

Implementation of an Eta Belt Domain on Parallel Systems

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Abstract

We extend the Eta weather model from a regional domain into a belt domain that does not require meridional boundary conditions. We describe how the extension is achieved and the parallel implementation of the code on the Cray T3E and the SGI Origin 2000. We validate the forecast results on the two platforms and examine how the removal of the meridional boundary conditions affects these forecasts. In addition, using several domains of different sizes and resolutions, we present the scaling performance of the code on both systems.

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Abstract

We extend the Eta weather model from a regional domain into a belt domain that does not require meridional boundary conditions. We describe how the extension is achieved and the parallel implementation of the code on the Cray T3E and the SGI Origin 2000. We validate the forecast results on the two platforms and examine how the removal of the meridional boundary conditions affects these forecasts. In addition, using several domains of different sizes and resolutions, we present the scaling performance of the code on both systems.

1 Introduction

By the end of the year 2002, NASA will launch the satellite Triana. It will be the first Earth observing mission to provide a continuous, full disk view of the sunlit Earth. Two of the instruments that Triana will carry are EPIC, which will deliver science products such as total precipitable water, cloud height, aerosol index, total ozone, and a global visible cloud field image, and NISTAR, which obtains precise radiometry integrated over the entire sunlit disk. This unique set of observations has tremendous potential to aid in our understanding of the total Earth system and the effects of natural and human-induced changes in the global environment.

As part of the HPCC Program at NASA GSFC, we have started a project (called the SunFlower Project) whose goal is to simulate some of the Triana observations and to assess the impact of Triana data for weather and climate predictions. Using the near-continuous cloud parameters observed by Triana and numerical simulation, we intend to produce a realistic climatology of full three-dimensional daily global cloud coverage.

For the simulation of the atmosphere within this project we are using the Eta model [4, 2]. In order to compare Triana and the Eta model data on approximately the same grid without significant downscaling, the Eta model will be integrated at a resolution of about 15 km. The integration domain (from -70 to +70 deg in latitude and 150 deg in longitude) will cover most of the sunlit Earth disc and will continuously rotate around the globe following Triana. The cloud data assimilation is intended to run and produce 3D clouds on a near real-time basis. The moving domain will get its lateral boundary

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conditions from a lower resolution belt domain. Such a numerical setup and integration design is very ambitious and computationally demanding in terms of memory management, efficiency of the code and accuracy of the forecast produced.

The Eta model was originally designed for regional integration domains. Rancic *et al.* were able to expand the regional integration domain into a belt-like domain [6]. This belt-like domain was still seen as just a large regional domain in the sense that it used meridional boundary conditions (no periodicity). With such a choice, although producing acceptable forecasts [6], we could not meet the requirements of the SunFlower Project. The National Centers for Environmental Prediction (NCEP) subsequently released a new version of the Eta model code. We modify this code for belt domain (supposed to provide lateral boundary conditions for the moving domain in the SunFlower project) integrations. This new code, called the Eta-belt, no longer requires meridional boundary conditions, rather it incorporates periodicity. The objective of this paper is to test the efficiency of the Eta-belt in terms of both parallel performance on the Cray T3E and the SGI Origin 2000 and forecast results.

An outline of this paper is as follows. Section 2 gives a general description of the Eta weather model. Section 3 explains the strategy used to extend this model from a regional domain into a belt domain. In Section 4, we provide an overview of the two platforms. Numerical experiments appear in Section 5. We formulate some remarks and conclusions in Section 6.

2 The Eta Model

The Eta model [4] is a limited-area atmospheric model that serves as the major regional model at NCEP. It is a primitive-equations model based on finite differencing for the computation of atmospheric dynamics and physics under hydrostatic assumptions. The model employs the concept of “step-mountain” vertical coordinates and uses a semi-staggered horizontal distribution of variables, known as the Arakawa E-grid. Two major principles built into the model’s design are: maintaining integral constraints of the continuous equations within finite-differencing approximations, and minimizing, or completely avoiding, artificial filtering of short waves. The model also utilizes a variety of sophisticated physical parameterization schemes. The Eta model is used for real-time forecasting by many groups at institutions worldwide, and it has shown remarkable skill in forecasting precipitation scores, as well as in the development and movement of severe storms [4, 5]. For general information on the Eta model, refer to the following web site: <http://www.srh.noaa.gov/ftproot/ssd/NWPMODEL/HTML/eta.htm>.

