NUMERICAL EXPERIMENTATION BEFORE MAP

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Summary: The Mesoscale Alpine Programme (MAP) aims to better understand and forecast the three-dimensional circulation above and around the Alps and to study the orographically influenced heavy precipitation systems frequently occurring in the vicinity of the Alpine arc. This paper presents the numerical experimentation carried out to prepare the MAP field phase. The emphasis is put on the results of high resolution non hydrostatic models obtained for 2 MAP MAP selected cases that lead to damaging flash floods (Vaison la Romaine, Sept. 1992 and Brig, Sept. 1993).

1 THE MESOSCALE ALPINE PROGRAMME

The Mesoscale Alpine Programme (MAP) is joint research initiative between European and American scientists aiming to better understand and forecast the dynamical and physical processes that

- govern precipitation over major complex topography including hydrological aspects and
- determine the three-dimensional circulation patterns in the vicinity of large mountain ranges.

The strategy is to focus on key orographic mesoscale effects that are exemplified in the Alpine region (cf. MAP Design Proposal).

One of the core MAP topics relates to the study of orographically-influenced events of deep convection and frontal precipitation to ascertain their scale-interaction, internal structure and microphysical characteristics. Intimately linked to these atmospheric processes is the hydrological response of Alpine watersheds. The second relates to the consideration of the phenomena and processes that give rise to Alpine drag effects with particular regard to the role of three-dimensionality, transience, the boundary layer, cloud processes and the Coriolis effect. These core activities will be supported and complemented by related climatological studies and dynamical studies linked to Alpine aspects of climate and stratosphere-troposphere exchange.

The MAP is designed as a multi-year programme structured in three phases -an extended $\simeq$3 year preparatory period, a 13 -month field phase including a shorter intensive special observing period of 3 months (planned for 15 August-15 November, 1999), followed by an evaluation period. In Phase I activity will centered on the climatology of Alpine mesoscale weather systems, numerical experimentation and the detailed evaluation of the performance of current forecast models, the testing of new observing systems. This information base will serve to refine hypotheses on the pertinent phenomena and processes. It will concomitantly help to fine-tune the design and observational strategy for the field experiments of Phase II, which will be undertaken with a state-of-the-art range of instrumentation, and will involve the acquisition of specific and detailed data sets. Integral feature of Phase III will be the assembly and analysis of the observational field data, the testing of hypothesis, and the application of the results in the context of operational forecast models.

2 Numerical experimentation carried out during phase I

During MAP Phase I, numerical experimentation aims to evaluate the predictive skill of current weather prediction models on MAP events, to improve data assimilation and initial conditions of the models and to help the design of the field phase. More than 30 scientists are active in the MAP working group on numerical experimentation. A dozen of models (including 5 non-hydrostatic models) are currently used for MAP preliminary studies.

The activities of this working focus on the following tasks:

- Systematic forecast evaluation: The precipitation forecasts provided by four operational models (Aladin from Météo-France, from DWD, SM from SMA, and LAMBO from SMR/ER) will be analyzed and compared with the high resolution precipitation data set compiled by C. Frei. The period of comparison covers the August to November season of the years 1994 to 1997.

- Mesoscale data assimilation: At the meso-scale, data assimilation is a challenging research topic in itself and various methods with various levels of complexity (from pointwise observation nudging up to the 4 dimensional variational data assimilation) are and will continue to be investigated after the MAP field phase.

- Observing System Simulation Experiment: The potential benefit of a wind profiler network is being assessed in Switzerland. This study will also be used to define the optimal locations of the additional profilers that will be installed during MAP SOP. Simulations concerning the observation of mesoscale precipitating systems with ground-based and airborne Doppler radars is attempted using outputs from numerical models for MAP related cases. This study will help to precisely define the scaning characteristics with these radars and to determine the accuracy these measurements could give.

- Case studies Case studies taken from past MAP related episodes are performed to improve and fine tune the numerical models. 12 situations have been selected and documented by collecting all the available observations including non GTS data. They correspond to heavy precipitation episodes and/or foehn cases, both north and south of the Alps. The MAP modelers are strongly encouraged to work on these selected cases and to provide their model outputs in a pre-defined format to the MAP data center.[1]
- Set up of high-resolution real time forecasts : During MAP SOP, a special effort will be made to provide high-resolution forecasts to support the conduct of the experiment (e.g. aircraft mission planing). This will be achieved by nesting the MC2 Canadian fully non-hydrostatic model in the SM Swiss operational model with special products made available for the MAP operation center. The distributed-memory parallel version of MC2 will allow to cover an exceptionally broad area of order of of 1000 km x 800 km with a resolution of 2 km, including therefore most of the Alpine massif.

3 Case studies

3.1 Numerical setting

Two MAP selected cases, Brig and Vaison la Romaine, have been simulated with the non-hydrostatic MESO-NH model recently developed by CNRM and LA (Lafore et. al., 1997). The system of equations is based upon the anelastic formulation proposed by Lipps and Hemler (1982). The model has a fairly comprehensive physical package: ECMWF radiation, turbulence based upon the prediction of the turbulent kinetic energy, ISBA soil/atmosphere interface, explicit Kessler microphysical scheme, and Kain and Fritsch convection scheme.

