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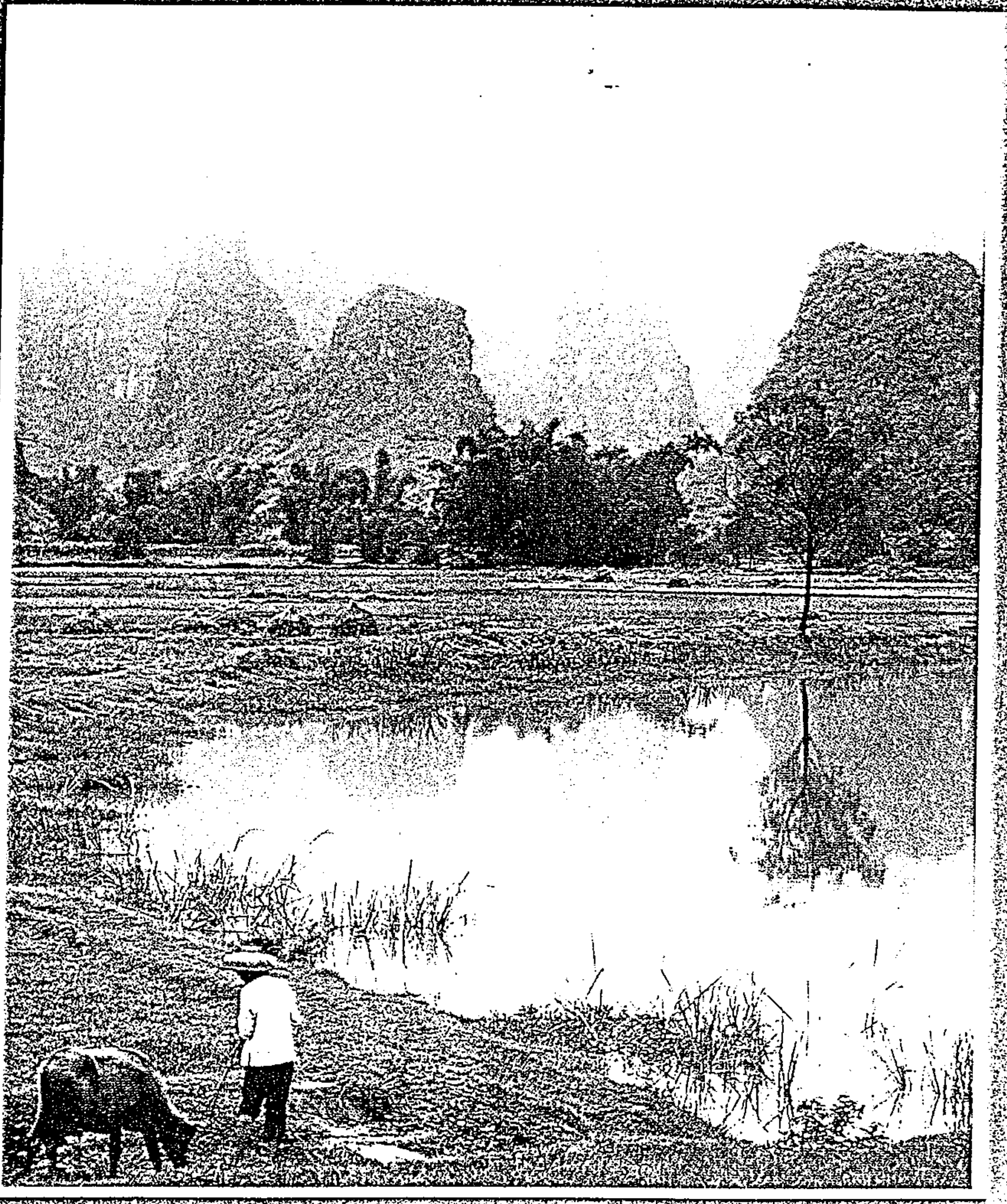

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THE ALADIN PROJECT: MESOSCALE MODELLING SEEN AS A BASIC TOOL FOR WEATHER FORECASTING AND ATMOSPHERIC RESEARCH

by members of the ALADIN international team

Introduction

The acronym ALADIN (*aire limitée adaptation dynamique développement international*) describes several facets of an international project (for limited area mesoscale modelling) involving as many as 110 persons from the 14 national Meteorological Services (NMSs) of Austria, Belgium, Bulgaria, Croatia, the Czech Republic, France, Hungary, the Republic of Moldova, Morocco, Poland, Portugal, Romania, Slovakia and Slovenia. We shall first describe the four "vital" characteristics of this project, before making a more in-depth analysis of its historical, organizational, scientific and technical aspects.

