**Doina BANCIU defended his thesis**

# Specific small-scale moist diabatic forcing in Aladin at the limit of the hydrostatic assumption

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## Introduction

The advancements of computing technology and research on atmospheric processes have allowed the use of higher and higher resolution in the numerical weather prediction models leading to more and more accurate forecast of meso-scale phenomena. The Aladin model, especially designed for the simulation of meso-scale phenomena, has been built in a very flexible manner, in order to be integrated over different domains within a large range of resolutions, from tens to 1-2 kilometres (in the case of the non-hydrostatic version). Nowadays it is run operationally in almost all the countries involved in the Aladin project at resolutions between 7 and 17 km, with the trend of increasing resolution to cover the needs of the national meteorological services.

It is generally recognized, that using of high resolutions is not sufficient for the simulation of the meso-scale phenomena. Depending on their scale, better-adapted physical parameterization schemes are necessary too. In this sense, the aim of this thesis was the tuning and improvement of the moist diabatic processes representation in the Aladin model at high resolutions, up to the limit of the hydrostatic assumption, supposed to be used for operational purposes. It should be underlined that the Arpege-Aladin system constitutes an ideal frame for the study of resolution dependency of the physical parameterizations; the two models shared the same physics and throughout their operational use it is easy to obtain information about the physical parameterization behaviour at different geographical regions and resolutions.

The moist diabatic processes in the atmosphere involve the phase transformation of the water. Between these processes, the deep convection is the most important one due to its influence on large scale circulation by the latent heat release, the vertical transport of mass, momentum, humidity and pollutants. Convection, especially when it is organized in meso-scale convective systems, is responsible for the most of severe weather events like intense showers, floods, squalls, thunderstorms and hail. Inside the cores of the convective updrafts (with vertical velocities that can exceed several meters per second) the vapour condensation occurs very quickly, leading to large concentration of cloud-condensed water and the dominant processes responsible for precipitation are coalescence and riming (Houze, 1997). Differently from convective precipitation, the stratiform precipitation is associated to the saturation in weak vertical motions, in the absence of instability to the vertical displacement (Bister, 1998), where the dominant process is vapour deposition.

In a numerical predication model the definition of the stratiform and convection precipitation contains some kind of ambiguity. Usually the grid-scale precipitation is considered stratiform and the convective precipitation is considered to be a sub-grid process. But convection can develop anvil clouds, with stratiform character, covering large areas. Also, depending on the model resolution, the convection can occur on the grid scale.

In the Arpege/Aladin model the precipitation parameterization is done by two distinct schemes. The convection scheme takes into account the sub-grid variability of the atmospheric fields and computes the condensation even in the absence of the saturation at the grid-scale. The stratiform (large scale) precipitation scheme considers the saturation departure at the grid point, eliminating the entire humidity surplus through precipitation.

In the thesis frame, the work has been concentrated on the convection parameterization scheme, as one of the most resolution depending scheme and only few attempts have been made to introduce a prognostic equation for the condensed water. The problem of the partition between the convective and large-scale precipitation has been especially addressed.

## The deep convection parameterization scheme

For the parameterization of the deep convection, the Arpege/Aladin model uses the mass flux type Bougeault scheme (1985). When starting the work on the thesis, the scheme contained only small modifications, determined by its implementation in the specific frame of the model (Geleyn et al, 1994):

1. use of the semi-implicit algorithm and of a protection against non linear instability for mass-flux type computations;

2. introduction of a variation with the height of the entrainment rate, starting from a maximum value at the bottom and relaxing exponentially towards a minimum value at the top in order to simulate the fact that thinner clouds entrain proportionally more than deeper clouds;

3. use of the Arpege/Aladin specific thermodynamic framework for precipitation fluxes;

4. consideration of the sub-cloud evaporation but without any impact on the mass-flux (hence it is not equivalent to a downdraft parameterization);

5. introduction of the distinction between ice and liquid phases of the falling precipitation.

The problem of the resolution dependency (i.e. the double count of the precipitation when increasing resolution, more and more precipitation represented by the convective parameterization being also diagnosed by the large scale precipitation scheme), was partially cured by a modulation of the humidity convergence used in the Kuo-type closure assumption by a factor depending on the resolution (following the results of Piriou, 1991).