The original version of the Eta model was designed and optimized for efficiency on vector based architectures. Computational demands for very fine resolution and large problem domains motivated the development of a distributed memory parallel option for the Eta model. The Eta model is parallelized using a standard two-dimensional data domain decomposition. Two- and three-dimensional data arrays containing prognostic variables (wind velocity, temperature, moisture, and pressure), as well as diagnostic and intermediate fields, are horizontally partitioned, and the resulting subdomains are distributed over the available processors (see Figure 1). Computations on the horizontal mesh use explicit time differencing.

The parallel code for the Eta model uses two types of communication: local and global. Local communications, where the data are exchanged only by neighboring processors, are typical for explicit time-differencing. Global communications involve the computations done by the master processor, which are then distributed among all processors, and are mainly used for I/O procedures within the Eta model code.

The parallel Eta code is written in Fortran 90 and uses MPI for interprocessor communications.

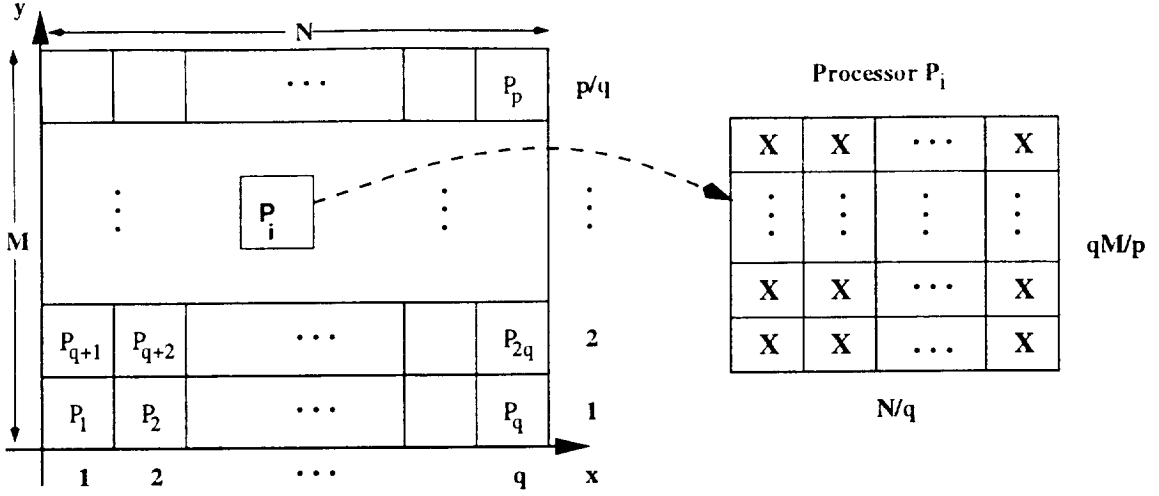


Figure 1: Domain decomposition and mapping: the $N \times M$ grid points are mapped into p processors that are decomposed into a $q \times \frac{p}{q}$ array. Each processor gets $N/q \times qM/p$ grid points.

3 Design of the Wrap-Around Belt-Domain

In the above parallel implementation of the Eta model, it is assumed that the integration domain is a regional domain requiring zonal and meridional boundary conditions. Our objective is to extend the regional domain into a belt one where there are no meridional boundary conditions.

Rancic *et al.* first implemented a belt-like domain with the Eta code. This domain was a large regional one still having meridional boundary conditions. However, their implementation kept all the properties of the Eta model. In particular, their numerical experiments showed that their belt model generally produces better skill than the regional model and more significant improvement with the increase of resolution [6]. With the release of a new version of the Eta code (having improved physics, more vertical levels, etc.), we initiated an effort to design a fully periodic belt model. The idea was to modify the model integration code (on parallel computers), as well as the preprocessing and postprocessing procedures (on workstations), by stretching the regional domain in the left and right directions so that the left and right boundaries overlap.