The concept

While it is generally accepted that today's numerical weather prediction (NWP) requires international collaboration and that a model of cooperation between NMSs of differing technological levels must be mutually beneficial, despite the obvious imbalance, the combination of the two ideas had apparently never been proposed before. Yet, such is the backbone of the ALADIN concept: NMSs with less experience in operational NWP bring their scientific know-how and a fresh view of NWP problems while *Météo-France* ensures the organization of the project and its links with advanced technologies; this distinction will become less and less pronounced as the project progresses. All partners accepting the rules of the project are, by definition, equally free to benefit from the fruits of the common work for both research and operational applications.

The system

ALADIN was entirely built on the notion of compatibility with its "mother" system, IFS/ARPEGE. The latter, a joint development between the European Centre for Medium Range Weather Forecasts (ECMWF) and *Météo-France*, was only meant to consider global NWP applications; hence the idea, for ALADIN, to complement the IFS/ARPEGE project with a limited area model (LAM) version, while keeping the differences between the two softwares as small as possible. It was, therefore, absolutely necessary to copy the organization of the code from one system to the other. The key words for this organization are *integration* (all applications are developed and maintained inside a single software piece); *flexibility* (as many options as possible available on simple manipulations of unformatted input files); *modularity* (one function = one single piece of code); and *generality* (as few restricting assumptions as feasible, both for the science and for its algorithmic transcription). Furthermore, the duality between ARPEGE (global with the possibility of variable resolution) and ALADIN (LAM), sharing the same grid-point dynamics and physics, is a formidable advantage for tackling the NWP challenges of the coming years at high resolution. For example, inside the two projects, advanced (variational) data-assimilation aspects have mostly been tackled in the global framework, while high-resolution aspects (non-hydrostatism) were explored in the LAM framework, always keeping open the possibility of transfer from one side to the other. The strict application of the integration-flexibility-modularity-generality (IFMG) rule inside the ALADIN part of the work is now a rather well-established practice. Of course, the compatibility with IFS/ARPEGE complicates matters. There are, for instance, four types of ALADIN routine: those common with IFS/ARPEGE (e.g. physics or grid-point dynamics); those duplicating the scientific functions of one IFS/ARPEGE routine in the LAM framework (e.g. spectral computations); those duplicating the controlling functions of one identically named IFS/ARPEGE routine (e.g. organization of one time step); and those specific to ALADIN (e.g. coupling with larger-scale information). This complexity is especially penalizing for the crucial maintenance process, which is copied from the IFS/ARPEGE one, i.e. it is organized around "cycles" (fully validated releases every six to nine months). Currently, the IFS/ARPEGE cycle 17 exists, as well as the ALADIN cycle 7, the latter being phased with cycle 16 of ARPEGE. The difference of 9 between the numbers simply reflects the fact that the ALADIN project was launched roughly four years after IFS/ARPEGE. The help of ECMWF staff in solving these complex problems is gratefully acknowledged here.

The use of configurations

Five are currently fully validated (the number is likely to increase in the near future, given the momentum of the project): (*a*) the creation of the "geographical" conditions for any given geometry of the LAM, anywhere on the globe; (*b*) the creation of initial and/or lateral boundary conditions starting from an ARPEGE or an ALADIN file; (*c*) the optimal interpolation analysis module nicknamed CANARI; (*d*) the model integration itself (with its digital filter initialization (DFI) option); and (e) the fully compatible post-processing Full-Pos (itself not an independent configuration but a variant of one (*d*) time-step).

The advantage of this structure is that all these applications can be driven from a single "object" version of the code, for any localization, geometry, number and spacing of vertical levels, etc., with the implicit certainty that all these characteristics will be compatible with all consecutively employed configurations, as well as the definitions of basic constants (gravity, radius of the Earth, gas constant, etc.) and of thermodynamic functions (saturation pressure and derived expressions). Contrary to the above-mentioned maintenance problem, which required much individual investment for a few key persons, this advantageous simplified use of the code (simple unix-scripts) was a bonus for a project that needed to involve many part-time ALADIN scientists (average presence in Toulouse = 25 per cent of that of the "standard" team member).

