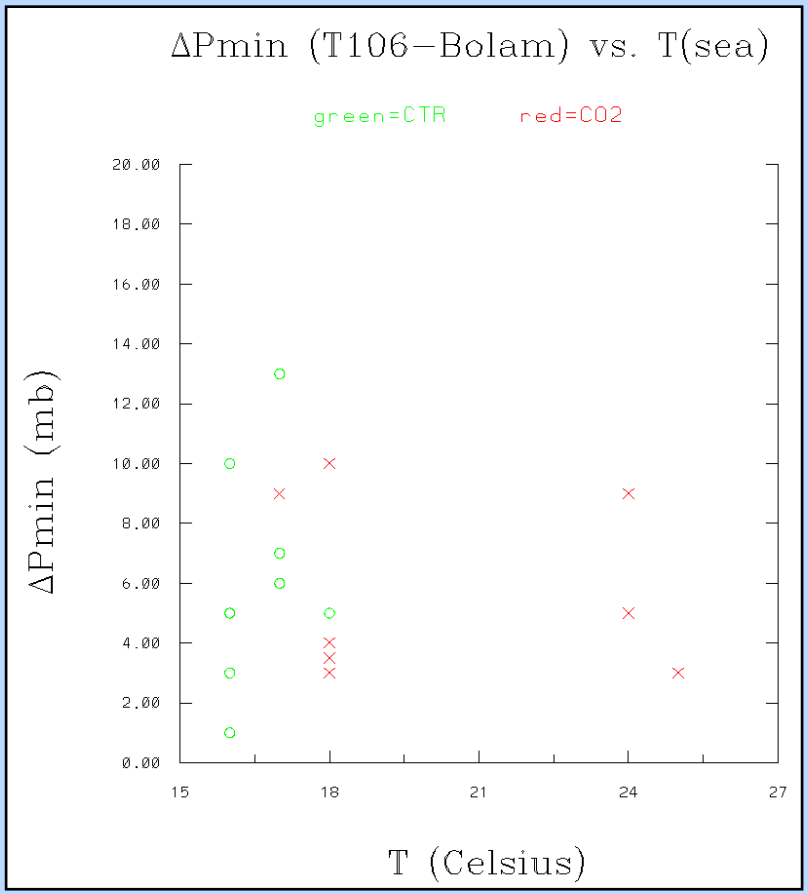


Verification of model QPF



Regionalization and downscaling: application of *BOLAM* in EU project ***STOWASUS***

'Regional STOrm, WAve and SUrge, Scenarios for the 2100 century'
(E. Kaas, DMI)



Storm characteristics in the Mediterranean in a doubled CO2 scenario (Malguzzi & Lionello, 2000)

New non hydrostatic model (BOLAM-NH, '*MOLOCH*')

Model dynamics (Malguzzi, 2001):

