

Large Atmospheric Computation on the Earth Simulator: Progress Report and Preliminary Analysis

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The tropical phase of Hurricane Earl (1998) has been simulated with the Mesoscale Compressible Community (MC2) atmospheric model. MC2 achieved an excellent parallelization performance on the Earth Simulator. The preliminary analysis shows a good agreement with satellite cloud distributions and precipitation analysis. The simulated results provide an indispensable dataset for further research on the structure and development process of the hurricane.

Keywords: The Earth Simulator, Hurricane Earl, ultra-high resolution simulations, hurricane life cycle, tropical cyclogenesis, extratropical transition and redevelopment of hurricanes

1. Introduction

The Large Atmospheric Computation on the Earth Simulator (LACES) project, a collaboration between Canadian and Japanese research institutes, began in 2004 and has been running in production mode throughout 2005. This study focuses on the very high resolution (1 km grid spacing) simulation of the development, intensification, movement and extratropical transition (ET) of Hurricane Earl (1998). The unique quality of this simulation is the domain size, which allows a broad spectrum of wavelengths in the interior of the domain to evolve freely, thereby minimizing the effects of the distant boundaries. A database containing the results of the simulation has been constructed by researchers at Recherche en Prévision Numérique (RPN), and preliminary diagnostics have been generated.

2. Model Performance on the Earth Simulator

One of the primary challenges at the early stages of the LACES project – primarily addressed in 2004 – was to ensure that the Mesoscale Compressible Community (MC2) atmospheric model (Benoit 1997) performed well on the large number of processors available on the Earth Simulator

(ES). Since the Meteorological Service of Canada has only recently migrated from SX6 machines to a superscalar architecture, the MC2 code was already tuned for performance on vector processors. Parallelism is implemented using a standard Message Passing Interface (MPI) and the interprocessor communication load is minimized by capitalizing on the locality of data in the MC2 (Thomas 1997). The large domain is broken into $N \times M$ tiles (integrated on a total of $N \times M$ processors), where each tile is set to the near-optimal grid size of 500×50 grid points.

The results of the scalability tests completed in late 2004 show that the parallelization ratio of the MC2 exceeds 99.99% (Desgagné 2005), sufficient to allow the model to run efficiently on the entire ES platform. Production runs began in late 2004, and have continued throughout 2005 on 3960 processors (495 nodes), with a total grid size of $11000 \times 8640 \times 51$ with a 22×180 tile topology. The total memory requirement for this job is approximately 7.5 TB, and the aggregate performance of the simulation falls just short of 10 Tflops.

3. Production Results

The model and grid configurations utilized during the pro-

duction phase of the LACES project was described by Desgagné (2005), and comprises a triply-nested domain as shown in Fig. 1. Results for the outer domains – with grid spacings of 50 km and 10 km – were generated by RPN researchers at the early stages of the project. Only the very high resolution grid (1 km grid spacing) requires the unique computing capabilities of the ES. As shown in Fig. 1, this domain extends from the eastern Pacific Ocean to Europe and Africa. With a time step of 6 sec imposed by the small grid spacing, and 75% of the total ES resources required at runtime, both execution and wait times are large given the heavy mean computational load on the machine.

The results from the production component of the LACES project have been transferred from the ES to a large database designed by researchers at RPN. Although this data is currently accessible only by collaborators on the project, release to the more general academic community is planned once preliminary diagnostics have been performed and the consistency of the database has been verified. Problems with the transfer of some of the data has resulted in missing tiles in the archive, an issue that has been addressed in late 2005, in part through retrieval from existing storage facilities at the ES, and in part using a re-execution strategy. At the current rate of progress, it is expected that the offline database will be complete by early 2006.

Preliminary diagnostics center on an evaluation of the simulation from a meteorological perspective (Desgagné 2006). The tropical phase of the Hurricane Earl's lifecycle (defined for this study to include the tropical cyclogenesis, intensification, and landfalling stages) is analyzed in detail here, and similar analyses of the two other phases (transition and reintensification) will be undertaken once the simulation database is fully coherent.

The structure of the system in the simulation compares

well with that of observed storm (Fig. 2). Given that there was no discernible tropical circulation present in the initializing analysis at 1800 UTC 31 August, the ability of the model to accurately develop a hurricane is remarkable. Although a right-of-track bias persists throughout the integration, the precipitation distribution associated with the hurricane is well represented in the LACES results (Fig. 3). This result is of particular significance since the accurate simulation of precipitation requires that the fundamental forcings within the system and its local environment are well represented in the model atmosphere. Note that the majority of the difference between the observed and simulated precipitation distribution in Fig. 3 arises from the lack of observed values (left panel) over the open ocean and Mexico.