The multiple applications

At the time of writing, ALADIN is in a pre-operational or operational state for five applications (see map of participating countries and domains of integration in Figure 1):

- At *Maroc-Météo*, full LAM application including data assimilation, 16.6 km mesh, 169 x 169 points, 27 levels;
- At *Météo-France*, fine-mesh dynamical adaptation forecasting, 12.7 km mesh, 189 x 189 points, 27 levels;
- For RC-LACE (NMSs of Austria, Croatia, the Czech Republic, Hungary, Slovakia and Slovenia, the application running in Toulouse on purchased computing resources and monitored by RC-LACE scientists), the same, 14.7 km mesh, 205 x 181 points, 27 levels;
- In Slovenia, the same, 11.7 km mesh, 61 x 61 points, 27 levels, coupled to the RC-LACE application;
- In Romania, lagged-mode fine-mesh dynamical adaptation forecasting, 12.3 km mesh, 89 x 89 points, 27 levels.

A sixth application is in preparation in Belgium: 7.0 km mesh, 97 x 97 points, 27 levels, coupled to ALADIN-France.

History of the project

Only the main events will be mentioned here, relative to the political, financial and technical aspects.

November 1990: *Météo-France* offers the NMSs of Bulgaria, the Czech Republic, Hungary, Poland, Romania and Slovakia jointly to develop and maintain a LAM version of the ARPEGE system with a view to a mutually beneficial collaboration in NWP and mesoscale modelling.

January 1991: The so-called MICECO support (from the French Ministry of Foreign Affairs