A series of multiply-nested simulations with increasing horizontal resolution (50, 10, and 2 km) has been performed. The computational domains considered for the different simulations are shown in Fig. 1. At high resolution (2 km), clouds and precipitation were assumed to be explicitly resolved and the convection scheme was turned off. Initial and boundary conditions

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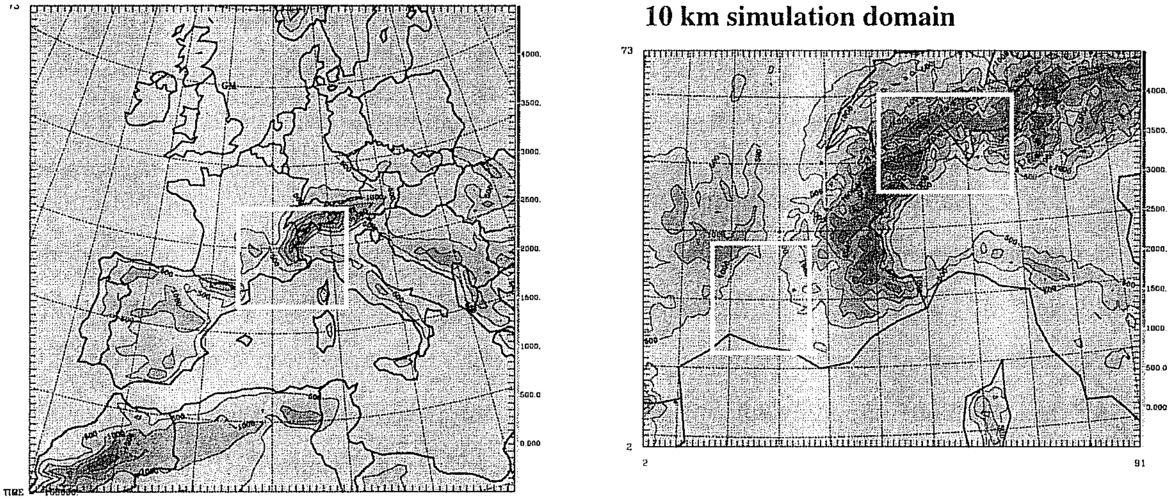
[1] The MAP data center is available at www.map.ethz.ch

50 km simulation domain

10 km simulation domain



2 km Brig simulation domain

2km Vaison simulation domain

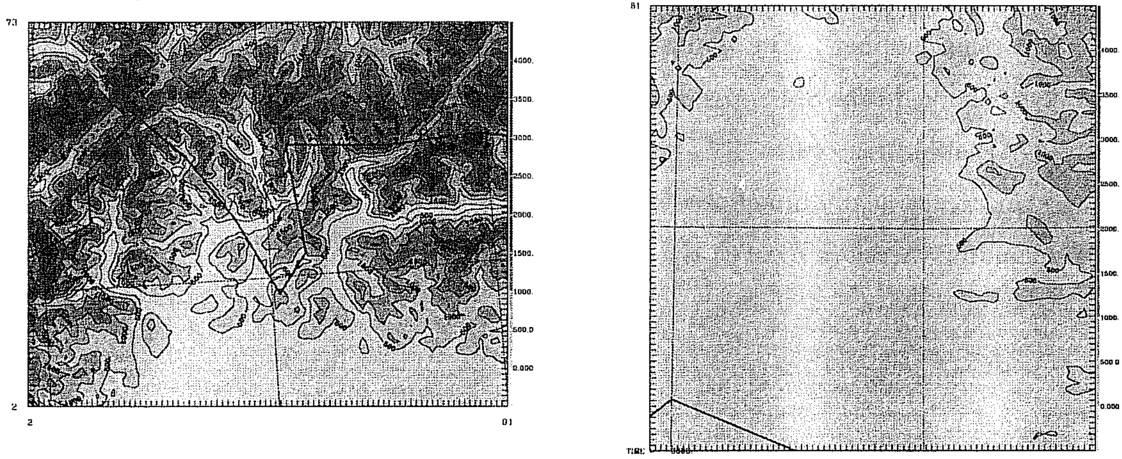


Figure 1: Computational domains used for the 50, 10 and 2 km simulations. The Brig domain is centered over the Lago Maggiore area at the Swiss-Italian border. The Vaison domain is centered over the Rhône valley in France.

for the 50, 10, and 2 km simulations were obtained by a temporal and spatial interpolation of respectively ECMWF analysis, 50 km and 10 km MESO-NH results.

3.2 The Brig flash flood

The so-called Brig episode lasted for three days (22-24 September, 1993). Heavy precipitation started over South-Eastern France and progressively moved eastwards to northern Italy, with quite exceptional amounts exceeding at some stations 300 mm in a few hours. The small city of Brig (South Switzerland) experienced a very damaging flash flood on the 24th, after 3 days of continuous and intense precipitation. Our study is focussed on the first day of the episode.

The synoptic analysis of September 22 shows a deep trough over Spain, moving slowly eastward, and evolving into a cut-off low located east of Valencia on the 23rd at 00 UTC. South eastern France is under a diffluent region associated with an upper-level jet streak exit. On the low levels a fast southern flow ahead of a cold front sustains on the region a strong advection of warm and moist Mediterranean air. These ingredients, combined with the topographical features of the area, makes the situation quite favorable to the development of strong convection. According to Barret et al. (1994), these conditions are the typical conditions encountered during most of the extreme rainfall events over south-eastern France.

