Real-Time Weather Forecasts Using a Mesoscale Atmospheric Model

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INTRODUCTION

Operational weather forecasts in Catalonia are still mainly based on synoptic numerical models from several national weather services around Europe. Although the Spanish weather service is currently running a high resolution limited area model (Rodríguez and García-Moya, 1995), few professionals outside the official meteorological service have access to most of its output products due to a restricted dissemination policy.

As computer power is increasing, and many regional communities can afford high-performance computers to assist their technological development, the use of them to run numerical models to generate local weather forecasts is straightforward. Taking advantage of the growth of these computing facilities, decentralization of the operational simulations over small regions might be a trend in the near future to satisfy the public exigencies for reliable and accurate weather forecasts.

In 1994, as a result of an agreement between the Catalonian Research Foundation (FCR), the sewage company of Barcelona (CLABSA), and the Department of Astronomy and Meteorology of the University of Barcelona, in 1994 a state-of-the-art numerical atmospheric mesoscale model was installed at the Cray of the Catalonian Supercomputer Center (CESCA). After a quite successful 2-year testing period, the project has entered in a new phase which is aimed to provide operational mesoscale weather forecasts over Catalonia.

MESOSCALE MODELS

There is no precise definition of a mesoscale model. Twenty or thirty years ago, models that had a grid resolution that was significantly less than the highest resolution operational model run at the time were often referred to as mesoscale models. Thus, models which were typically run with a grid resolution of less than 100 km and had a more detailed description of diabatic physics were often called a mesoscale model. Strictly speaking, according to the Orlansky classification, these models were capable of simulating only the meso-α scale circulation.

As computers have become more powerful, modelers have added more detailed physics to these existing models and executed them with a higher grid resolution. The focus of mesoscale simulations has shifted to the lower end of the meso-α and the meso-B scale, *i.e.*, with grid increments in the 10 to 50 km range.

The identification of a mesoscale model is becoming more obscure as researchers have recently begun to execute nested cloud-scale resolutions models over domains large enough to simulate both meso-B scale and cloud-scale processes. In essence, the atmospheric models are evolving into multiscale models in which larger scale versions of a model simulate the synoptic flow while nested versions of the same model simulate the meso-α, meso-B and possibly even the cloud-scale circulations.

Despite the substantial progress that has been made in the development of mesoscale models during the past decade, and the widespread use of these systems in recent years, there are still a number of problem areas that need to be addressed before mesoscale simulations can achieve their ultimate potential:

a) The parameterization of moist convection and its interaction with grid scale moisture physics.

b) The parameterization of the boundary layer in which shallow and deep convective clouds are rooted.

c) The modeling of surface processes, especially the flux of moisture from the surface of the earth into the atmosphere.

d) The representation of clouds and their interaction with radiative processes.

e) The availability of sufficient data to define mesoscale features in the initial state. However, lack of observational data is not as critical as it can be thought at first glance. Although mesoscale models are initialized using synoptic surface and radiosonde data, the success of mesoscale models is the result of the fact that a significant fraction of mesoscale features result from the non-linear interactions between coarse scale features and the forcing supplied by differential low-level heating due to small scale features of the earth's surface (*e.g.* land/water boundaries) which are fixed in time and can be accurately mapped.

f) The assimilation of data from new observing systems (satellite, radar,. . .) into the mesoscale model in a beneficial manner.

g) The insatiable thirst for higher computational power. As computers become more powerful, atmospheric models have quickly consumed all of the increased power by using higher resolution grids and incorporating more detailed physics. Thus, the processing time for the "best" simulation always tends to be the maximum acceptable time for a particular research or operational applications.

MODEL OVERVIEW

The mesoscale model installed at the Cray YMP of our supercomputer center is an upgrade of the *Mesoscale Atmospheric Simulation System*, hereafter referred to as MASS. It is a 3-dimensional hydrostatic primitive equations mesoscale model designed to be run with horizontal grid point resolutions of about 10 to 100 km, with 20 to 40 levels in the vertical. The model has the ability to perform nested simulations, *i.e.*, simulations over areas enclosed in a larger simulation region which numerical output is used as first guess and boundary condition data for the smaller scale simulation.