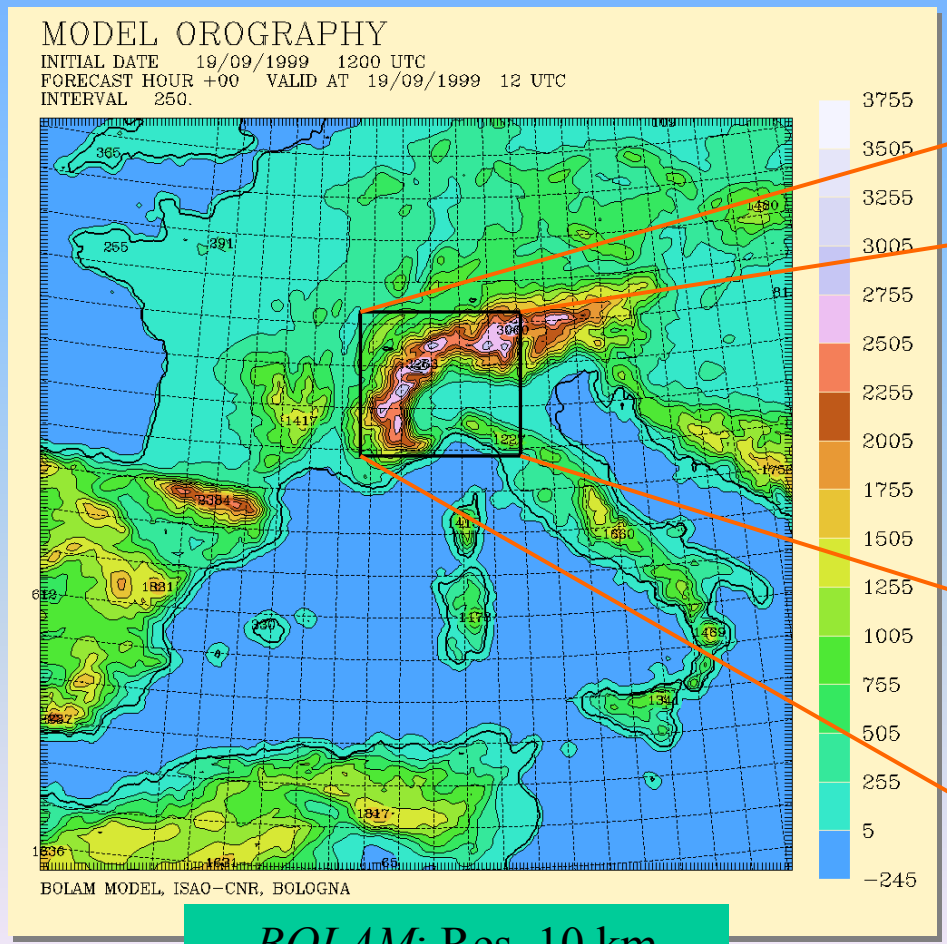
- non hydrostatic, fully compressible;
- Arakawa C grid; hybrid terrain follwing coordinate, relaxing to z at ~8000 m
- time split, semi-implicit for vert. prop. sound waves, FB for horiz. prop. waves
- advection: FBAS (Malguzzi & Tartaglione, 1999); also Weighted Average Flux WAF (Toro 1989; Hubbard & Nikiforakis, 2001)

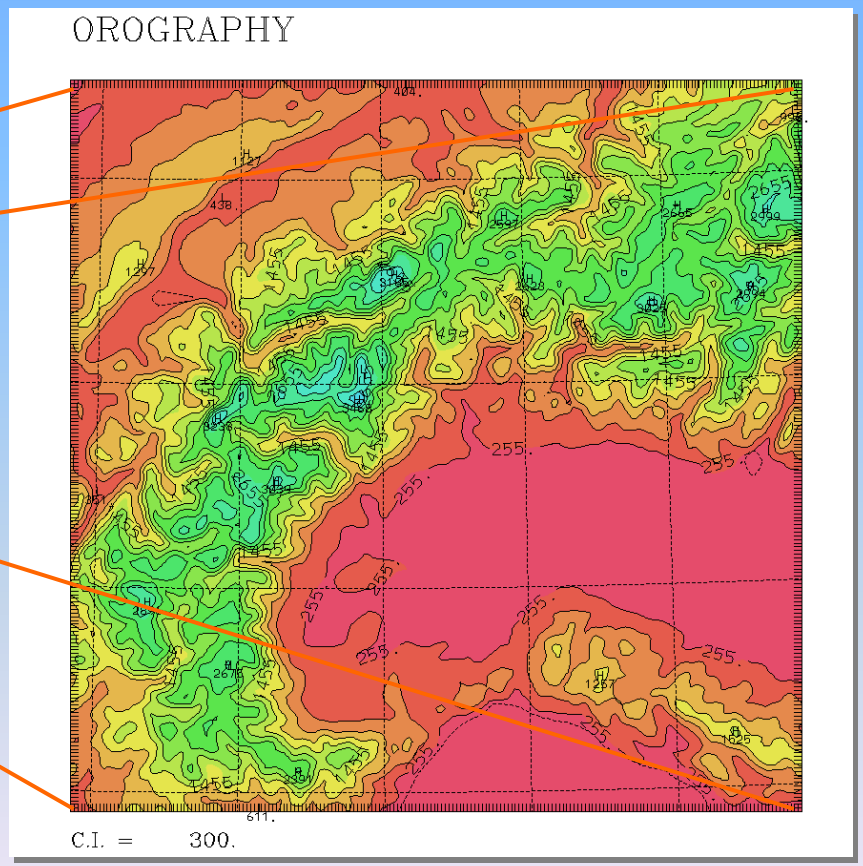
Model physics:

- provisionally similar to BOLAM, except for cloud microphysics (Drofa, 2001; partly based on Rutledge and Hobbs, 1983)

Non hydrostatic *MOLOCH* nested in BOLAM:

MAP IOP 2b (Malguzzi et al., 2001)

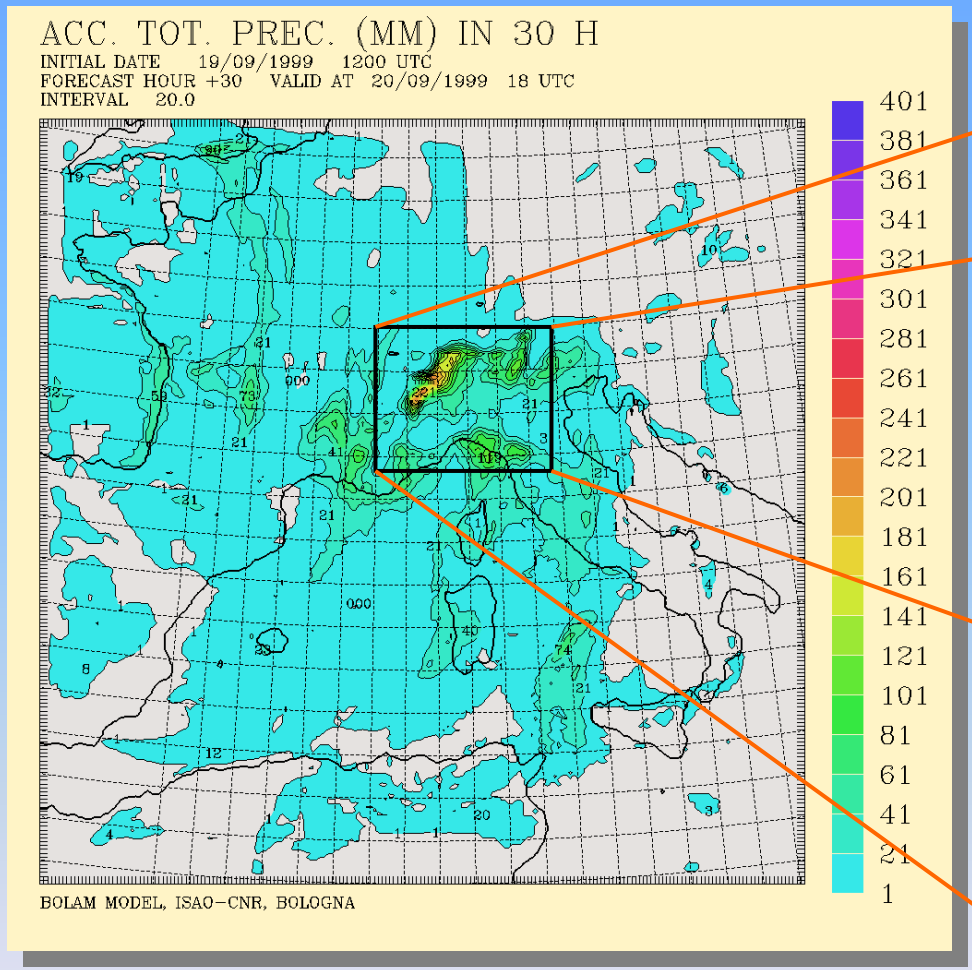


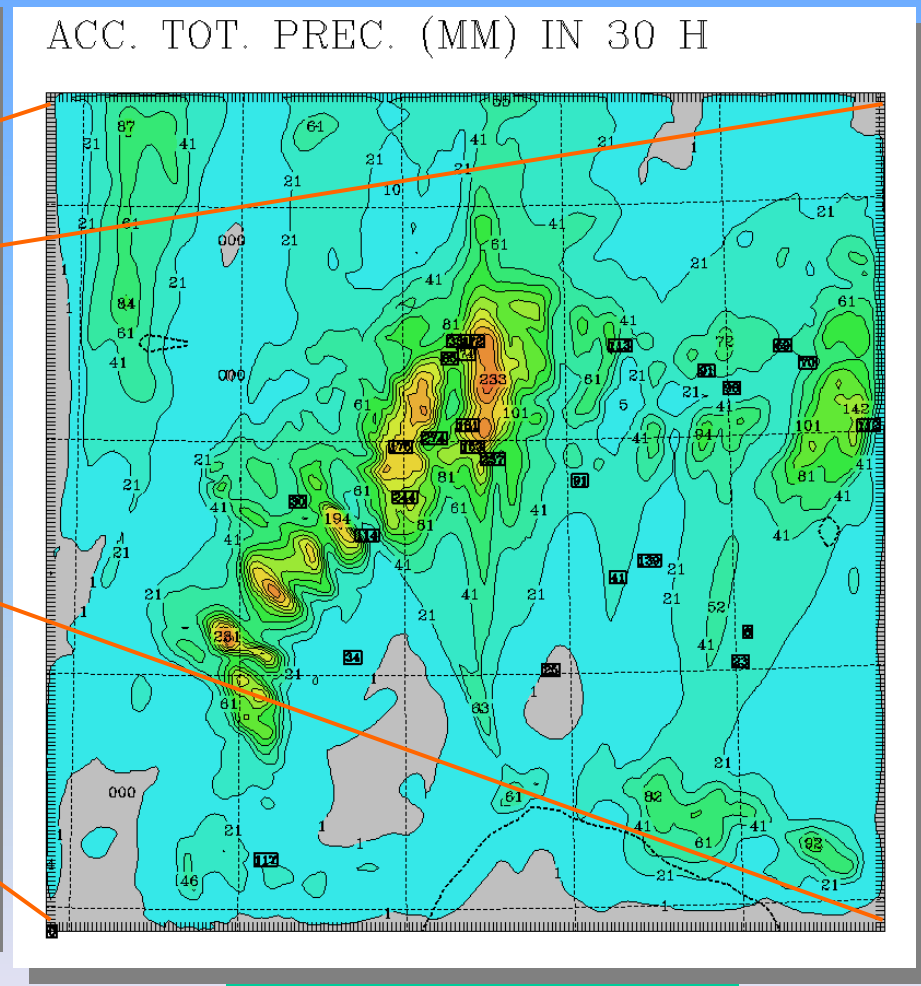


BOLAM: Res. 10 km

MOLOCH: Res. 2 km

30 h accumulated precipitation, MAP IOP 2b