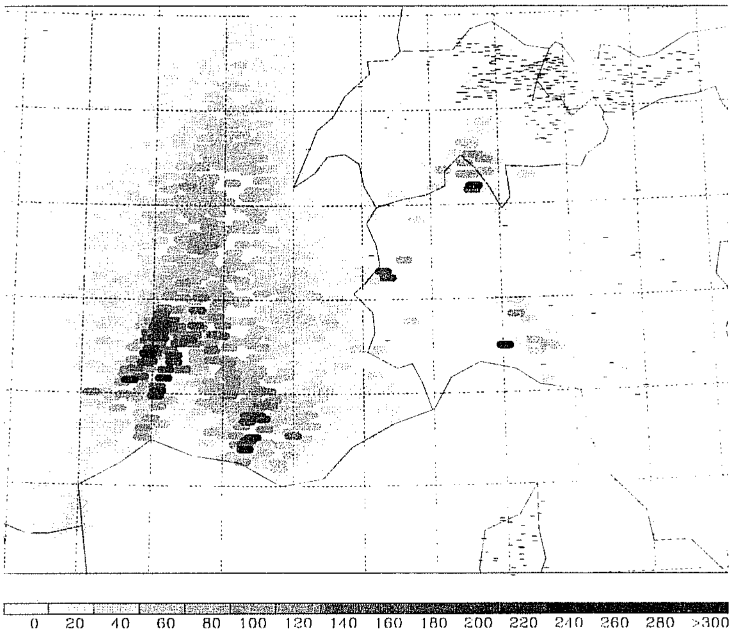
In the morning of September 22, a convective line forms on the West side of the Rhône valley and rapidly evolves into a V-shape regenerative convective system. This system remains quasi-steady from 9 UTC to 13 UTC, giving 200 to 300 mm of precipitation over the Cévennes mountains on the south-eastern flank of Massif Central. A second system develops slightly north east of the former one and remains very active between 12 UTC and 16 UTC, extending the area of strong precipitation. In the afternoon a third system forms above the Rhône delta at 17 UTC, moves slowly eastward and produces up to 250 mm of precipitation in the Marseille area.

Fig. 2 compares the observed 24h accumulated precipitation with the results of the 10 km simulation. The observations have been extracted from the MAP data high resolution data set. The data coverage is fairly dense except for Italy where most of the stations are still missing. The overall computed precipitation pattern is consistent with the observed one. The maximum over south-eastern Massif Central is well captured both in intensity and location. The maximum over South Switzerland seems reasonable although the lack of Italian data does not allow to assess its spatial extent to the South. However, there is a major failure in the simulation, the model misses almost totally the maximum that occurred over the Marseille area. This deficiency does not seem to be model-dependent. The MC2 Canadian model run at the same resolution over

24H ACCUMULATED PRECIPITATION (MM)
BRIG EPISODE: 22/09/93 06 UTC --> 23/09/93 06 UTC

930922 hres 06to06
24H CUMULATED PRECIPITATION (MM)

Observed



prec sim fmi00 2206 2306
24H CUMULATED PRECIPITATION (MM)

Computed

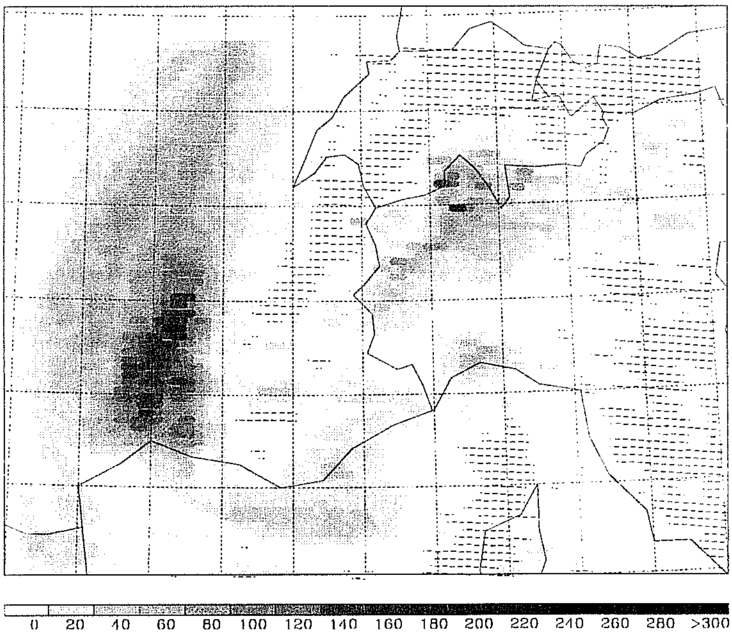


Figure 2: 24 h accumulated precipitation for September 22, 1993 (Brig episode), observed (top frame) and computed with the 10 km simulation (bottom frame).

a much wider domain produces very similar results. This point will further detailed with the second case study, but it seems that the beta-mesoscale models have difficulties in reproducing the migration of convective systems across the Rhône valley.

Fig. 3 presents the results of the most nested simulation. This simulation has been carried out with a 2 km resolution over a domain centered on the Lago Maggiore area, i.e. one of the two MAP target areas selected for the heavy precipitation objective. The figure compares the instantaneous computed precipitation rate with the Monte Lema radar image for Sept. 22, 15:00 UTC. The results are encouraging. The model was able to reproduce the location and organization of the convection. Moreover, comparison between animated model outputs and radar pictures shows a great similarity in the life cycle of the convective cells. The precipitating systems appear to be maintained by a discrete regenerative mechanism, with individual cells propagating north-eastward along the mean-flow direction.