The model incorporates a high resolution Blackadar type planetary boundary layer parameterization and detailed surface energy and moisture budgets that include the parameterization of surface hydrology and evapotranspiration. Both cloud water/ice and precipitation are included among the model forecast's variables, and their mutual interaction as well as the interaction with water vapor are parameterized. The effects of sub-grid scale cumulus convection may be handled by three different schemes (Kuo-Anthes, modified Kuo-Anthes and Fritsch-Chappell) that can be chosen depending on the model grid spacing. Longwave and shortwave radiation at the surface and within the atmosphere and their interaction with clouds and precipitation are included in the parameterization.

Most of these parameterizations require appropriate databases of surface properties, such as terrain elevation, normalized difference vegetation index (NDVI), land-water boundaries, sea surface temperature (SST), land use and soil type. Since the simulation area is larger than the catalan region, for which high-resolution databases of those magnitudes are available, public-domain data sets are used for the whole area. In order to avoid inhomogeneities in the surface representation of the simulation domain, no attempt is made to merge both fine and coarse data sets.

MASS also contains a data preprocessor that can create a complete model initialization data set as well as boundary condition data from a variety of observational and gridded forecast data. The observational data is interpolated to a set of regularly spaced grid point by means of an optimum interpolation scheme.

Major components of MASS are listed in Table I. More information about this model can be found in the publications of Kaplan et al. (1982), Koch et al. (1985), Zack et al. (1991) and Kaplan and Karyampudi (1992).

OPERATIONAL FORECASTS WITH MASS

At the time of writing these lines, a new phase of the project initiated in 1994 is under way. It will be aimed to provide real-time mesoscale forecasts for the catalan region. Until now the efforts have been concentrated in performing case simulations in order to tune MASS to properly work in our area as well as to assess its performance as a forecast tool.

Usually 24-hour large scale simulations have been run on a grid with 55 km grid-point spacing, 55x55 grid points in the horizontal, and 20 levels in the vertical, as shown in Fig. 1. Synoptic surface and rawinsonde observations and first guess data from the 12-hour forecast of the U.S. National Meteorological Center's Medium Range Forecast model (MRF) are incorporated in the initialization process. The MRF is also used to provide boundary conditions every 12 hours.

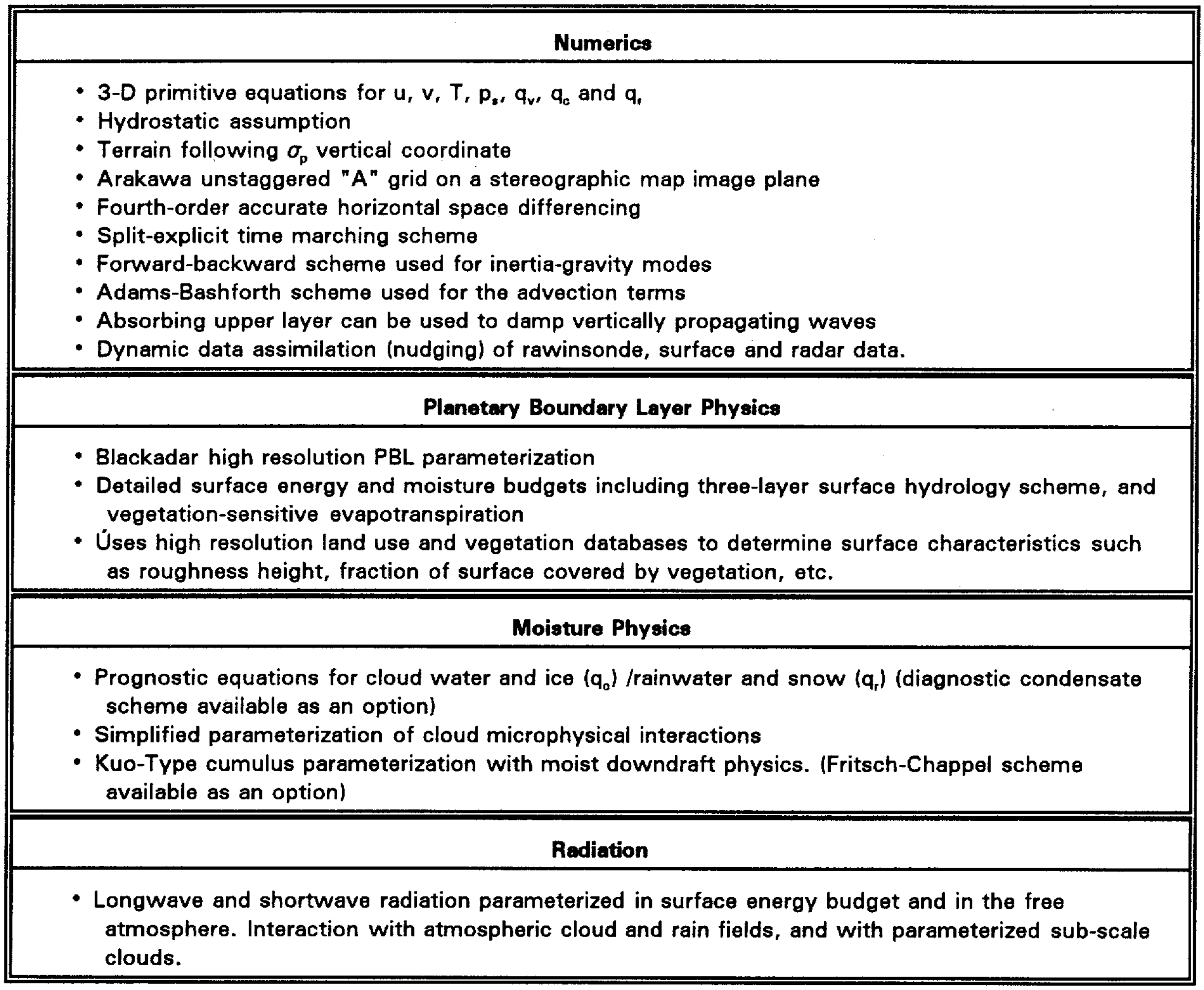
Nested simulations are initialized about 6 hours later and executed for 18 hours of simulated time on a grid with 10 km grid-point spacing, 55x55 grid points in the horizontal and 20 levels in the vertical, as depicted in Fig. 2. It becomes apparent that the finer mesh of the grid allows for a better representation of the Pyrenees and coastal ranges in the terrain field. This simulation is initialized by interpolating the output from the larger scale simulation, which is also used to provide boundary conditions every hour for the duration of the simulation.