3.1 Preprocessing

The preprocessing system converts global analysis data from NCEP into initial and boundary conditions for the Eta model. This system had to be adapted to provide the periodic initial and boundary conditions needed by an equatorial belt domain rather than the isolated regional domain for which it was designed. Rather than explicitly enforce periodicity throughout this lengthy code, the 360 degree belt region is extended by several degrees at either end, and these end regions are correctly loaded with input data based on the periodic requirement. With these end regions included, most of the preprocessing code is able to continue to regard the domain as an isolated region centered about the equator and prime meridian, and correct interpolation is obtained right up to the dateline without any explicit knowledge of the periodic boundary condition at this location. At output, the extended end regions are discarded so that a strictly periodic data set over 360 degrees is supplied to the model.

3.2 Model Integration

The idea here is to still work with a 360° domain and to incorporate the periodicity by modifying the code so that grid points along the right and left meridional boundary become neighbors (instead of isolated points). We used the regional domain version of the code and introduced changes in the domain decomposition so that each processor has right and left neighbors unlike the case with the original belt-like domain. In that case, the left-most processors marked one meridional boundary, the right-most set marked the other. In this new case, processors having portions of the domain on the left side communicate with those assigned to the right side of the domain. Figure 2 gives a representation of this decomposition strategy. In addition, some subroutines were modified (for example the one performing horizontal advection) and arrays were redimensioned to reflect this change.

Compared to the regional domain code, the new code performs a little more interprocessor communication but the same amount of computation.

P_{p-q+1}	P_{p-q+2}	P_{p-q+3}	...	P_p	P_{p-q+1}
<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;">• • •</div> <div style="text-align: center;">• • •</div> </div>					
P_{q+1}	P_{q+2}	P_{q+3}	...	P_{2q}	P_{q+1}
P_1	P_2	P_3	...	P_q	P_1

Figure 2: Domain decomposition for the belt domain.

3.3 Postprocessing

The postprocessing system converts output data from the Eta model into a form suitable for use with our graphical data package. This system has two stages—one to interpolate from Eta coordinate levels to standard pressure levels, and another to interpolate from the Arakawa E-grid to a regular cartesian grid. For both stages, the original isolated regional version has been modified in order to correctly perform the horizontal smoothing and interpolation procedures near the lateral periodic boundaries.

4 Description of the Platforms

For the set of experiments presented here, we employed two architectures: the Cray T3E and the SGI Origin 2000 (SGI O2K).

Cray T3E:

The Cray T3E is a massively parallel processor system which consists of 32 to 2048 Processors Elements (PE). Each PE is a 300 MHZ DEC Alpha 21164 microprocessor capable of 600 million floating point operations per second and has a DRAM memory of 64 megabytes to 2 GB. We employed a 256 PE Cray T3E configuration located at the NASA Center for Computational Sciences at NASA Goddard Space Flight Center.

	Domain 1	Domain 2	Domain 3
Coverage	50S-50N	70S-70N	50S-50N
Resolution	1/2 deg	1/2 deg	1/3 deg
Grid points	$720 \times 201 \times 38$	$720 \times 281 \times 38$	$1080 \times 301 \times 38$
Forecast length	48 hours	48 hours	48 hours

Table 1: Description of the domains.

SGI Origin 2000

We used the 512-processor SGI Origin 2000 available at the Numerical Aerospace Simulation high performance facility at NASA Ames Research Center. It is currently the largest single-image system in existence, with one operating system and a single address space. It has 192 GB main memory, a 2-TB FC Raid Disk Subsystem, and 327 GB disk storage. Each processor is a 400 MHZ R12000 Processor.

Our implementation of the belt domain was first tested on the Cray T3E and then ported to the SGI O2K. The only major changes made to port the code to the SGI O2K were modifications to some system calls specific to each platform.