3.3 The Vaison la Romaine flash flood

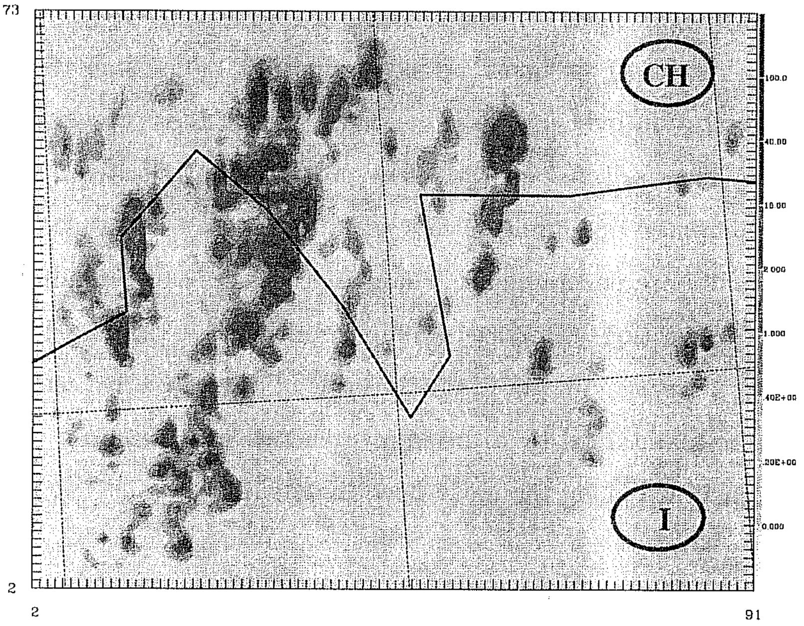
Late in the morning of 22 September, 1992, several mesoscale convective systems generated a flash flood in the city of Vaison la Romaine, France, on the southern foothills of the Alps. They produced 300 mm of rain in 24 h, reaching 220 mm in 3 hours in the vicinity of the city. Other places in South Eastern Massif Central also recorded very intense precipitation and damage but not to the level occurring around and in Vaison where 35 people died and hundred of houses were destroyed.

The Vaison situation has been extensively studied (Bénech et al., 1993; Sénési et al., 1995) by Météo-France. The Peridot operational forecast run with a 35 km grid mesh underestimated by a factor of 2 the total rain production, it caught the north western precipitation core (but largely underestimating the peak value 65 mm versus 300 mm) and missed completely the Vaison core. A second simulation performed with a research version of Peridot run at a 10 km resolution showed significant improvement, although the Vaison precipitation core was misplaced and overestimated by 50%.

Fig. 4 compares the observed 24 h accumulated precipitation with the 10 km MESO-NH simulations. MESO-NH gave about the same results than Peridot: two precipitation cores, one at the good location but the other one 40 km too far north west.

For this situation, the 2 km experiment seems to perform better. Fig. 5 shows the time evolution of the computed hourly accumulated precipitation between 9 and 13 UTC and can be compared with Fig. 6 where are shown the corresponding observations. At high-resolution, the model was

MESO-NH SIMULATION 22-09-93 15 UTC



MONTE LEMA RADAR 22-09-93 15 UTC

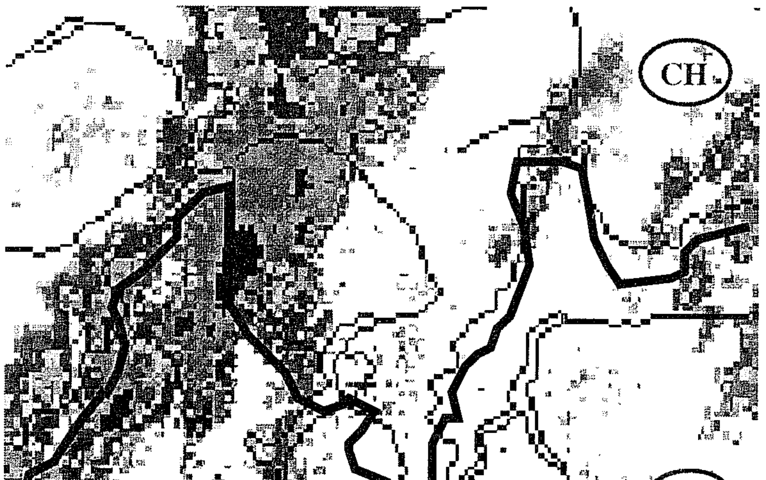
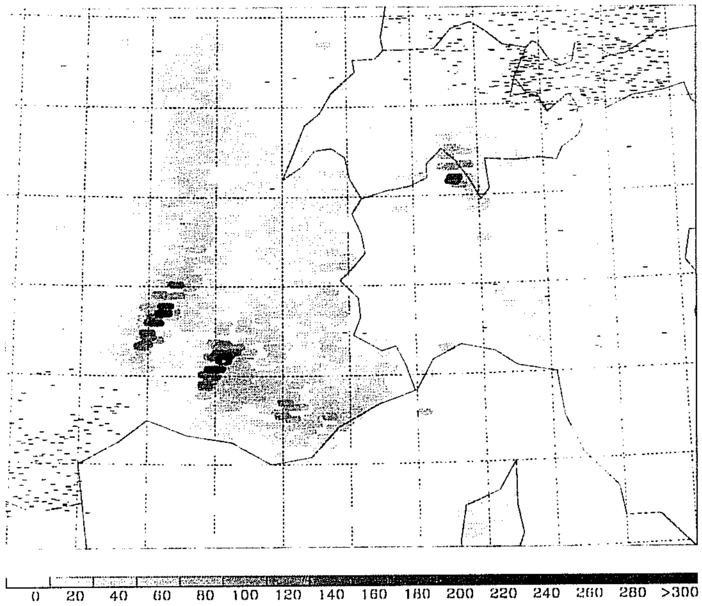


Figure 3: Instantaneous precipitation rate simulated with a 2 km horizontal resolution over the Lago Maggiore area at the Swiss-Italian border (top frame). Comparison with the Monte Lema radar observations (bottom frame) shows the model fairly well captured the location and the organization of the convective cells.