Steps of a typical case-study simulation are reported below:

1. Generation of a discrete 3-D grid. Surface characteristics are interpolated and assigned at the intersections of the bottom of the grid. This procedure has to be repeated every two weeks as properties such as vegetation indexes and sea surface climatological temperature change.
2. Ingestion, error checking and normalization of atmospheric observations. Initialization data comes from conventional synoptic surface and radiosonde stations.
3. Data analysis and initialization by means of an optimum interpolation scheme. First guess data is provided by the U.S. Medium Range Forecast model.
4. Preparation of lateral boundary condition data from the numerical output of the U.S. Medium Range Forecast model.
5. Execution of the large-scale simulation. Solving the model equations, a complete set of prognostic meteorological variables is calculated over each grid-point at discrete time-intervals. In other words, the model computes the evolution of the atmosphere as time goes on.
6. Data from the previous simulation is used to feed a new simulation over an embedded region, the so-called *nested simulation*.

With the current MASS configuration, a complete simulation takes about 6 hours of CPU time in the Cray of our supercomputer center. Four and a half hours are employed for the nested simulation. It becomes apparent that a considerable effort has to be done to obtain real-time forecasts with MASS. Several issues

Table 1.



Numerics

- 3-D primitive equations for u, v, T, p_s, q_v, q_c and q_r
- Hydrostatic assumption
- Terrain following σ_p vertical coordinate
- Arakawa unstaggered "A" grid on a stereographic map image plane
- Fourth-order accurate horizontal space differencing
- Split-explicit time marching scheme
- Forward-backward scheme used for inertia-gravity modes
- Adams-Bashforth scheme used for the advection terms
- Absorbing upper layer can be used to damp vertically propagating waves
- Dynamic data assimilation (nudging) of rawinsonde, surface and radar data.

Planetary Boundary Layer Physics

- Blackadar high resolution PBL parameterization
- Detailed surface energy and moisture budgets including three-layer surface hydrology scheme, and vegetation-sensitive evapotranspiration
- Uses high resolution land use and vegetation databases to determine surface characteristics such as roughness height, fraction of surface covered by vegetation, etc.