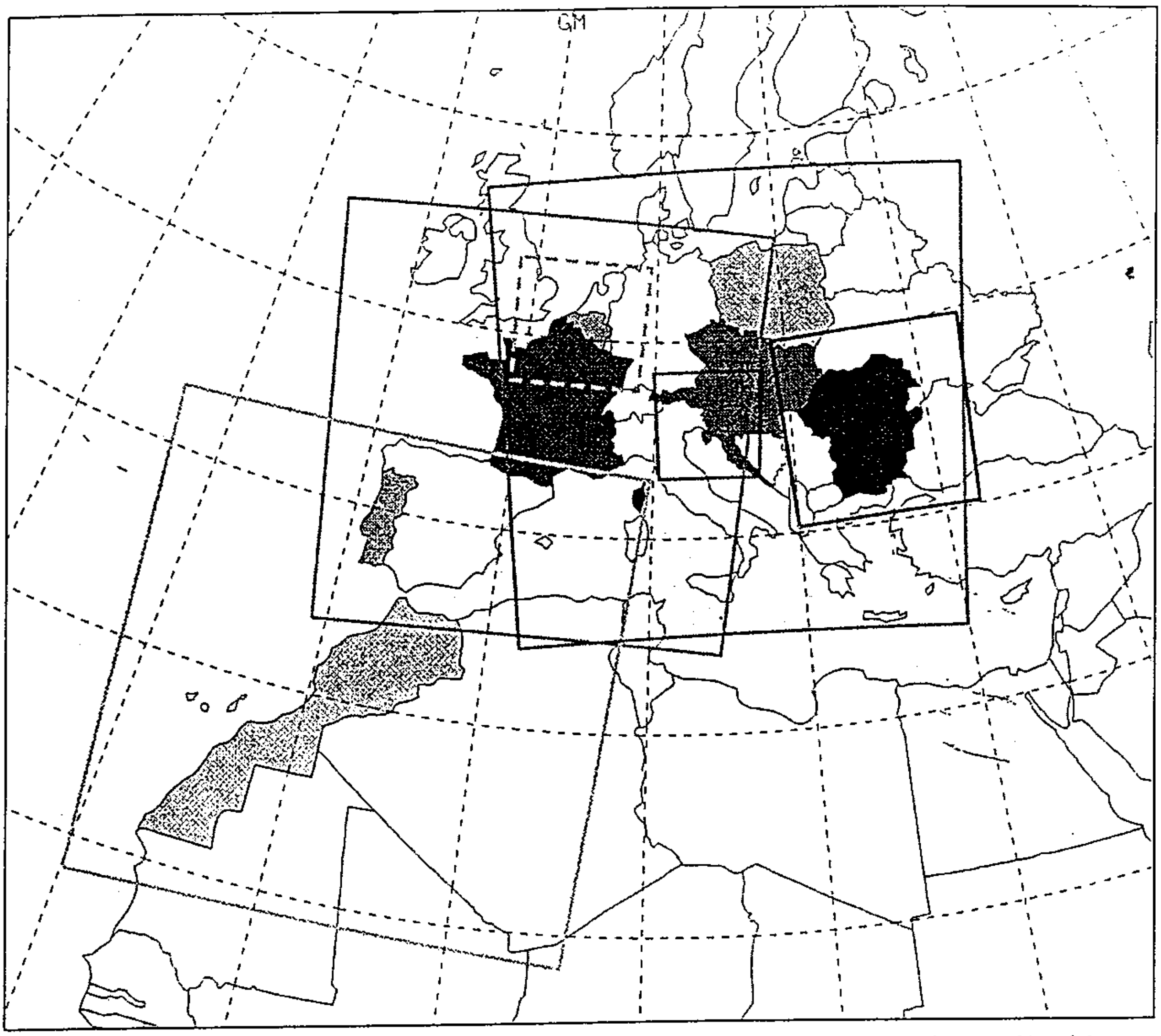

Figure 1 — Map of the ALADIN partners (with RC-LACE and SELAM grouped under one shade of grey each) and the operational pre-operational (broken lines) domains

for the visits to Toulouse of the specialists of the partner NMSs) that will be the continuous and main source of financing for the project is acquired.

March 1991: In Paris, three scientists from the NMSs of the Czech Republic, Hungary and Romania evaluate the feasibility of the proposed common project.

September 1991: Start of the active phase of the project in Toulouse: Slovakia declines the offer to participate but, meanwhile, Austria, through what will be the RC-LACE endeavour, joins in. Thus, 17 people from seven countries start to work on the project LAM-ARPEGE (that will be renamed ALADIN one month later).

August 1992: The French Ministry for Research accepts to finance four Ph.D. grants in the framework of the ALADIN project. These would allow the scope of the project to be enlarged by studying basic questions related to its usefulness and further evolution.

October 1992: Cycle 0 of the ALADIN library is ready.

January 1993: The Commission of the European Communities selects the pre-operational work on ALADIN as one of the subjects financed under the so-called PECO action, in a competitive context (1 to 35).

November 1993: The NMSs of Morocco, Slovakia and Slovenia join the project. The nine partners carry on the efforts towards a first quasi-operational implementation in Toulouse for the benefit of the central and eastern European NMSs.

May 1994: The work of the seven members of the PECO-financed pre-operational team (with the additional contributions of the Ph.D. students and an established team of *Météo-France* scientists) leads to a successful conclusion. ALADIN becomes quasi-operational on *Météo-France*'s C98 computer on 31 May. Although the application is run only once a day (in sequential mode with respect to ARPEGE), up to 36 hours only and without a specific data-assimilation cycle, proof of the wisdom of the concept is nevertheless at hand.

April 1995: The NMSs of Croatia and Spain (the latter will later leave) join the project.

December 1995: A workstation version is built (still in dead-branch mode with respect to the development cycles) by the SELAM group (NMSs of Bulgaria and Romania, later to be joined by the Republic of Moldova). This work also prepares the way for the distributed-memory version of ALADIN foreseen for cycles 6 and 7 of the library.

January 1996: RC-LACE and *Météo-France* sign an agreement to use the J916/12 computer in Toulouse as host for an ALADIN-LACE pre-operational application from 1 July 1996 to 31 December 1997 in order to provide a transition for the build-up of the central European joint application of ALADIN between the six contributing NMSs.

February 1996: The success of the first Ph.D. phase (two theses already defended and two about to be defended) leads the French Ministry for Research to renew the grant. Five new Ph.Ds. are thus now in the pipeline.

March–August 1996: In a form of cascade, the five above-mentioned applications start their cycle of pre-operational to operational status.

November 1996: in Paris, the Directors of the ALADIN partner NMSs sign a Memorandum of Understanding (MoU) that formalizes and regulates the further progress of the project, in the presence of the Secretary-General of WMO, Prof. G. O. P. Obasi.

March 1997: The Czech NMS launches a computer ITT with the aim of transferring the central European application from Toulouse.

Organization of the project

The organization described below is the one in use until now. It will surely not be that of the future, since several questions (transition to multiple operational status, transition from "platform dependent" to "standard open" code, multiplication of the declarations of interest of potential new partners, ...) require a more formalized and less centralized solution.