24H ACCUMULATED PRECIPITATION (MM)
VAISON EPISODE: 22/09/92 06 UTC --> 23/09/92 06 UTC

920922 hres 06to06
24H CUMULATED PRECIPITATION (MM)

Observed



prec sim blm01 2204 2222
24H CUMULATED PRECIPITATION (MM)

Computed

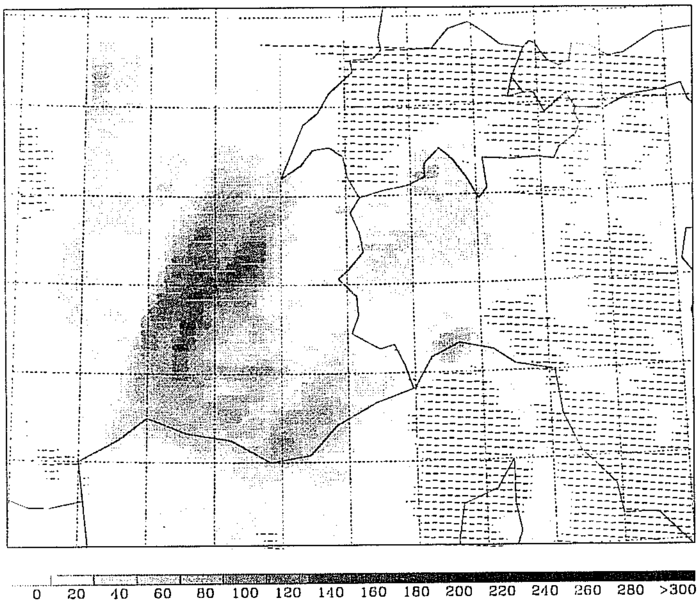


Figure 4: 24 h accumulated precipitation for September 22, 1992 (Vaison la Romaine episode, observed (top frame) and computed with the 10 km simulation (bottom frame).

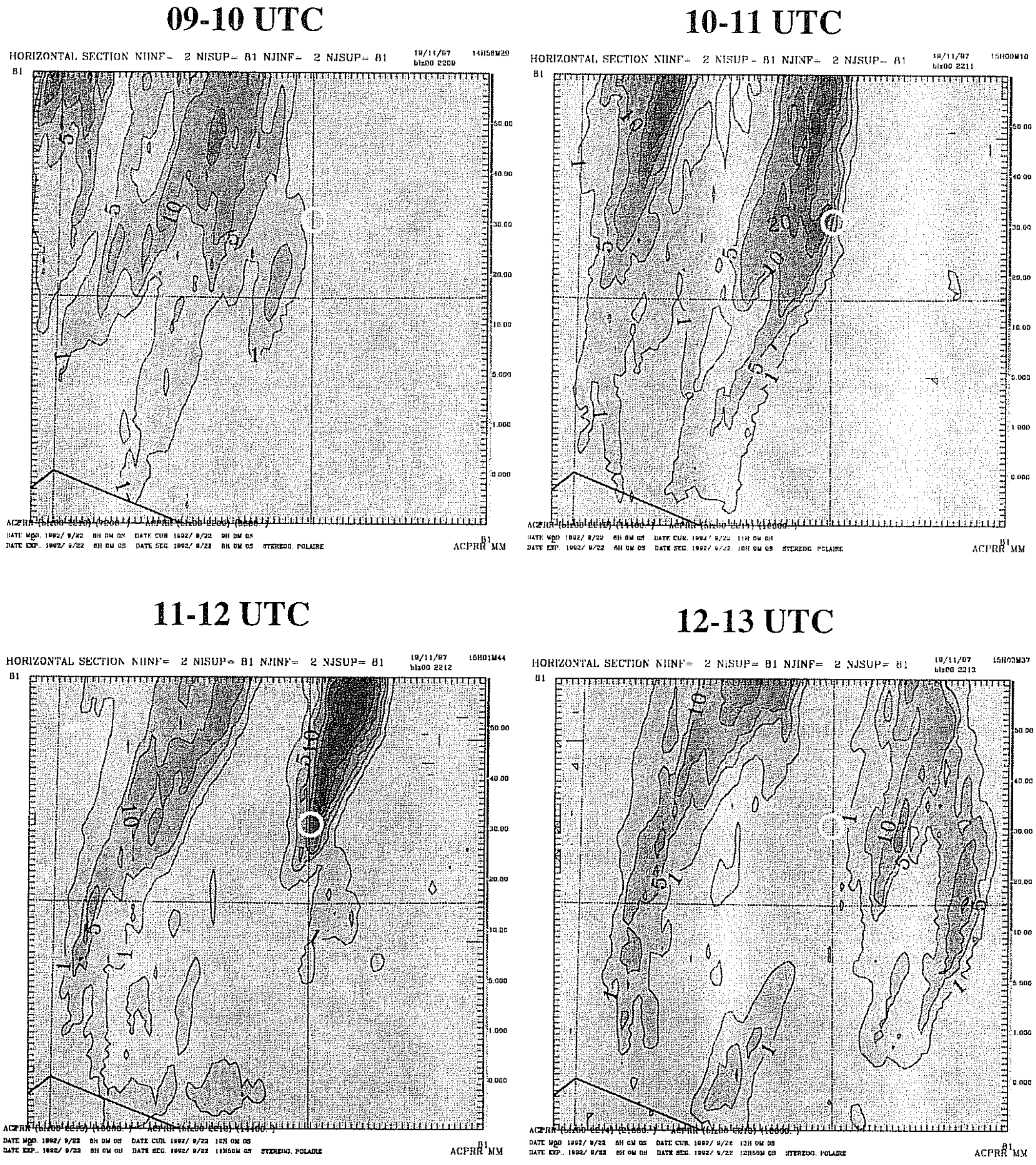
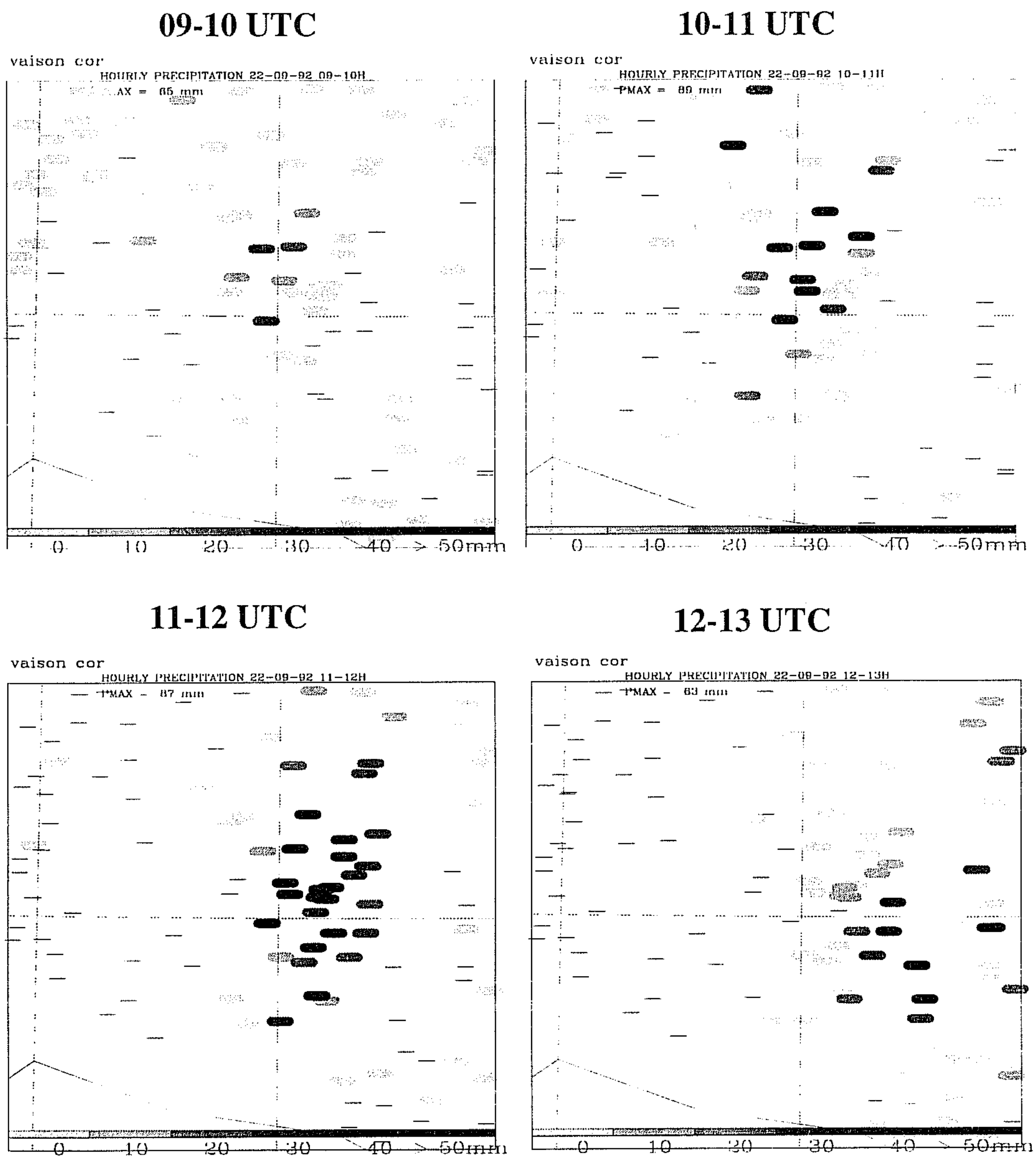