Moisture Physics

- Prognostic equations for cloud water and ice (q_c) /rainwater and snow (q_r) (diagnostic condensate scheme available as an option)
- Simplified parameterization of cloud microphysical interactions
- Kuo-Type cumulus parameterization with moist downdraft physics. (Fritsch-Chappel scheme available as an option)

Radiation

- Longwave and shortwave radiation parameterized in surface energy budget and in the free atmosphere. Interaction with atmospheric cloud and rain fields, and with parameterized sub-scale clouds.

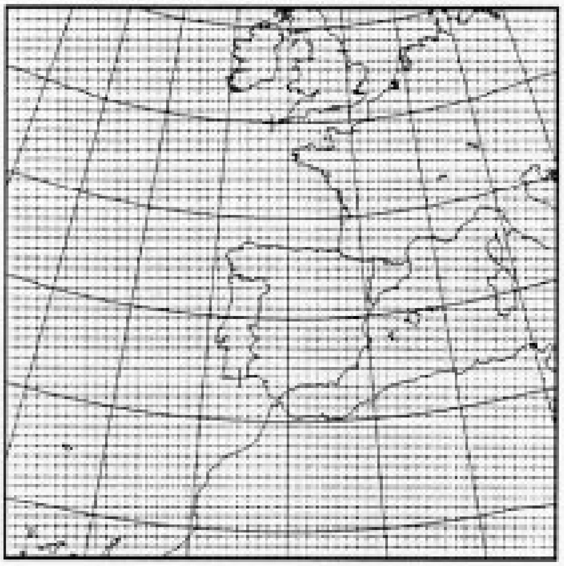


Figure 1: MASS large-scale simulation area.

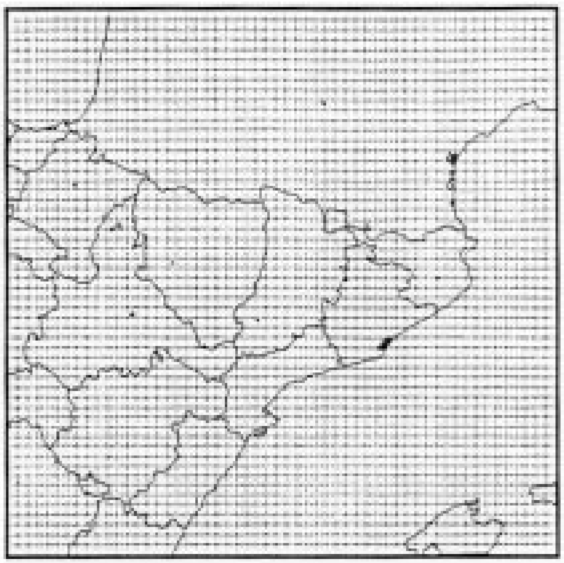


Figure 2: MASS nested simulation area.

have to be considered in order to build up a suitable operational package.

1. MASS physics can hardly be simplified as we have learnt from our case studies.
2. MASS code must be revised in order to optimize the use of computer resources. However, it can not be completely rewritten since the current version is more than 700,000 lines long. The most time-consuming subroutines will have to be isolated and reformulated.
3. To speed up the simulation time, vectorial and parallel processing capabilities of the Cray computer will play an important role. Some parts of the simulation process can be easily parallelized: initialization of different variables can be done simultaneously, the nested simulation can be run slightly delayed from the large-scale simulation, independent parameterizations can be run simultaneously.
4. Cray resources will have to be concentrated to this project during the simulation hours.

It is believed that the required time for a complete operational forecast can halve the present simulation time. Taking into account that enough observational data is not available until about 03 UTC, 24-h forecasted charts can be ready at 8 o'clock in the morning (local time), a quite acceptable time.

CONCLUSIONS

After a 2-year testing period, MASS seems to be quite skilled to provide very good weather forecasts over Catalonia. MASS has been challenged with mesoscale convective systems that often affect the Mediterranean basin of the Iberian Peninsula, and has performed satisfactorily. Events that were grossly underforecasted by typical operational models were reasonably captured by the nested simulation.

The next step currently underway is directed to provide operational mesoscale forecasts with MASS. At present, it is too early to anticipate whether MASS can be adapted to run daily 24-h simulations on our Cray computer. However, from the above discussion it seems it should be possible.

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