BOLAM: Res. 10 km

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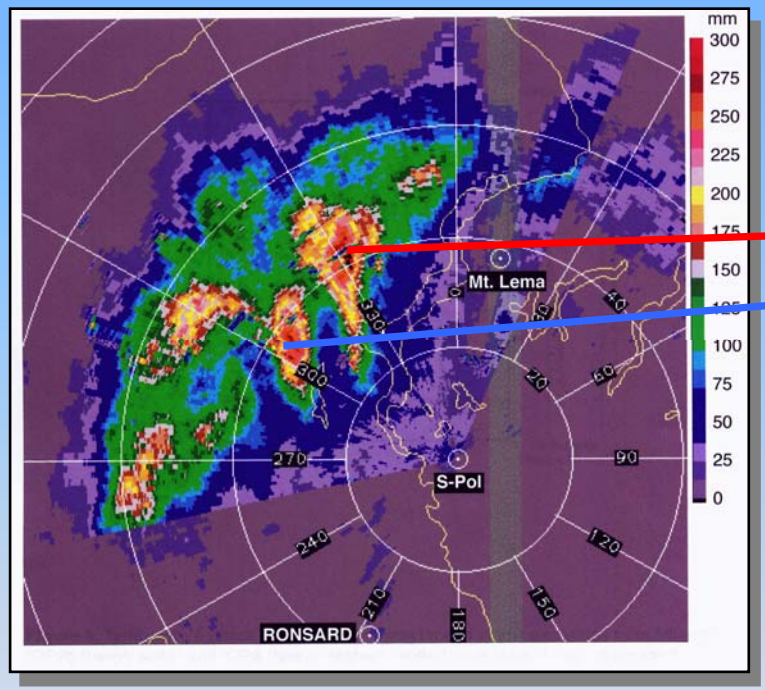
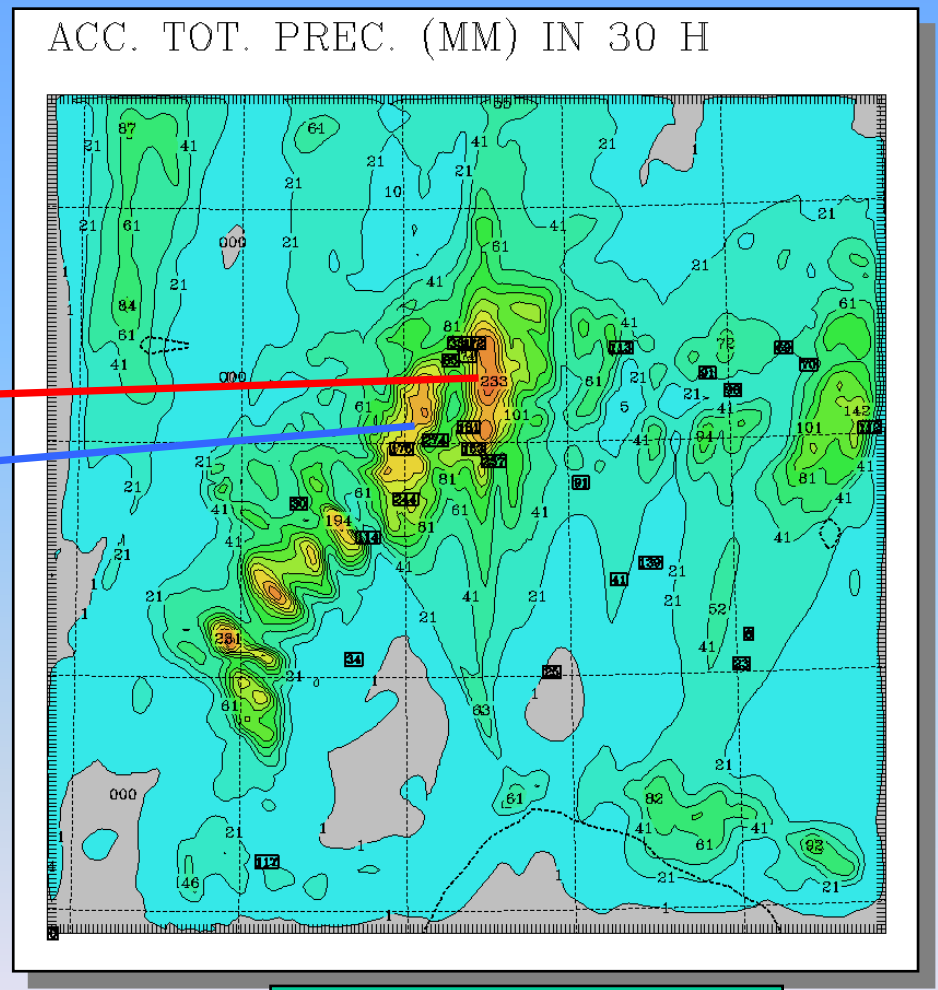
30 h accumulated precipitation, MAP IOP 2b