Figure 5: Time evolution of the hourly accumulated precipitation computed with the 2 km simulation. The white spot indicates the location of Vaison la Romaine.



hourly accumulated precipitation

Figure 6: Time evolution of the observed hourly precipitation rate.

able to capture the frontal convective line responsible of the largest rain accumulations over the Vaison area. The peak intensity occurs at the right time and the eastward propagation is fairly consistent with the observations. These results are quite preliminary, however they highlight the potentialities of nested high resolution simulations.

4 FURTHER NUMERICAL DEVELOPMENTS

4.1 Mixed phase clouds and precipitation representation

The explicit microphysical scheme of the model has been refined to account for mixed phase clouds and precipitation. The scheme now predicts the mixing ratio of six atmospheric water categories: water vapor, non precipitating and precipitating liquid water, non precipitating ice, aggregates and graupeln. Precipitating particles are assumed to be distributed according to generalized gamma functions. For each particle type, the mass-diameter and fall velocity-diameter relationships are expressed as power-laws that can easily be adapted to any specific type of hydrometeors. This large flexibility should allow to take the best advantage of the in-situ microphysical measurements that will be collected during MAP field phase. The multiple interactions operating between the different water categories are accounted for through the parameterization of 35 microphysical processes (nucleation, conversion, riming, melting, sedimentation, ...). A special effort has been devoted to simultaneously develop advanced diagnostics tools. On-line budgets are available for each water category allowing to evaluate the respective contribution of each microphysical process. Simulated radar parameters (e.g. reflectivity, Doppler velocities,...) are obtained as a by-product of the model outputs and will permit a more straightforward comparison with airborne or ground based radar observations.

This microphysical scheme has been extensively tested on different cloud systems with the bi-dimensional version of the model: an African squall line observed during the COPT experiment, and winter orographic clouds documented during SCPP over Sierra Nevada (Pinty et al., 1997). The scheme evaluation has been pursued in three dimensions on the two cases of Brig and Vaison la Romaine. The mixed phase scheme has been activated only for the 2km resolution simulations for which it is expected the strongest sensitivity to the ice phase.