The Eta code requires double precision computations. On the Cray T3E, by default, each variable is declared in double precision. However, the default on the SGI O2K is single precision. To solve this problem, we introduced the compilation option (`-r8`) that sets all real variables to double precision and we also modified some arguments in specific MPI calls. We use general optimization levels: `-O3` on the Cray T3E and `-O2` on the SGI O2K.

5 Numerical Experiments

In this section, we report the results of our experiments by briefly validating our forecasts and by presenting the scaling performance of our code on both the Cray T3E and the SGI Origin 2000 (SGI O2K). For this study, we consider three domains, which were preprocessed on an SGI workstation.

Domain 1 and Domain 3 cover the region extending from 50°S to 50°N at 1/2 deg and 1/3 deg resolution respectively. Domain 2 is of 1/2 deg resolution and covers 70°S-70°N (see Table 1). All three domains have the same number of vertical levels (38). It is important to note that Domain 3 is 2.25 and 1.6 times as large as Domain 1 and Domain 2 respectively. For all the domains, the initial conditions were derived from the state of the atmosphere on June 10, 1999 as given by NCEP’s global analysis data.

We analyzed the forecast results obtained from both the Cray T3E and the SGI O2K by computing their root-mean-square differences. The differences were significantly small, and the forecasts were “identical” on the two systems.

We now briefly examine the forecasts produced by the Eta-belt. In Figure 3 we present the sea level contour plot for Domain 2 and in Figure 4 the geopotential height at 500 mb for Domain 3, each after a 48-hour forecast period. The figures look reasonable, and the runs did not generate any spurious boundary noise. Similar results were achieved with experiments using prescribed boundary conditions for up to 15 days [1]. In addition, note that the contour lines at the left and right sides exactly match. This shows that the periodicity of our Eta-belt was properly implemented.

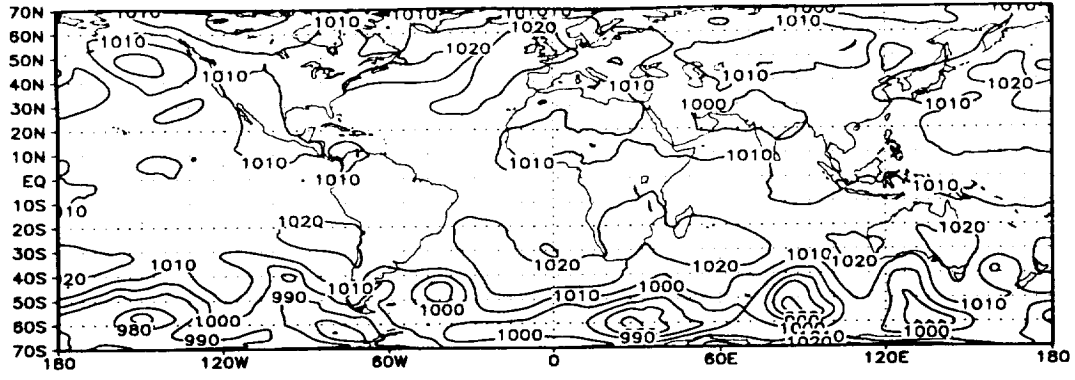


Figure 3: Domain 2: sea level pressure after a 48 hour forecast.

As it was presented in [6], we can also show that

- The forecast skill of the Eta-belt consistently improves with the increase of the horizontal resolution.
- Compared to the regional model, the Eta-belt generally has better skill and more significant improvement when the resolution is refined.