During last years, the diagnostic convection scheme proposed by Bougeault in 1985, originally orientated towards large scale, was, step by step, enriched with specific features of meso-scale parameterizations. A series of modifications of convection parameterization was implemented operationally in 1999 and 2000, in the so-called CYCORA and CYCORA-bis (CYclogenesis COnvection RAdiation) packages together with other modifications concerning the dry turbulent transport and radiation. The part of convection (well described by Luc Gérard in the physical parameterization documentation) inside these packages refers to:

1. **The introduction of the convective downdraft parameterization** following the Ducrocq and Bougeault scheme (1995).

2. **The improvement of the convective momentum transport** by:

a. Introduction of the entrainment term.

b. Tacking into account the vertical wind shear, i.e. the cloud-environment pressure difference (Gregory et al, 1997, Kershaw and Gregory, 1997). The wind computation is carried out only for the active layers ("CAS" approach - Connex Active Segments, see Gérard, 1998).

3. **The modification of the moist adiabatic computation** by:

a. Allowing a continuous transition between «equi-geopotential»; and «equi-pressure»; treatment (Bellus, 1999);

b. Taking into account the moist adiabatic capacity of reaching the lifting condensation level and introducing some kind of penalty for dry atmosphere;

4. **The amelioration of the updraft profile** by introducing:

a. The modulation of the entrainment rate by the cloud buoyancy;

b. The "ensembling" entrainment

c. The enhancement of the detrainment rate at the cloud top.

5. **The treatment of the turbulent fluxes** by introduction of a symmetry in the averaging manner of the humidity and enthalpy turbulent flux but with different scaling

6. **Limitation of the available humidity convergence for convective updraft parameterization** by substracting the large scale precipitation

7. **The possibility to use a CAPE based closure assumption** for the evaluation of mass flux, but the operational version uses the closure based on the humidity convergence,

where modifications 1, 2b, 3a, 4a,c, 6 belong to CYCORA package and 3b, 4b and 5 to CYCORA-bis.

The actual moist convection parameterization scheme, used operationally in Arpege and Aladin models, is the result of the common effort of the members of the Arpege and Aladin teams. The author of this thesis has worked on the development of some of the involved modifications, contributing mainly to the introduction of convective downdraft parameterization (Banciu and Geleyn, 1998 a, b, 1999), of a entrainment rate modulated by the cloud buoyancy (Banciu and Geleyn, 2000), of a variable detrainment rate for the convective momentum transport and also to a solution of the resolution dependency (Banciu, Gérard and Geleyn, 1999) and for the treatment of the turbulent fluxes of dry static energy and humidity. It should be mentioned that despite of the included modifications, the Bougeault scheme keeps its numerical efficiency; a re-organization of the code scheme was necessary at a certain moment, which has been carried out by the author.

The modifications validation and the tuning of the free parameters of the whole package represent an important part of the work around this thesis, using the 1d, 2d and 3d versions of the Arpege and Aladin models, tacking into account the most recent developments of other parts of the models.

## Simulation of the meso-scale convective systems

The simulation of the meso-scale convective systems constitutes a real challenge for any numerical prediction model. Deeply linked to the convection parameterization, the realism of the simulations will reflect the quality of the used scheme. The ability of the Aladin/Arpege model to simulate such systems has been tested for well-documented situations in those development the convective downdrafts and vertical shear play an important role: TOGA-COARE squall line of February 22, 1993, the flush flood over south-eastern France of September 22, 1992 (the "Vaison la Romaine" case), the squall lines of June 7, 1987 (over southern France) and of July 22, 1992 (the "Cleopatra" case, over Southern Germany,

The impact of every modification of the convective parameterization was firstly assessed in the 1d version of the model for the TOGA-COARE squall line. The strategy developed by Redelsperger and Bechtold (1999) has been used for the initialization and model forcing. Several diagnostics like temperature and humidity budgets, temporal variation of the mass flux and precipitation, apparent heat source and humidity sink, have been used for the results evaluation. As an example, the temperature and humidity tendencies using the operational scheme before October 1999, the modifications included in CYCORA and CYCORA-bis are presented in figure 1.