From September 1991 until recently, work on ALADIN centred around visits to Toulouse of scientists of all partners, their ALADIN-related work at home being mostly conditioned by the tasks they had been performing in Toulouse (this situation, of course, is rapidly changing as the operational versions are transferred outside Toulouse). The number of hours of work shared in Toulouse with colleagues of all origins allowed a homegeneous and united team to be formed. The main difficulty of the set-up was the financing of the travel and visits, with an average of nearly 15 people working on the project (7.9 visitors and 3.9 *Météo-France* staff in Toulouse, 3.0 persons in the other places (see Figure 2 for the distribution among the different partners). Generally speaking, travel was provided by the partners and the grants for the stays were funded by *Météo-France* or by French ministries or raised in competitive applications by either all partners or by *Météo-France* and one partner for bilateral support or directly financed by the partners. The fact that some 17 different sources are involved gives an idea of the complexity of this financing scheme.

The necessary formalization of the project before its decentralization was completed by the signing last autumn of an MoU by all 14 partners. It lays down the principles observed by ALADIN since the beginning, the choice of software, conditions of its use by the partners and of membership of, admission to, and withdrawal from the ALADIN "club".

Scientific content of the project

The relevance of all that has already been said to a scientific-technical topic may appear rather thin. One has to realize, however, that modelling aspects of meteorology will rely more and more on tools developed in an operational environment, which will require more and more "industrial" methods for their production and maintenance. In that respect, all the above information anticipates the working conditions that atmospheric science will witness in the 10 coming years. Nevertheless, all that "environment" is still there to foster scientific and technical progress and that will be the subject of this text from now on.

We shall first review the common points between ARPEGE and ALADIN:

- Both models use the spectral technique for the horizontal representation of fields. This means that special provisions have to be taken for the use of a bi-Fourier LAM representation. The solution chosen here is that of Machenhauer and Haugen (1987) that requires the so-called bi-periodicization of