Fig. 7 presents the results obtained for the Brig situation and illustrates the sensitivity of the results to the ice phase. When the ice is accounted for, the rainfall intensities are weaker but the downwind extend of the precipitation is significantly increased, modifying thereby the spreading of the rain over the different watersheds. Difference field between the ice and no-ice experiments

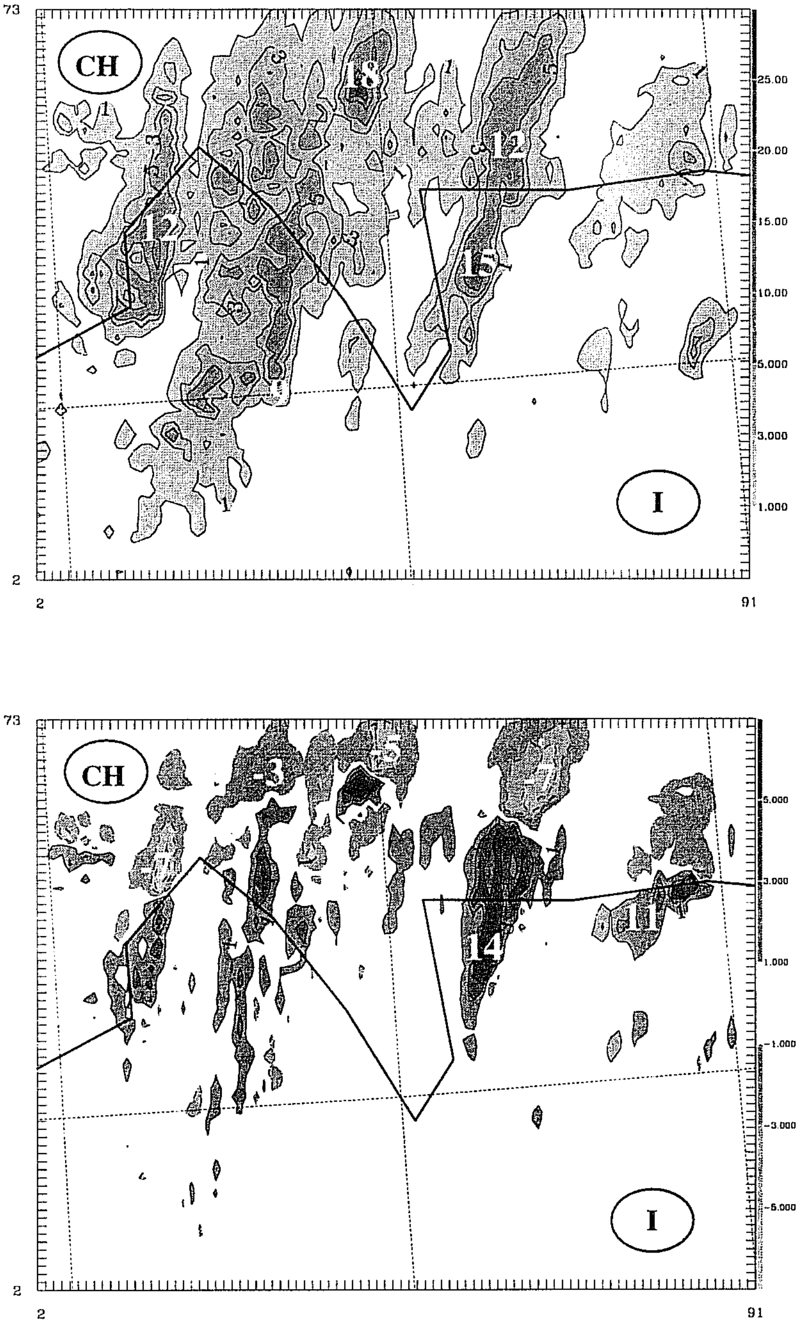


Figure 7: Simulated accumulated rainfall (in mm) for September 22, 1993, between 12 UTC and 15 UTC over the Lago Maggiore area. The top figure is obtained from a simulation including the ice phase. The bottom figure is the difference field between a simulation with ice and a simulation without ice. When the ice phase is not taken into account, the precipitation is overestimated upwind and underestimated downwind.

reveals that the precipitation is overestimated upwind and underestimated downwind by the warm microphysical scheme.

4.2 Grid nesting technics

This technic allows to simultaneously run several models of different resolutions The lateral boundary conditions can then be refreshed at every time step of the coarse grid model and not every hour or more as it was the case in the above simulations. Moreover, in the case of two-way grid nesting the small scale information generated by the most nested model can be sent back to the coarse grid model.

The technical development is now implemented in the MESO-NH model and preliminary tests are presently run for idealized cases of bi-dimensional trapped lee waves in order to be in a well controlled case where reflection or smoothing effects can be more easily seen, as compared to a real case. Some linear tests have been achieved without any numerical diffusion and indicates that the nesting procedure performs a good job.

The potential of this technics is clearly evidenced on Fig. 8. The upper part of the figure shows the results obtained over a 250 km domain with two different grid meshes, 4 km and 1 km. Only the fine mesh simulation captures the non-linear non-hydrostatic trapped lee waves extending downstream with a 12 km wavelength (Durran et al., 1995). A third simulation has been run in a nested mode over a 80 km sub domain centered over the mountain crest. Results are presented in Fig. 8d that has to be compared with Fig. 8b corresponding to the same resolution but to a much larger domain. The quality of the nested simulation is fairly good, the discrepancies do not exceed 5 %. It was not necessary to increase the numerical diffusion to smooth the results and no problem arose for resolution ratios greater than 2. These results could probably still be improved by allowing the fine mesh model to also interact with the coarse mesh model (two-way interactive grid nesting).

5 CONCLUSION

High-resolution nested models seem to have some potential for simulating heavy precipitating events. This modeling technic will be further investigate before and after the MAP field phase to determine up to what extend heavy precipitation events or foehn episodes are precdictable. More specifically, are we able or will we be soon able to provide accurate forecasts of - the hourly rainfall distribution over a 1000 km2 water shed, - the onset and time duration of foehn within a given valley, - the occurrence and location of gravity wave breaking?