S-POL radar

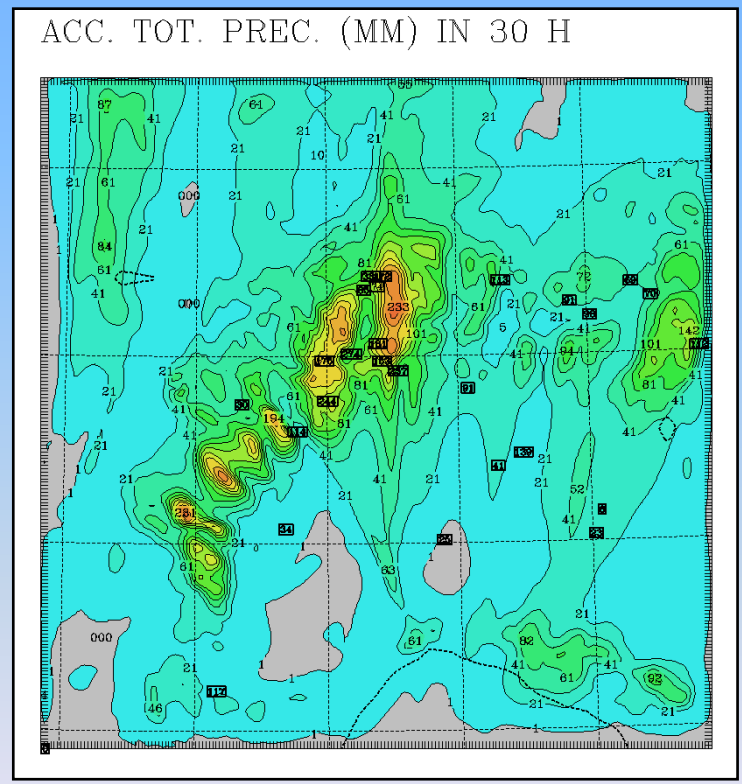
MOLOCH: Ris. 2 km

Intercomparison of simulated precipitation with non hydrostatic models at high resolution (2 km) on MAP IOP2b case