4. Discussion

The 2005 production phase of the LACES project is nearing completion, and collaborators on the project already have access to results that cover the majority of the simulation period. Initial diagnostics from the tropical phase of the LACES production simulations are promising. The structure and intensity of the system are well represented, and the finescale nature of the ES results shown in Fig. 3 suggests that important processes are occurring in the model at scales smaller than those resolved by the traditional observational database. The realistic nature of the structures seen on the broad high resolution domain is verified by comparison with satellite imagery such as that shown in Fig. 2, where thin bands of cloud result from atmospheric processes that occur on scales previously unresolved over such a large area. As the initial LACES project enters its final stage, the examination of these structures and processes will be at the forefront of the research projects that employ this unique dataset.

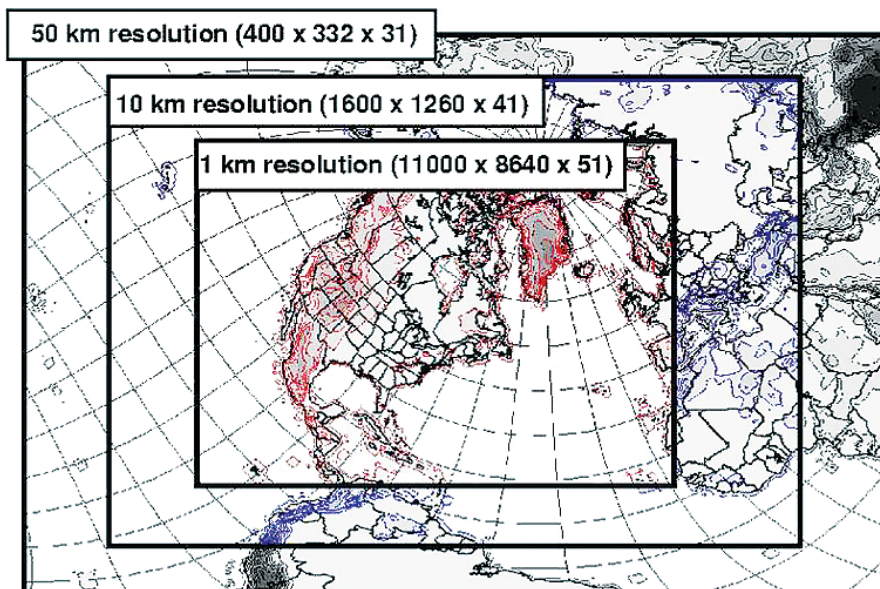


Fig. 1 Nesting strategy for the LACES simulation of Hurricane Earl.