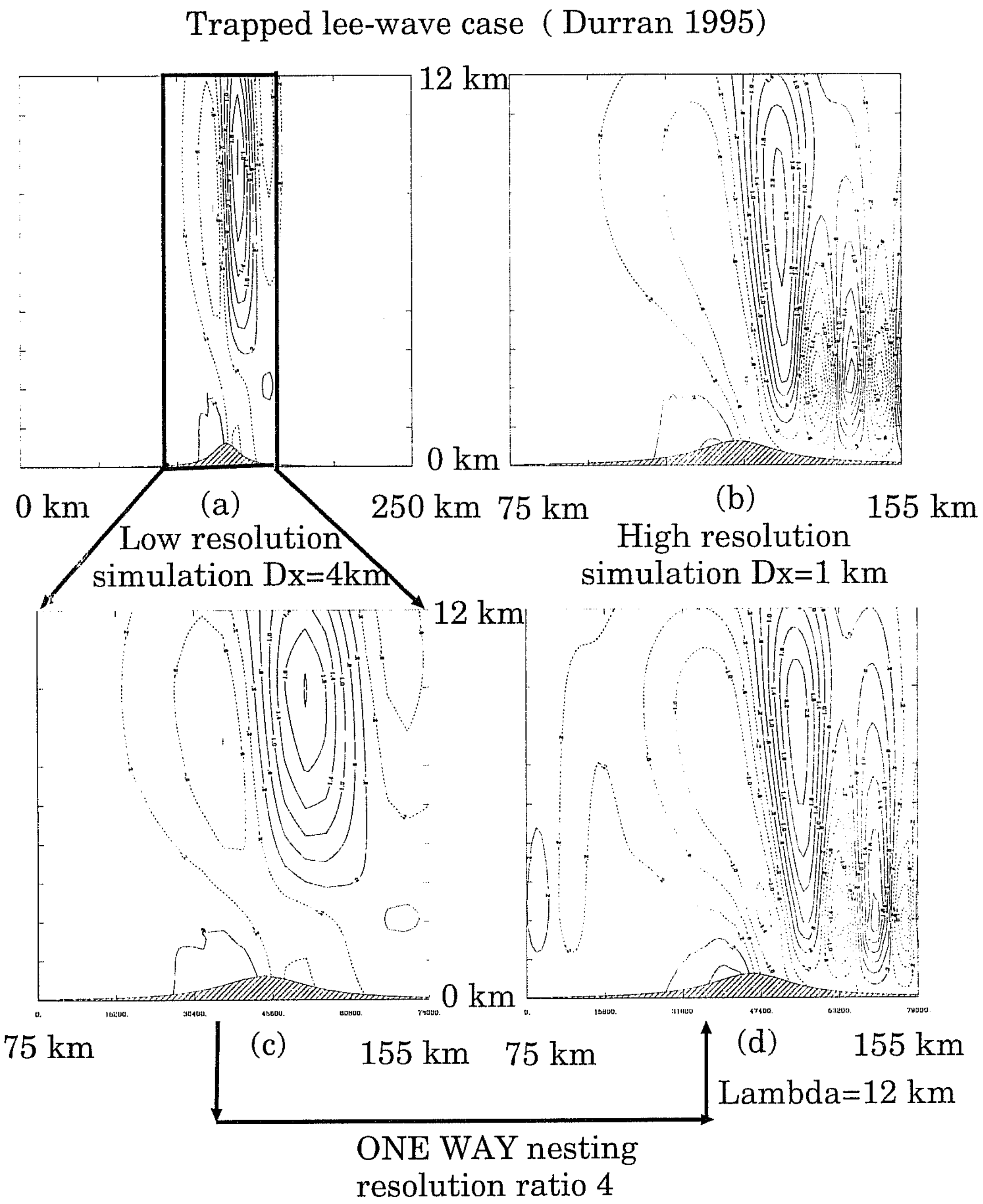


Figure 8: Vertical velocity fields obtained for the trapped lee wave case (contours every 0.4 m/s): a) coarse grid simulation ($\Delta x = 4km$) run over a 250 km domain, b) fine grid simulation ($\Delta x = 1km$) run over the same domain but shown in the central 80 km sub-domain indicated by the black rectangle, c) zoom of the coarse grid simulation over the central sub-domain, d) fine grid simulation run over the central sub-domain and nested in the coarse grid simulation.

References

Durran. D., 1995: Do breaking mountain waves decelerate the local mean flow? *J. Atmos. Sci.*, *52*, 4010–4032.

Barret I., V. Jacq, J.C. Rivrain, 1994: Une situation à l'origine de pluies diluviennes en région méditerranéenne. L'épisode orageux des 22-23 Septembre 1993 sur le Sud-Est de la France. *La Météorologie.* 38–60.

Bénech B., H. Brunet, V. Jacq, M. Payen, J.C Rivrain and P. Santurette, 1193: La catastrophe de Vaison la Romaine et les violentes précipitations de Septembre 1992: aspects météorologiques. *La Météorologie.* 72–90.

Lafore J.P. et al 1997: The Meso-NH Atmospheric Simulation System. Part I: Adiabatic Formulation and Control Simulations. *To appear in Annales Geophysicae*

Sénési, S., P. Bougeault, J.L. Chèze, P. Cosentino and R. Thépenier 1996: The Vaison-la Romaine Flash Flood: Meso-Scale Analysis and Predictability Issues. *Wea. Forecasting, 11* 417–442

Pinty J.P. & groupe de projet Meso-NH, 1997: Schéma microphysique pour les nuages en phase mixte dans Meso-NH: Description et résultats. *Atelier de Modélisation de l'Atmosphère Proc.*