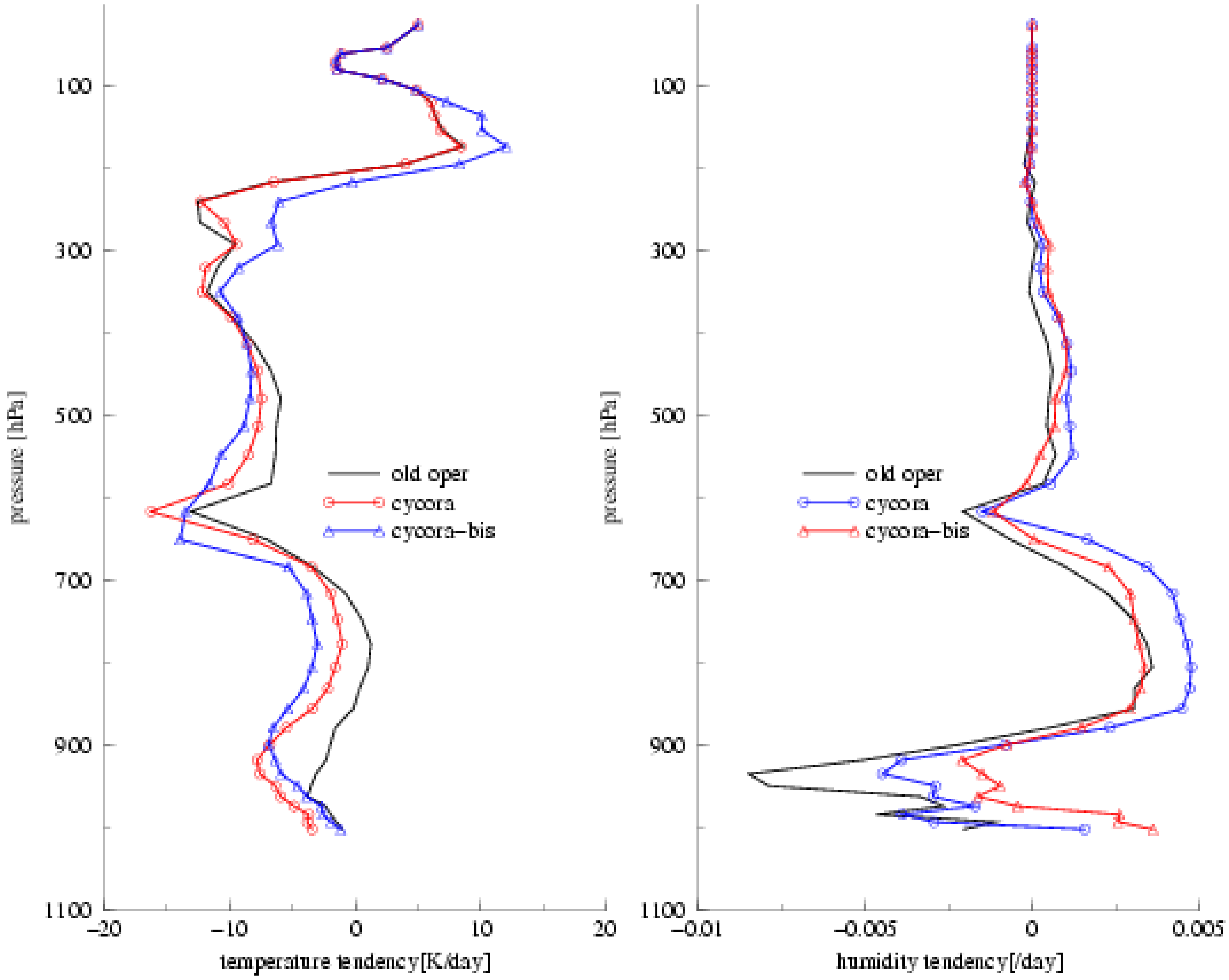

*Fig. 1 The temperature and humidity tendencies for simulations using the old operational scheme ("old oper"), the CYCORA ("cycora") and CYCORA-bis ("cycora-bis") packages.*

The results of the simulations have been compared with the output of the resolving cloud model of Redelsperger and Sommeria as well. Even with the inherent limitations, the 1d model was successfully used for the evaluation of the convection parameterization scheme.