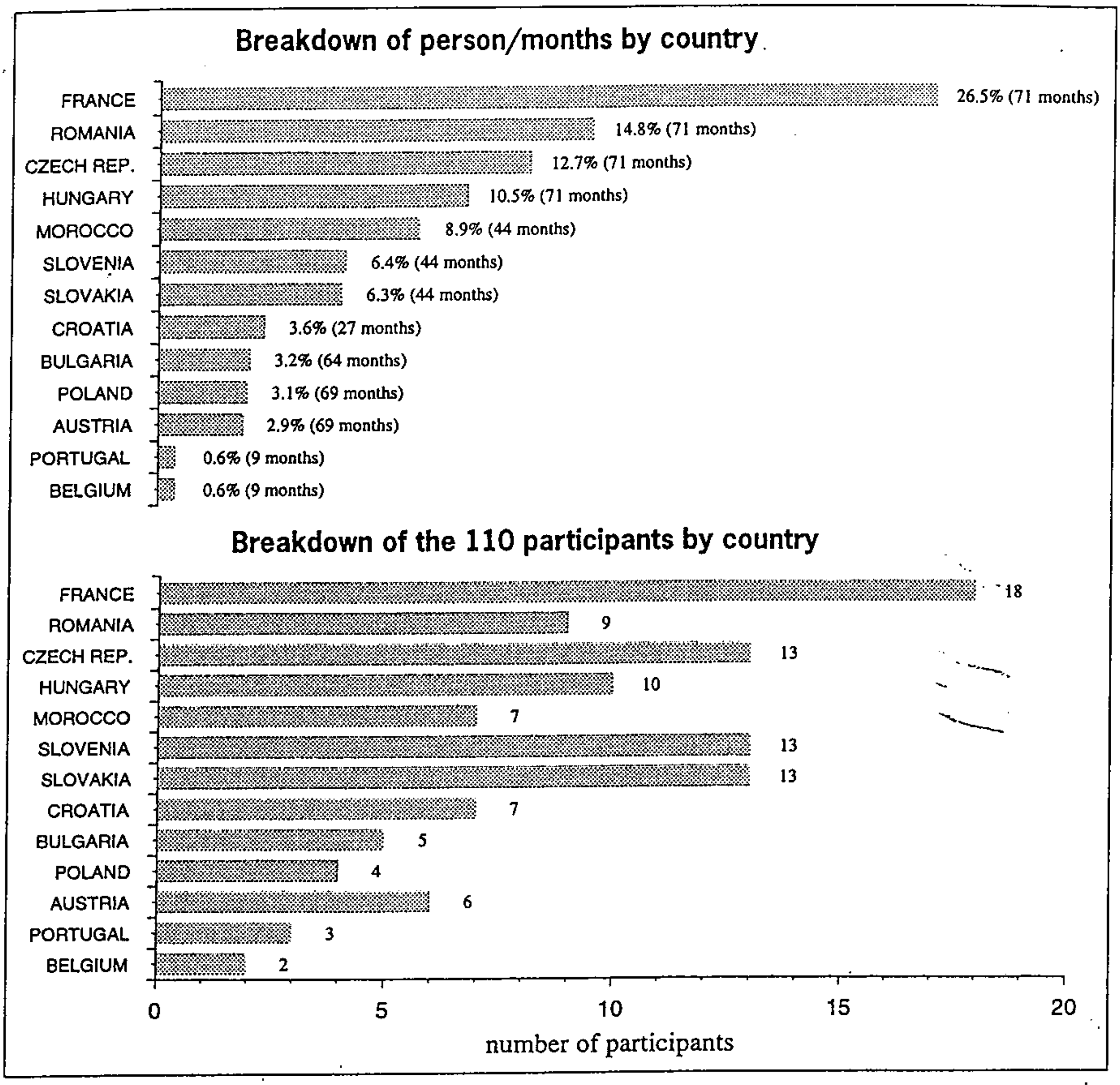

Figure 2 — Participation in the ALADIN project for each partner: proportion of the total effort (together with the duration of the specific participation) and number of involved people (on 30 June 1997)

fields through a fictitious "extension zone". As an example, Figure 3 features the "extended" orography of the ALADIN-LACE application; one notices the smoothness and isotropic character of the transition from one side to the other through the additional zone. It is sometimes claimed that spectral methods are unsuitable for LAM applications and/or that they cannot represent sharp features for lack of "locality". Figure 4, representing 18-hour forecasts of 10 m winds, is a good counter example: no apparent boundary problems exist but many realistic features over land as well as over sea at the two grid-length scale do (plotting);

- The vertical discretization is hybrid (going progressively from "p" to σ);
- The time stepping now uses the semi-implicit semi-Lagrangian scheme with two-time-levels solution;
- The physics is for the time being identical with ARPEGE (which also benefited from ALADIN work); (see Geleyn *et al.*, 1994);
- The DFI technique is used, the latest, most efficient version (Lynch, Giard and Ivanovici, 1997) having been suggested in the framework of ALADIN;
- The CANARI and Full-Pos applications are mirrors of the ARPEGE ones, with specific steps linked to the LAM geometry.

The points specific to ALADIN concern:

- The bi-periodicization is accomplished only on the files interpolated from the coupling model (i.e. as seldom as possible) and can thus be performed with a quite sophisticated iterative combination of splines and filters;

- The form of the coupling function (i.e. the relative weight taken at each time step by the larger-scale solution near the boundaries of the LAM) that has been optimized as much as possible in the spectral context;
- The implementation of the semi-Lagrangian scheme in the case of trajectories originating in the "extension zone" which required an original treatment of the link between semi-implicit time stepping and coupling (Radnoti, 1995) as well as a specific adaptation of Rochas's idea about Coriolis terms in the two-time-level algorithm;
- The existence of a non-hydrostatic option, based on Laprise's "hydrostatic pressure" type of vertical coordinate, which also requires a redefinition of the "Simmons-Burridge" vertical discretization operators (Bubnova *et al.*, 1995).

Finally around the project itself:

- A special study (Caian and Geleyn, 1997) was performed to evaluate the respective merits of the stretched solution in ARPEGE and of the coupled solution represented by ALADIN; the conclusion was that the combination of moderate stretching for the global part and of local adaptation via the LAM solution is the best combination, given the current computing constraints;
- ALADIN was used as a tool for adjoint sensitivity studies on frontogenetic problems (Horanyi and Joly, 1996);
- A simplified physics package and its adjoint version for future mesoscale 4D variational