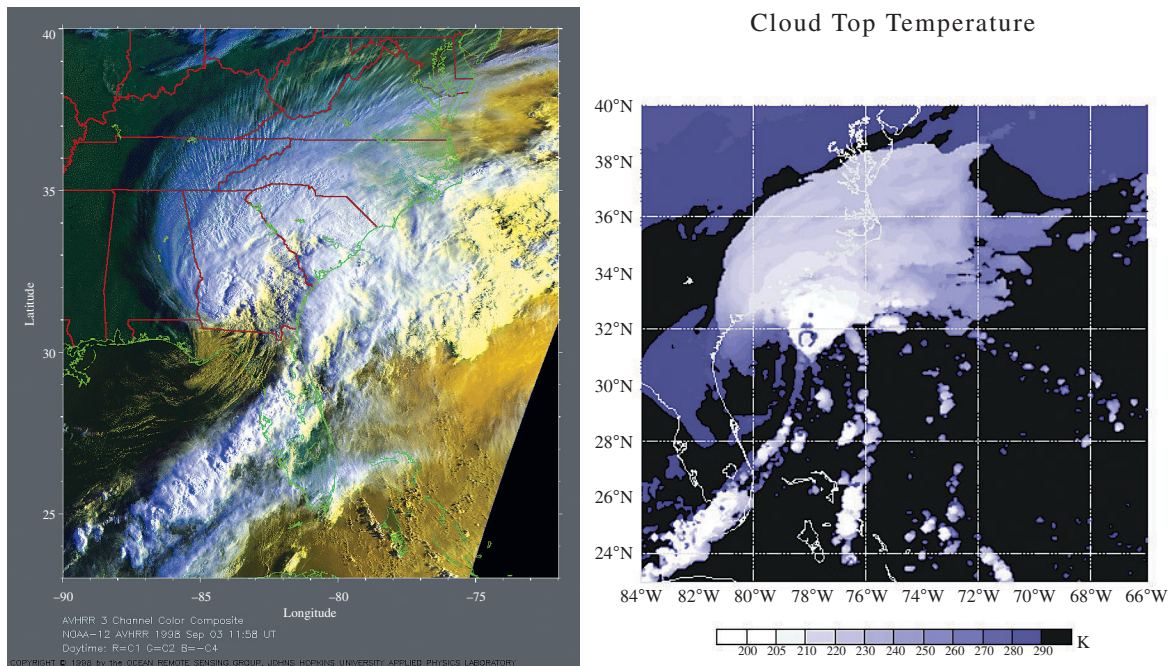


Fig. 2 Three channel composite satellite image of Hurricane Earl at approximately 1200 UTC 3 September (left). Lighter colors generally indicate higher cloud tops (colder temperatures), but the low angle sunlight from the east casts shadows to the left of convective towers. Cloud top temperatures from the LACES simulation (66 h) valid at 1200 UTC 3 September (right). Temperatures in Kelvin as indicated on the color bar beneath the figure. Note that the domain is the same size as that of the left panel, but is shifted 6°E to account for the right-of-track bias in the simulation.

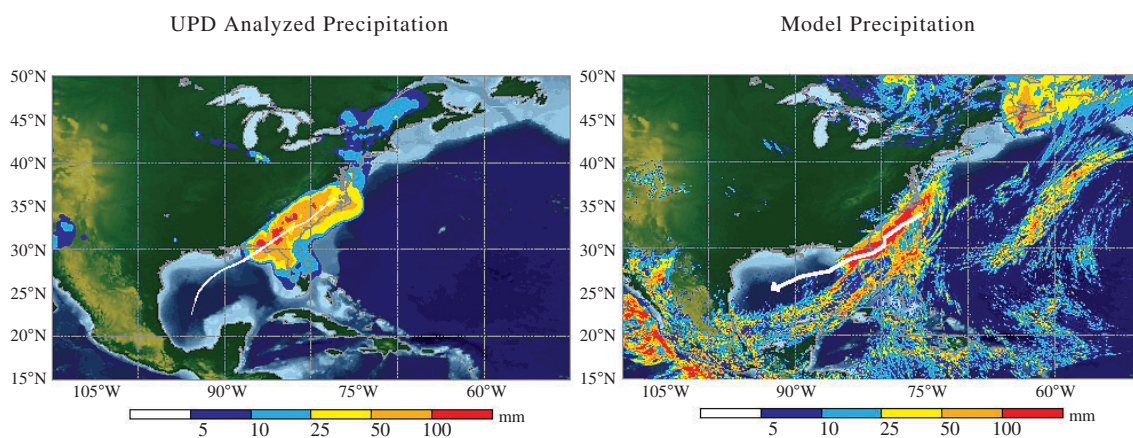


Fig. 3 Storm-total observed precipitation accumulation from the Unified Precipitation Database (UPD, left) and from the LACES high resolution simulation (right). The observed and model-simulated tracks of Hurricane Earl are shown with the heavy black lines in the left and right panels, respectively. The UPD data is primarily land-based and extends only to nearcoastal areas with radar coverage.

5. References

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地球シミュレータを使った大規模大気計算 (LACESプロジェクト) の進捗状況と予備的な解析結果

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ハリケーンEarl (1998年) の熱帯でのシミュレーションをMesoscale Compressible Community (MC2) 大気モデルで実施した。MC2は地球シミュレータ上で大変優れた並列化性能を達成した。予備的な解析の結果、シミュレーションは衛星観測による雲の分布や解析された降水分布とよく一致していた。シミュレーションの結果は、今後予定しているハリケーンの構造や発達過程の解析に不可欠なデータセットである。

キーワード: 地球シミュレータ, ハリケーンEarl, 超高解像度シミュレーション, ハリケーンのライフ・サイクル, 熱帯低気圧の発生, ハリケーンの温帯低気圧化と再発達