For the 3d simulations a successive nesting was applied to obtain the desired resolution: Arpege / Aladin 12.7 km / Aladin 7.3 km. The results have shown that the Aladin model is able to simulate the meso-scale convective systems (like quasi-linear system, frontal lines, squall lines) if the resolution is sufficiently high.

For the squall lines, the simulation accuracy have varied form one case to another (as one could expect taking into account that scale separation depend on the synoptic situation) : from the squall line absence in the simulations in the Vaison la Romaine case, to its delayed appearance in the July 7, 1987 case, up to a quite satisfactory evolution in the Cleopatra case. The found deficiencies (delay, wrong position, smaller surface wind velocity and temperature drop) could be partially explained by the insufficient quality of the initial state, mainly the poor representation of the humidity field. The best results have been obtained for the Cleopatra case, when the squall line developed over the continent, where the data density and quality was quit satisfactory.

The downdraft parameterization has a beneficial effect but under the expected level and quite difficult to evaluate. In the Vaison la Romaine case, even in the presence of the downdraft parameterization, it was not possible to simulate the squall line, which played a major role in the convective systems development leading to flood. However, a slight amelioration of the position and form of the precipitation areas was obtained. In the other cases the downdraft parameterization led to a quicker displacement of the squall line and to the intensification of the vertical velocity nuclei, associated with the squall line.

Also, the improvements of the convective momentum transport parameterization have positive effect trough intensification of the ascending velocity maximum and to the decreasing of the level when this maximum occurs. The use of the CAS approach is very important, its impact being even greater than those of wind shear consideration (Banciu and Bellus, 2000).

It seems that the limitation of humidity convergence by large-scale precipitation substraction can change dramatically the results. When it was used together with the humidity convergence modulation, a more realistic precipitation field was obtained for the Cleopatra case. Also more marked and stronger vertical velocity nuclei were noticed.

The use of the CYCORA package for the Cleopatra case simulation has shown an improvement (a more realistic precipitation and vertical velocity fields) but not very substantial (a too fast displacement of the squall line) when compared with the simulation using the old operational convection scheme (see figure 2 and 3 in comparison with the real satellite and radar data in figure 4).