(E. Richard et al, 2002)

	Cor. 1h	Cor. 6h	Cor. 27h	Mean Bias
MESONH	0.33	0.49	0.62	+28%
MOLOCH	0.31	0.47	0.62	-22%
MM5-RE	0.27	0.43	0.55	-16%
MM5-E1	0.37	0.53	0.63	+28%
MC2	0.30	0.47	0.63	-32%
MM5-E2	0.36	0.53	0.63	-10%

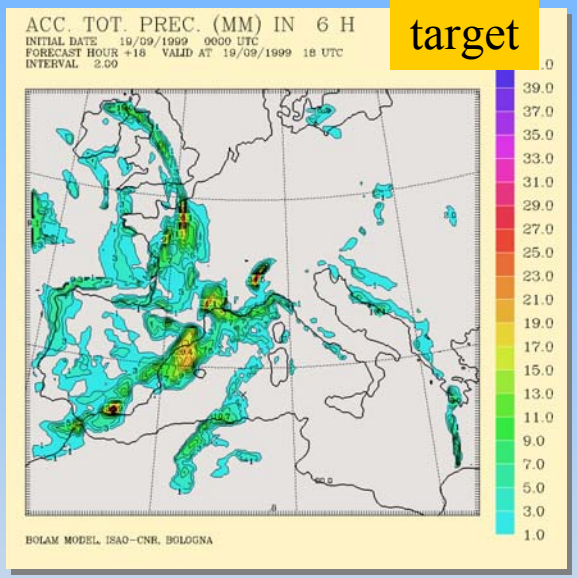
Table 1: Correlation coefficients between 1h, 6h, and 27h accumulated precipitation measured by the surface rain gauges and computed by the different models, and mean bias.



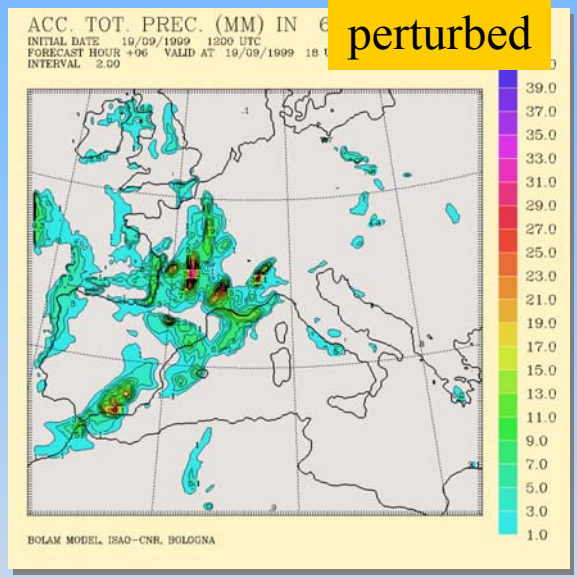
Perspectives...

- Assimilation of humidity and precipitation (from remote sensing):

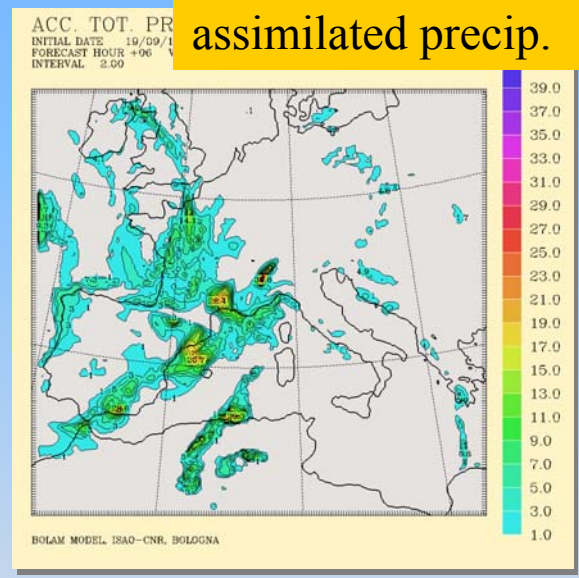
target



perturbed



assimilated precip.



- Predictability issues in the presence of orography and explicit convection, etc...