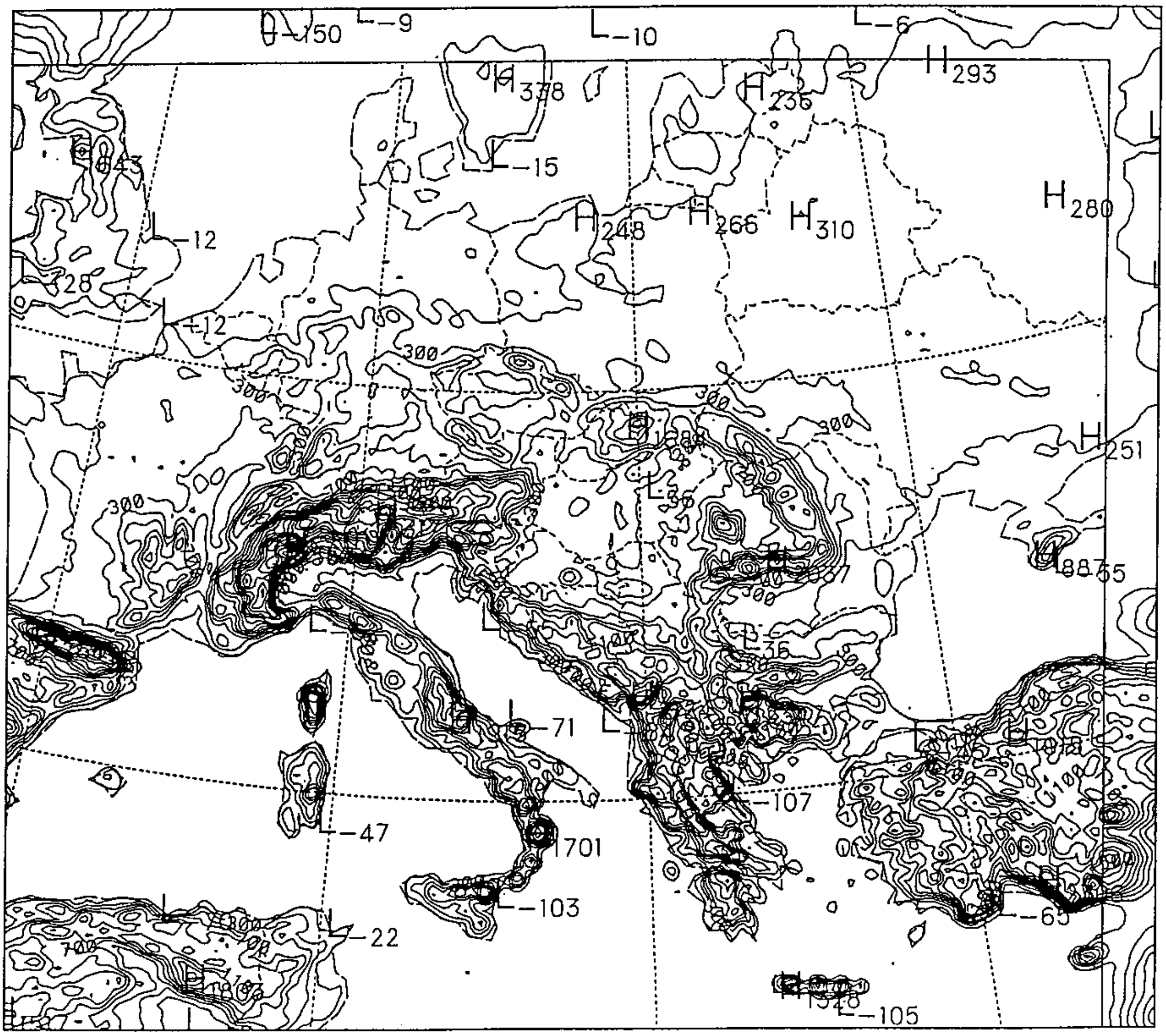

Figure 3 — "Extended" orography of the operational RC-LACE domain; the extension zone for bi-periodicization of the field is on the right and at the top of the figure.