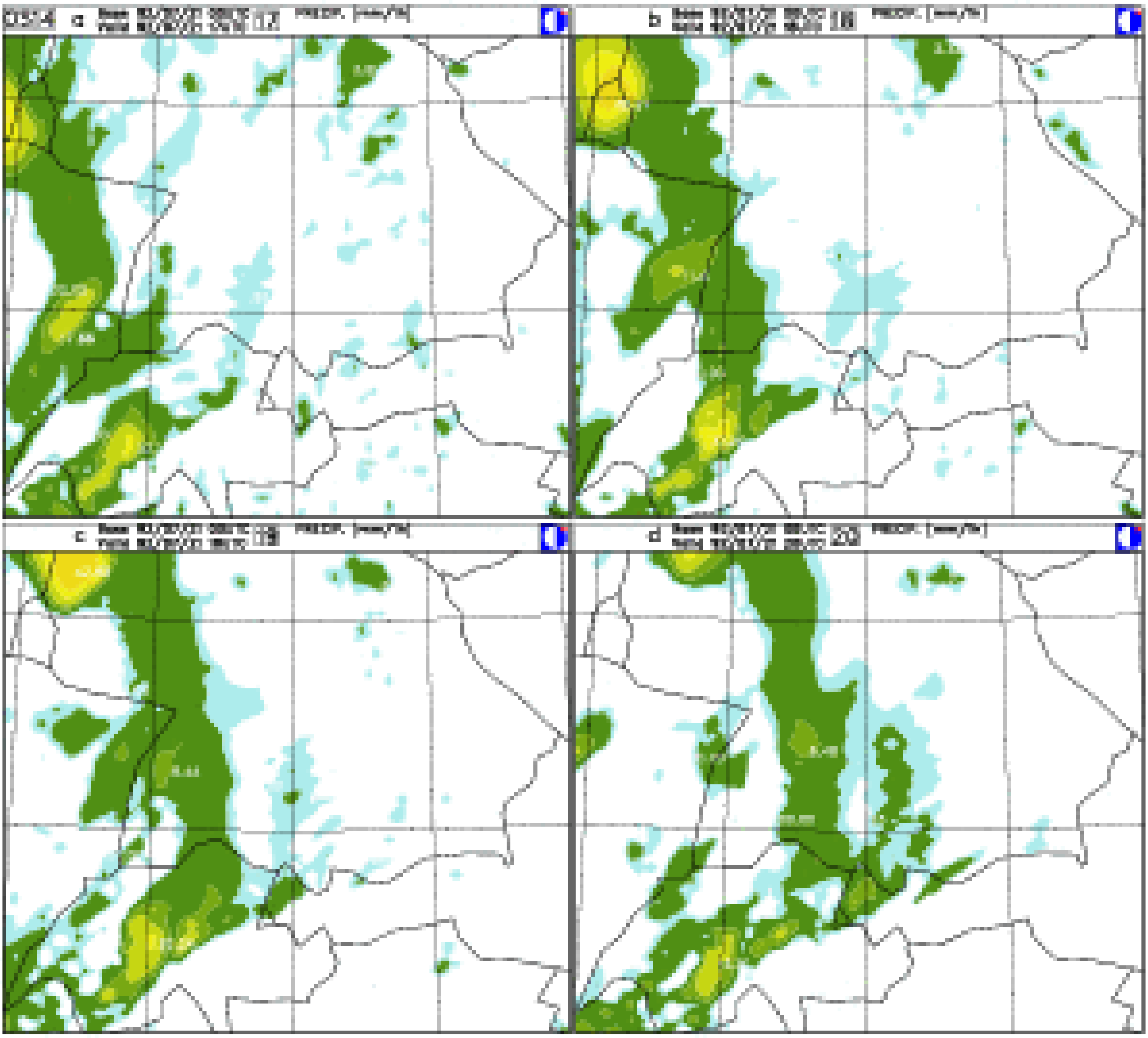

***Fig.2*** *One hour cumulated precipitation for a simulation using the operational convection parameterization scheme before October 1999, July 22, 1992, 17-20 UTC*