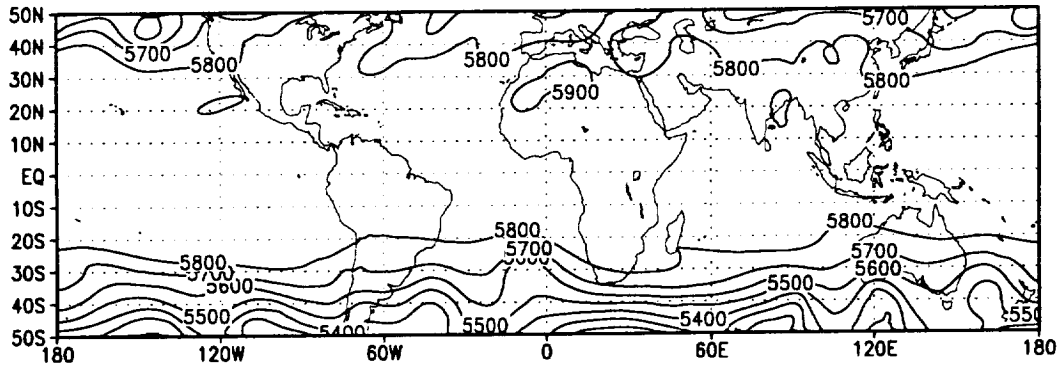


Figure 4: Domain 3: geopotential height at 500mb after a 48 hour forecast.

CPUs	SGI O2K		Cray T3E	
	Time	Speedup	Time	Speedup
64	1834	64.00	6426	64.00
128	1066	110.1	3612	113.8
256	909	129.1	2094	196.4

Table 2: Domain 1: elapsed times and speedup as function of the number of processors.

We introduce the parallel performance of the Eta-belt by recording for the three problems the elapsed time and the speedup when the number of processors (from 64 to 256) varies. The results are

reported in Table 2, Table 3 and Table 4.

Our first remark is that when we increase the number of processors, the elapsed times decrease. The use of a belt domain does not deteriorate the parallel performance. This is consistent with results obtained with regional domains [3]. Another interesting remark is that the Eta-belt code is faster on the SGI O2K. This is due to the fact that the SGI O2K uses faster processors and carry out more efficiently interprocessor communication and I/O.

On both systems, the efficiency of the code improves as the size of the problem increases (from Problem 1 to Problem 3). Though requiring more time to complete the runs, the Cray T3E displays the best scalability. If we were to make some extrapolations, we could claim that the Eta-belt would scale beyond 512 processors on the Cray T3E. This will not necessarily be the case for the SGI O2K. In fact, we integrated Problem 3 on the SGI O2K with 320 processors and we found out that the elapsed time was about the same as the one achieved with 256 processors. Finally, because of the amount of memory available on the SGI O2K, it is possible to integrate large problems with fewer number of processors.

CPUs	SGI O2K		Cray T3E	
	Time	Speedup	Time	Speedup
64	2516	—	N/A	—
128	1433	128.0	4917	128.0
256	1096	167.3	2742	229.5

Table 3: Domain 2: elapsed times and speedup as function of the number of processors.

CPUs	SGI O2K		Cray T3E	
	Time	Speedup	Time	Speedup
128	2226	—	N/A	—
224	1572	224.0	4609	224.0
240	1511	233.0	4257	242.5
256	1508	233.5	4166	247.8

Table 4: Domain 3: elapsed times and speedup as function of the number of processors.

As for the SunFlower project (described in Section 1), we plan to use the Eta-belt with a domain extending from 70 deg south to 70 deg north at 1/3 deg resolution (about $1080 \times 421 \times 38$ grid points). This belt domain will provide lateral boundary conditions to a regional domain continuously moving around the globe following the satellite Triana. The regional domain will extend from 70 deg south to 70 deg north and will cover a window of 150 deg in longitude at 1/6 deg resolution (about $900 \times 841 \times 38$ grid points). The belt and the regional domains will be integrated simultaneously in a two-way interaction mode. Such a demanding numerical setup can only be achieved on the SGI O2K (with 512 processors) because it offers a larger amount of memory and faster processors. However, we envision to use the Cray T3E for development and testing but the SGI O2K for the final Sunflower project experiments.

6 Conclusions

We have expanded the Eta atmospheric model from a regional domain model into a belt domain. Our numerical experiments, carried out on the Cray T3E and the SGI Origin 2000 have shown that the new code (on a belt domain) keeps the same forecast skill (or even does better) as the original one (on a regional domain). In addition, our forecast results were "identical" on the two platforms. The new code runs faster on the SGI Origin 2000, but it scales better on the Cray T3E.

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