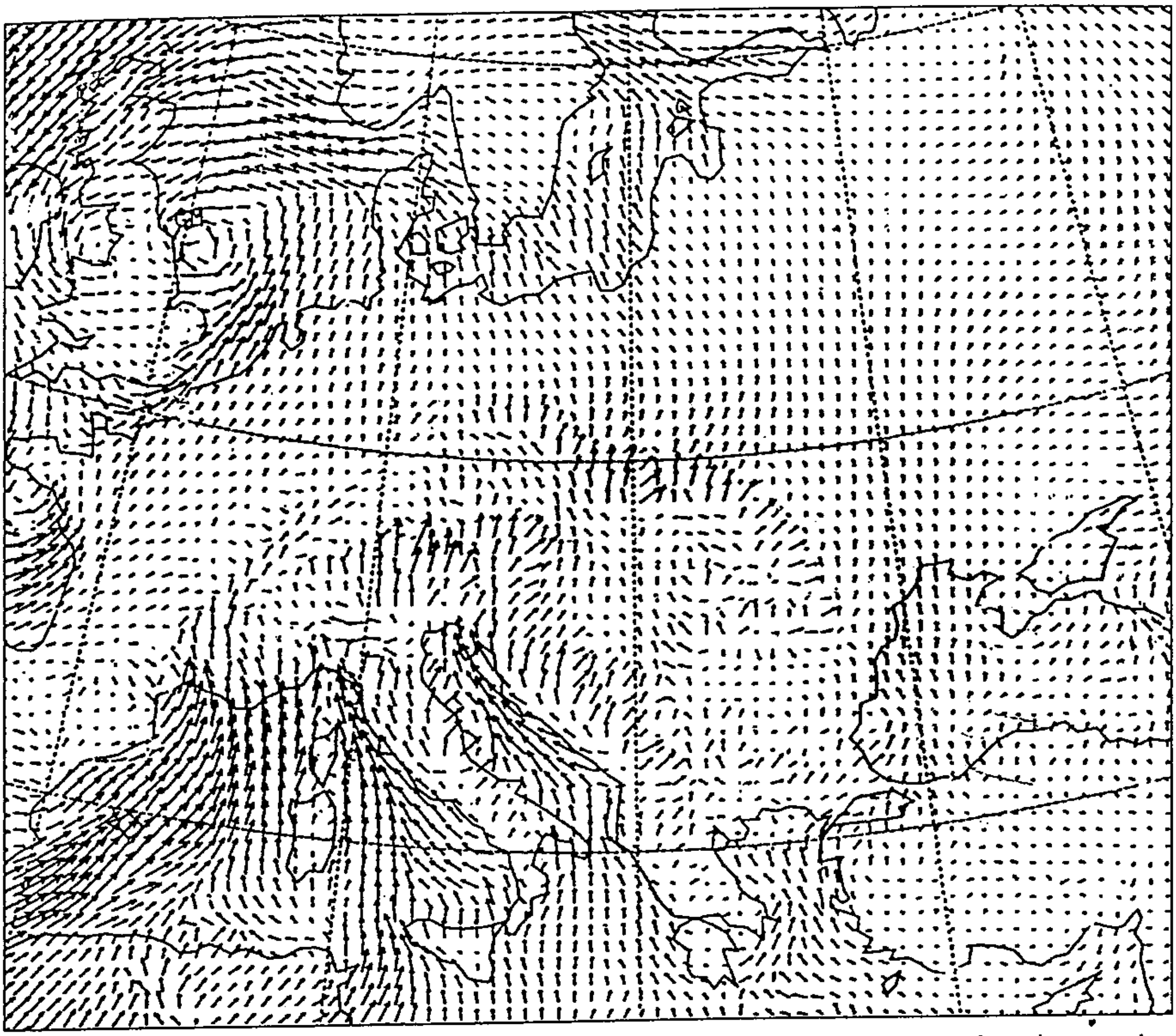

Figure 4 —Eighteen-hour forecast of the 10 m wind on 6 January 1996 at 00Z: notice the three mesoscale vortices around Brittany and Great Britain, the Adriatic channelling effect and several mountain barrier sharp effects.

data assimilation are currently being developed (Janiskova, Thépaut and Geleyn, 1996);

- Other important (past and present) topics of scientific activity are: the behaviour of the model's physics at the limit of validity of the hydrostatic assumption (and beyond); the conditions for a successful dynamical adaptation process; and the intrinsic properties of the semi-Lagrangian time-stepping scheme.

Some technical data about the project

This part will be short but important. The presented data are those concerning the speed of computation and the telecommunication needs for coupling. With the two-time-level version of the semi-implicit semi-Lagrangian scheme, the ratio of the collocation grid mesh size to the time step is about 26 m s^{-1}, a favourable number when compared with other operational NWP models. The number of individual instructions per grid point, level and time step can be estimated (coupling, DFI and post-processing included) for a standard run to about 7 700. For the coupling files, the figure to mention is 1.8 bytes per grid point, level and coupling file, under similar standard conditions and assuming a ratio of two between the mesh sizes of the coupling model and of the coupled model. These three numbers allow an estimation of the computing power and of the telecommunication bandwidth needed for any given application.

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