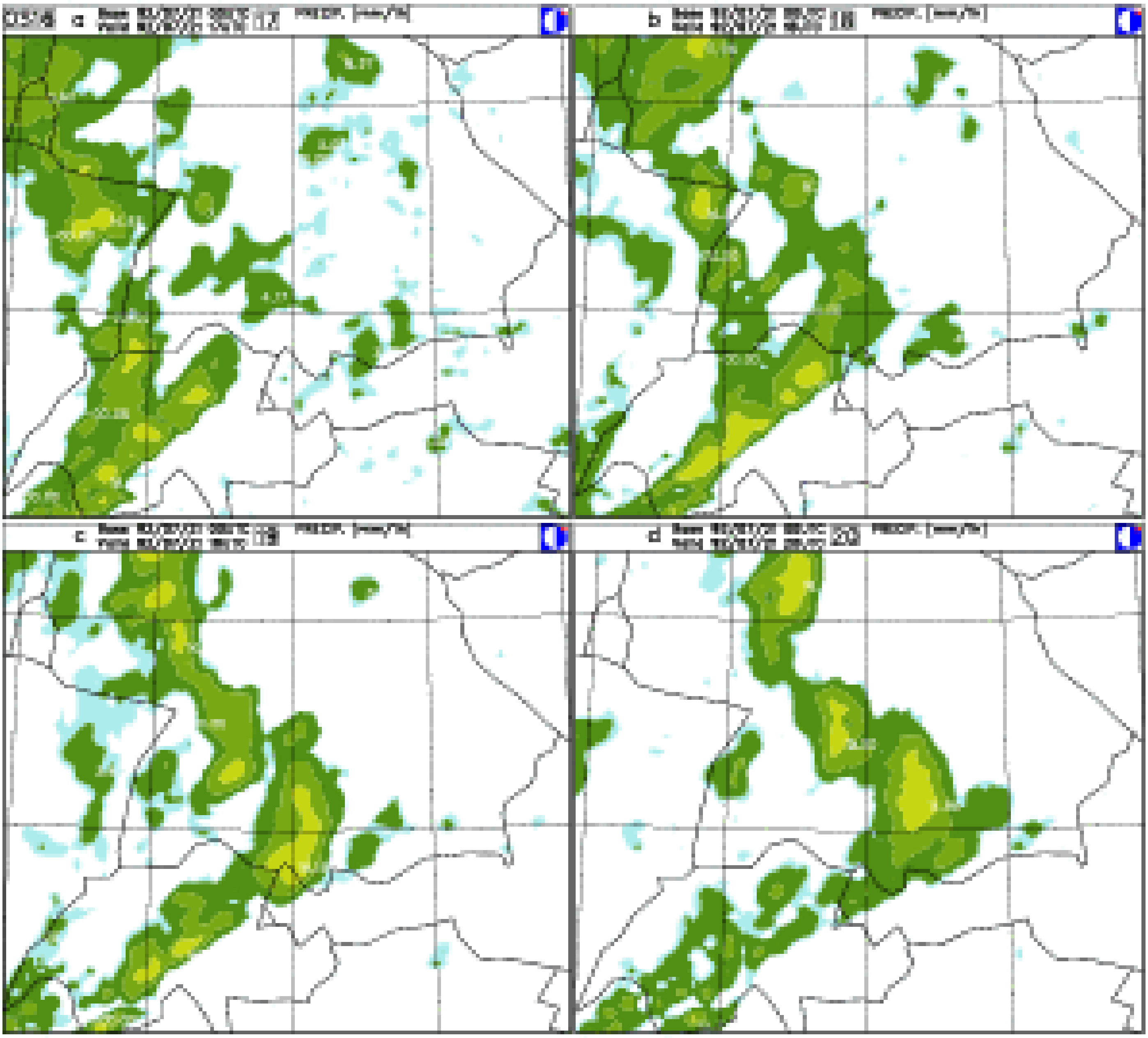

***Fig.3*** *One hour cumulated precipitation for a simulation using the CYCORA package, July 22, 1992, 17-20 UTC*

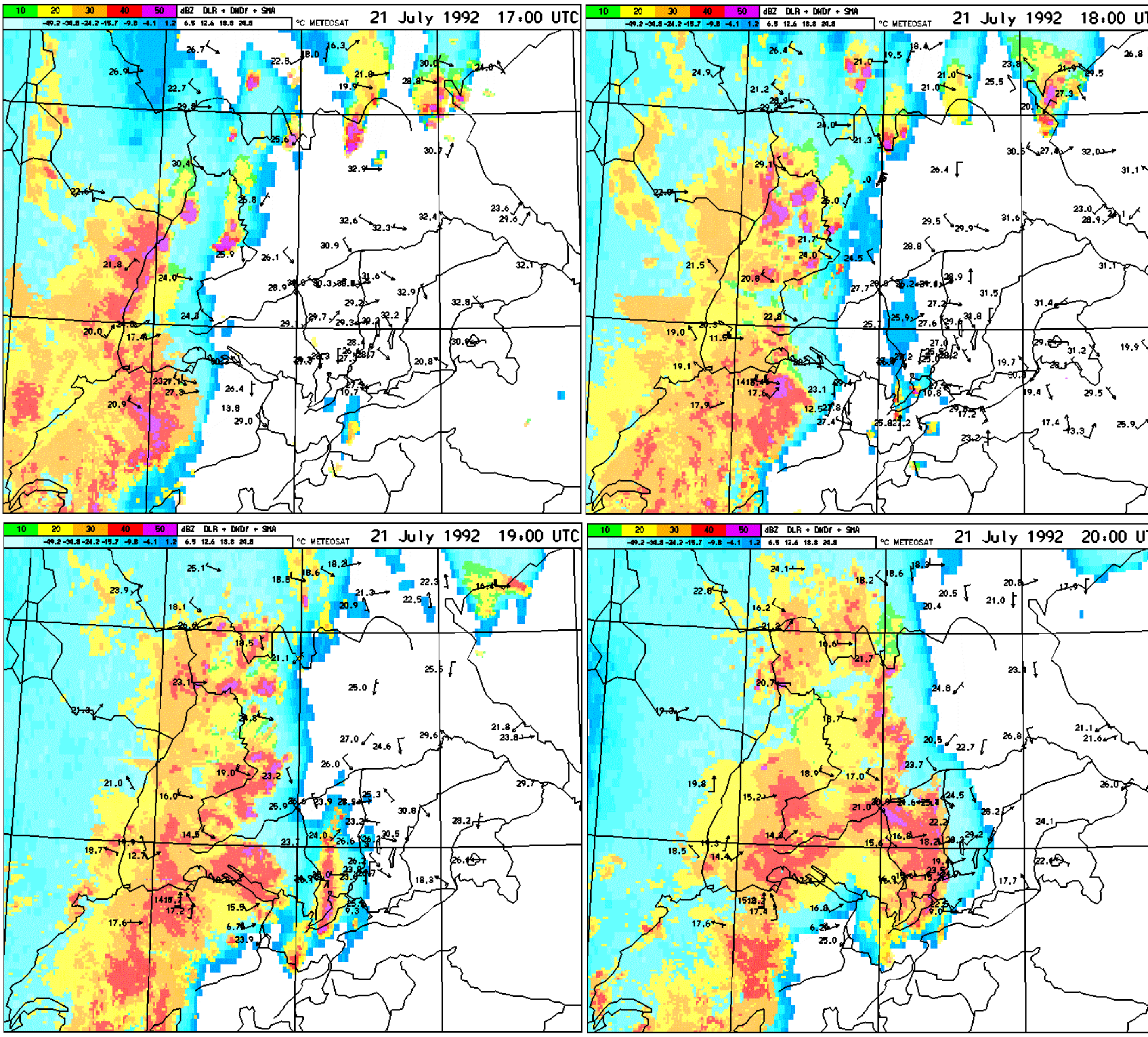

***Fig.4*** *Composite of METEOSAT infrared images and radar reflectivity for July 21, 1992, 17-20 UTC (after Finke, U. and T. Hauf, 1997).*

It should be mentioned that, inside this experiment, the boundary lateral conditions were obtained with the old convection scheme and there was no an assimilation cycle for the global Arpege model. The French colleagues have underlined the importance of the CYCORA package used inside the assimilation cycle in the case of the Christmas Storm of December 26, 1999, for which remarkable results were obtained. On the other side, one should be aware that the operational tuning of CYCORA package is a kind of a compromise between a better representation of the tropical convection and a more realistic simulation meso-scale convective phenomena, using the same free parameter tuning for the Arpege global model and the limited area model, Aladin. The further use of CYCORA-bis package for the simulation of the same case have not cured the deficiencies of the CYCORA simulation: the better representation of the quasi-stationary convective line, pre-existing ahead the squall line was lost and the precipitation field was more fragmented (see figure 5). Opposite, a more realistic structure of the vertical velocity field was obtained.

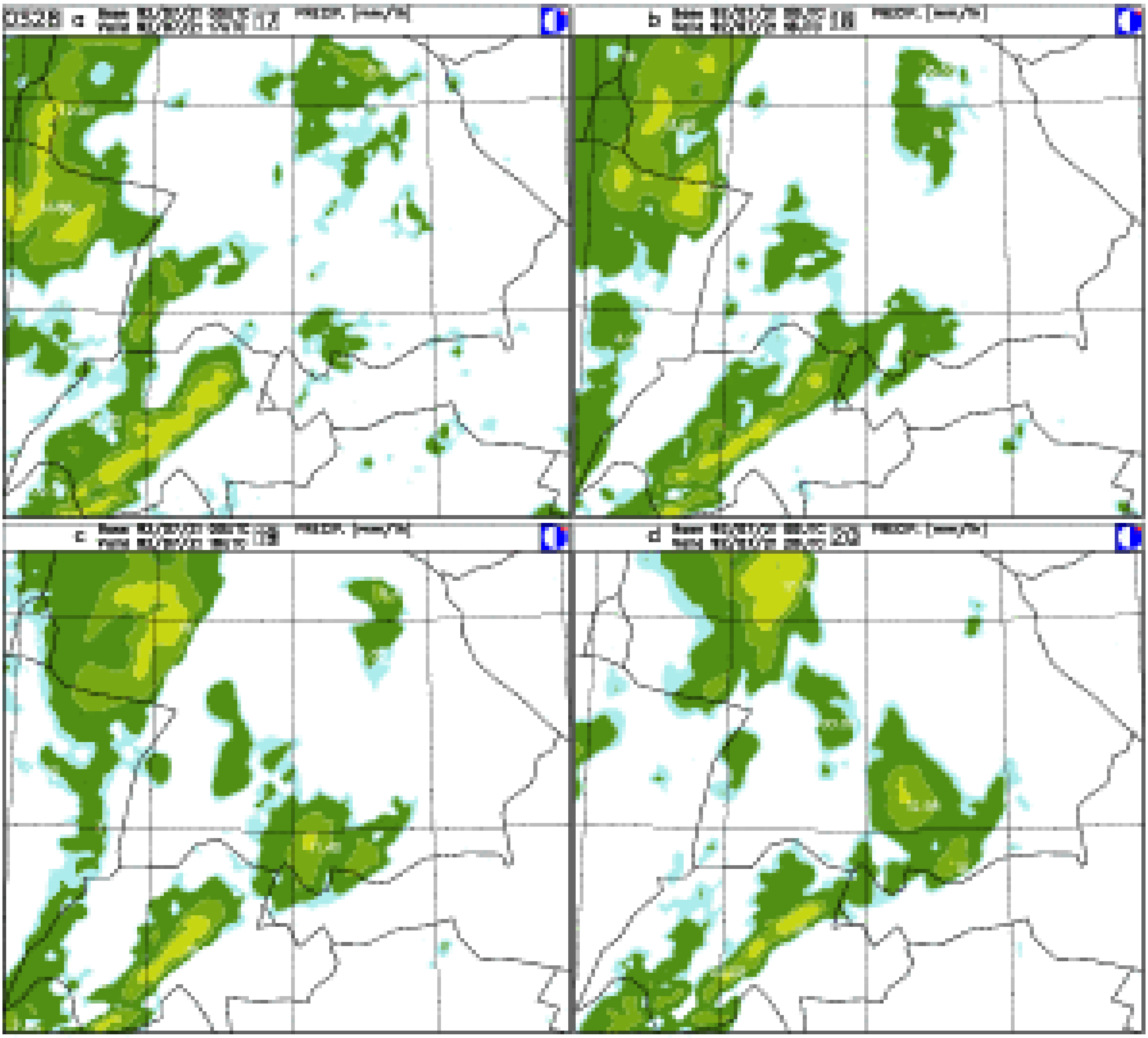

***Fig.5** One hour cumulated precipitation for a simulation using the CYCORA-bis package, July 22, 1992, 17-20 UTC*

The impact of the non-hydrostatic effect was not too big. Only a smaller influence of the taking into account the cloud-environment pressure difference and a slight decrease of the level of the maximum vertical velocity were noticed.

Besides the problems of the quality of the initial data and of the common tuning for the global and limited aria model, other fundamental problems appear by increasing resolution, the Bougeault scheme not being initially designed for meso-scale models. Some of the closure assumptions, like the existence of the quasi-equilibrium between the cloud and the environment lose their viability. The equilibrium between the large scale-forcing that destabilizes the atmosphere and the convection development that removes the unstable layers is realized in so called convective adjustment time. For large characteristic time of the large-scale forcing, the adjustment can be considered instantaneous, what represent in fact the quasi-equilibrium hypothesis. For a fast variation of the large-scale forcing, this hypothesis is not valid any more and the convection parameterization can be done by using the values of the large-scale parameters at a given moment. Some parameters characterizing convection, as mass flux or fraction area covered by clouds should become prognostic variables. Such a prognostic development of the Bougeault scheme has been already carried out by Luc Gérard (2000).

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